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ISAE 2023 - Proceedings

The 6th International Symposium on Agricultural Engineering - ISAE 2023
19th - 21st October 2023, Belgrade, Serbia

Belgrade 2023.

ISAE 2023 - Proceedings

The 6th International Symposium on Agricultural Engineering - ISAE 2023

Editors:
Dr. Ivan Zlatanović
Dr. Nedžad Rudonja

Publisher:
University of Belgrade - Faculty of Agriculture
Nemanjina 6, Belgrade-Zemun, Serbia

Publisher representative:
Prof. Dr. Dušan Živković

Editor in chief:
Doc. Dr. Tamara Paunović

Publishing office:
Printing Service of the Faculty of Agriculture
Nemanjina 6, Belgrade-Zemun, Serbia

Edition:
First

Number of e-copies:
100 copies

The publication of "ISAE 2023 - Proceedings" was approved for The 6^{th} International Symposium on Agricultural Engineering by the decision no. 231/23 from 12.12.2023. year of the Committee for publishing activities of the Faculty of Agriculture, University of Belgrade.

ISBN 978-86-7834-427-5

Belgrade 2023.

ISAE 2023 - Proceedings

The 6th International Symposium on Agricultural Engineering - ISAE 2023
19th - 21st October 2023, Belgrade, Serbia.
www.isae.agrif.bg.ac.rs

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Preface

Welcome to the 6^{th} International Symposium on Agricultural Engineering, a milestone event in our decade-long journey of advancing agricultural innovation. This Proceedeings encapsulates the essence of our ongoing commitment to exploring and sharing cutting-edge developments in the field of agricultural engineering.

Over the past ten years, our symposium has evolved into a vital platform for researchers, practitioners, and experts from around the world to converge, exchange ideas, and foster collaborations. It is within this collaborative spirit that this compilation of abstracts finds its purpose.

Within these pages, you will discover a diverse array of research, insights, and innovations that span the breadth of agricultural engineering. From precision farming and sustainable practices to the integration of digital solutions and robotics, these abstracts showcase the collective efforts to address the challenges and opportunities facing modern agriculture.

We would like to extend our heartfelt gratitude to all the authors who contributed their research and insights to this book. Your dedication to advancing agricultural engineering is commendable, and your contributions form the foundation of this symposium's success.

As we embark on this 6^{th} edition of our symposium, we look forward to the discussions, debates, and discoveries that will undoubtedly shape the future of agriculture. Together, let us continue to sow the seeds of innovation and cultivate a brighter and more sustainable agricultural landscape.

Thank you for being a part of the 6^{th} International Symposium on Agricultural Engineering.

Prof. Dr. Ivan Zlatanović
ISAE 2023 Scientific Committee President

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POTENTIAL OF URBAN GREEN ROOFS AS A HABITAT FOR BEES

UDC 62 Engineering. Technology in General

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INVITED PLENARY LECTURE

Abstract. *The intense development and urbanization of the cities last decades significantly influenced on increase of pollution and formation of urban heat islands. Further, the rapid urbanization impacted on decrease of green areas in cities. Looking at the data of development for Belgrade, Serbia, in a period from 2016 to 2020, the square meters of built space increased 350%. Furthermore, Serbia has 2.9·10^8 square meters of dwellings build before 2011, which means that the thermal properties of the buildings' envelope were much lower than it is now recommended. Moreover, with a intense urbanization, the number of bee population significantly decreased. All these issues represent a high potential for the refurbishment of buildings using green systems, either the green roofs or together green roofs and green facades. Different types of green roofs and facades are considered to be a good habitats for bees in urban areas, and a lot of cities worldwide recognized this potential. Serbia has a great potential for developing the green roofs at the top of the existing buildings, which need refurbishment, since the majority of these buildings has an optimal height for the bees habitat, up to eight floors. This concept is beneficial in many directions: contribution to energy efficiency and better indoor environmental quality, decrease of urban heat islands, decrease of urban pollution, increase of number of green areas in cities and in the same time saving of bee population in urban areas.*

Key words: *green roof, green façade, bees, urban habitat, building refurbishment*

1. INTRODUCTION

The urbanization of big cities last decades impacted significantly on decrease of green areas worldwide, which further implied with intense pollution and formation of urban heat islands. Also, besides a lot of efforts by the governments all over the world to decrease the energy needs in building sector, the energy consumption is even higher from year to year, especially for cooling demands. In that manner, the Republic of Serbia introduced the regulations concerning energy efficiency in buildings from 2011. when the first Rulebook on energy efficiency of buildings was adopted. That was a very significant effort to prescribe the maximum allowed U-values of buildings' thermal envelop and maximum allowed values of final energy needs for heating for various types of buildings. Nevertheless, in the Republic of Serbia, there are more than 2.1·10^9 square meters of dwellings build before 2011 [1], which means that the thermal properties of the buildings’ envelope were much lower than it is recommended by the Rulebook on the energy efficiency of buildings. Further, a lot of these old buildings have a flat roof, especially the ones build in a part of New Belgrade in a period from 1960s to 1980s. These buildings have a lot of problems with damaged facades and roofs, which further cause intensive heat losses and even leakages. All these issues offers a high potential for renovation of existing buildings, using green systems, both green roofs and facades. More, the intense urbanization impacted negatively on the population of insects, especially the bees. In order to overcome this problems: pore insulation properties of buildings' thermal envelope, damaged roofs, decrease of green areas and population of bees, the various scientists worldwide suggested the concept of urban green habitats for bees.

This paper deals with the current state of the building stock in Serbia and potential for the renovation using green roofs as the habitat for bees.

1.1. Existing building stock in the Republic of Serbia

The buildings are considered to be one of the biggest consumers of energy with a share of about 40% in European Union (EU) [2]. According to the data given in the literature [1], there are approximately 2.9·10^8 square meters of housing in Serbia which are built before 2011, when the Rulebook on energy efficiency of buildings was adopted. Some of them were under some type of the reconstruction, but a majority still has the same thermal envelope characteristics as when built. The typical U-values for external walls varies from 0.68 W/(m^{2}K) for free-standing family houses to 3.31 W/(m^{2}K) for free-standing residential buildings, while U-values for windows are about 3.5 W/(m^{2}K) up to 4.6 W/(m^{2}K) for existing building stock built before 1990 [1]. Besides the thermal envelop characteristics and the geometry of building itself, the energy consumption in buildings depends of the climatic conditions, HVAC systems and the automatic control system, the regimes of use of building, the occupants' behavior and exploitation costs. One of the most influential factors are thermal envelope properties, thus the first energy efficiency measure that should be undertaken is always the intervention on the envelope. When the losses through the envelope are minimized, than the application of other measures such as replacement of the energy source or implementation of the RES can be considered. The energy efficiency measures should be always implemented in the direction from the intervention on the envelope and low budget measures towards medium budget measures and at the end, if it is justified by other factors such as social and environmental benefits as well, even the high budget energy efficiency measures can be considered.

Besides the pure thermal characteristics of the envelope, the capital of Serbia, Belgrade, has a low percentage of green surfaces, about 30%, which is much lower than the average in European Union. From that, only 8% goes to urban green spaces [3]. Further, there are no legal obligations for new buildings concerning green roofs and other type of green areas, since there are no legislations which refer to green systems in Serbia. But, on the other hand, the Republic of Serbia is a member of European Federation Green Roofs and Walls [4] which is a significant step towards establishment of legislations concerning green systems. Furthermore, with a decrease of green areas in urban areas, the number of bee population significantly decreased.

All these previously discussed issues are the strong impeller for the future development of legislation base for the implementation of green systems in new and existing buildings in Serbia.

1.2. Population of bees in Serbia

According to the literature [3], there are 850 species of bees in the Republic of Serbia, from which only one, *Apis mellifera carnica,* can produce the honey. It is considered that this specie of bee is one of the most wanted because of their good resistance to diseases, other insects and parasites. This specie of bees has a lot of advantages, such as: gentle, non-aggressive nature, which is very desirable in populated areas, ability to adapt quickly to changes in the environment, better resistance to diseases, lower usage of propolis, longer life period, good adaptation to winter period, better orientation etc. Knowing the importance of the honey bees to the agriculture production and the survival of the variety of plants, it is crucial to make a long term strategy of protection and development of the honey bee habitats.

2. Green roofs

The concept of green roofs is very well known over the last decades, but their usage in the Republic of Serbia is very limited, while some of the cities worldwide has a large number of areas covered with green roofs (Fig.1). From the Fig. 1 it can be seen that the Berlin is a leading city with the highest number of green roofs area, with about 4000000 m^2, while the Copenhagen has about 40000 m^2 of green roofs area [4]. With other words, the total area of green roofs worldwide overcomes the number of 18 millions of square meters [4].

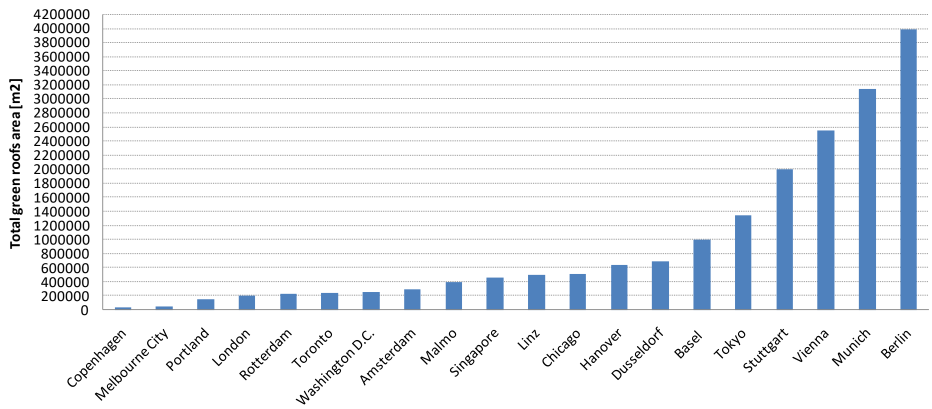

Fig. 1 Total area of green roofs by the cities worldwide (source: [4])

Green roofs are additional or integrated layers of the roof construction which contain substrate for the plant growing and the different type of plants on the top. They can be integrated into the roof constructions for new buildings or modular, added at the top of the roof constructions for existing buildings. Hence, the possibility of refurbishment of building with green roof system depends majorly of the existing construction and its stability. The green roofs consists of several types of layers which can be different depending on the location of the building, since the type of the vegetation is correlated to the climate conditions of the specific location. The usual layers are shown in Fig.2 [3]: hydro and thermal insulation, root protective barrier, drainage and filter layers, irrigation, growing medium and vegetation. The protective layers, such as waterproofing membrane, insulation and root protective barrier are used to protect the roof construction from the damages caused by water or root development. Then, the drainage layer has a function of water drainage from the green roof to the drainage and the root area transpiration and evaporation. It can be made from high-density polyethylene (HDPE), the polyamide monofilament fibers and similar artificial materials or from lightweight stone aggregate and expanded clay. Important part is the filter layer, with a function of protection of derange layer from the penetration of the small particles into the drainage structure. The growing medium is very important layer, which has a roles of thermoregulation and feeding of the vegetation. It consists from organic matters such as compost and peat, usually 20%, and mineral ingredients such as stone, brick or clay. The final layer of the vegetation depends of the type of the green roof.

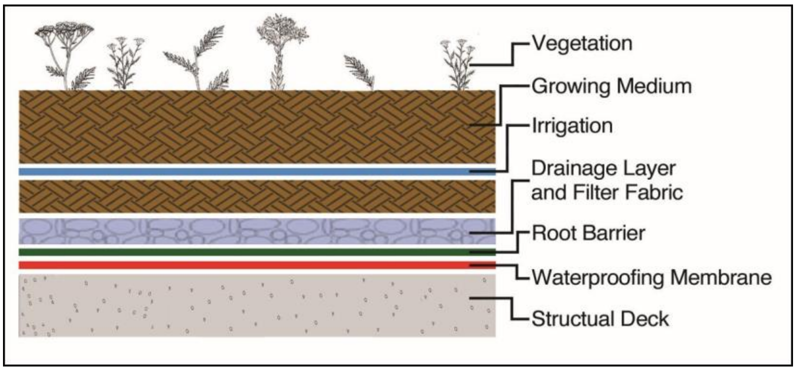

Fig. 2 Typical layers of green roof system (source: [3])

2.1. Types of the vegetation in the green roofs

Depending of the type of the vegetation and their weight, the green roofs can be intensive, semi-intensive or extensive. Extensive green roofs have the smallest depth, from 5 to 15 cm, while the intensive could have depth of growing medium up to 60 cm. Thus, the intensive green roofs are more demanding in several ways: the strength of the roof construction must be higher, the maintenance of this type of green roofs concerning irrigation, pruning and fertilization is more demanding, also the installation itself is more demanding and more expensive. On the other hand, intensive green roofs can be designed as a small parks and provide better insulation and higher benefits of usage for the occupants, while the extensive green roofs, due to the their lower weight, are appropriate solution for the refurbishment of the existing buildings. The main features of the green roofs are shown in Table 1.

Table 1 Features of the green roofs (data from the source: [5])

System	Extensive	Semi-intensive	Intensive
Weight with a maximum water capacity	50-150 kg/m2	120-350 kg/m2	More than 350 kg/m2
Substrate depth	6-20 cm	10-25 cm	More than 25 cm
Type of vegetation	Succulent, herbaceous, grasses	Herbaceous, grasses, shrubs	Grasses, shrubs, trees
Maintenance	Low	Moderate	High
Usage	Only maintenance	Pedestrian areas	Pedestrian, recreation, agriculture

One of the most important advantages of extensive roofs is lower weight in comparison with other types of green roofs and thus the possibility of application on the existing roof constructions. They can be applied on flat or hip roofs, depending of the type of the constructions, but due to the lower depth of the vegetation, but they cannot be passable for the users of the buildings. This type of roofs is easy for maintenance because of the low demanding vegetation, such as succulents, sedums, grasses, mosses and wildflowers.

The semi-intensive green roofs have the medium features in between the extensive and intensive green roofs, and thus the medium level of maintenance needs, cost and possibilities for pedestrian areas.

The intensive green roofs are more demanding, first of all in the bearing capacity of the roof construction and than in the maintenance needs, which further implies with much higher investment and exploitation costs. Due to their rich vegetation, they can be used as small parks and recreation areas, which further contributes not just to the energy savings, but to the aesthetic, environmental and social benefits of the observed areas.

2.2. The advantages and disadvantages of green roofs

The advantages of green roof system usage can be divided on ecological, social and economical advantages, while the disadvantages can be divided on economical, technical and social. Ecological benefits refer to pollution reduction in urban areas, absorption of noise and dust, decrease of the urban islands effects and increased biodiversity in urban areas. Further, social benefits are also very important, offering the possibilities for inhabitants of the cities to have more green areas for recreation and relaxing. Furthermore, economical advantages are the lower expenses for the energy for heating and cooling due to the better roof top insulation, protection of direct sun and better drainage. On the other hand, there are some technical obstacles for the installation of green roofs which could be considered as a disadvantage, together with the necessity for maintenance and higher investment costs. The most important advantages and disadvantages are shown in Fig.3.

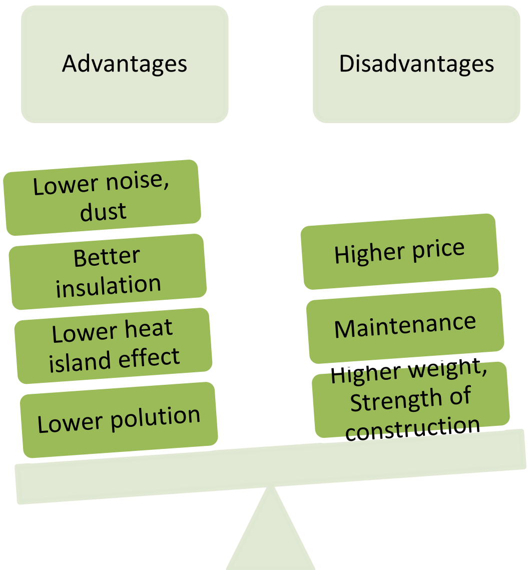

Fig. 3 Advantages and disadvantages of green roofs

3. GREEN ROOFS AS A HABITAT OF BEES - EXAMPLES OF GOOD PRACTICE

In last decades, the population of bees is significantly lower than it was previously. About 9.2% of European bees is endangered due to the higher usage of pesticides, diseases, urbanization and climate changes [6]. One of the good solutions for this problem can be development of green roofs suitable for bees. Although the variety of bee species are lower on green roofs then in their natural, on ground habitats, the green roofs are considered as the valuable bee habitats in urban areas. Also, the bee path often connects on ground habitats and green roofs which has a positive effect on pollination. One of the limitation factors can be the height of the building, since the bees are rarely seen on heights higher than 30 m above the ground level [7].

A various scientists researched the green roofs as a potential habitats for bees. Kratschmer et al. [8] researched the biodiversity and abundance of wild bees in Vienna, Austria, at nine different green roof locations. All roofs had different characteristics, age and height. They identified 90 different species of wild bees from 19 genera. Authors compared the sedums and wildflowers in green roofs and their impact on the variety of bee species and they concluded that sedums positively compensate the lack of wildflowers in a sedums' blooming period. The other group of researchers, Jacobs et al. [9] studied 20 locations of green roofs in Antwerp, Belgium, with an average surface of 280 m^2 and from 4 to 23 m height, with different types of sedum and combination of sedum, herbs and grass. They noted almost 600 individuals from 40 species of bees. Further, Colla et al. [10] studied six locations of green roofs in Toronto, Canada, where two of them were extensive green roofs. They noted 79 bee species from 24 genera on studied locations, where the abundance was higher for actively seeded green roofs in comparison to the passively seeded roofs. Furthermore, Tingfeng Wu [11] researched factors abundance and variety of pollinators on green roofs and concluded that it is very important to consult landscape architects when designing the green roofs since the type of substrate and plants are meaningful for bee habitats. More, Tonietto et al. [12] compared the bee abundance for parks, prairies and green roofs in Chicago, USA and concluded that from the 15 species of bees that contributed to the bee community varieties in habitats, the four of them noted as having their highest abundance at the green roofs. Moreover, Casanelles-Abella and Moretti [13] analyzed data on beekeeping for 14 Swiss cities in a period from 2012 to 2018 and concluded a high rise of number of beehives in a square kilometer, from 6.48 to 8.1 hives in a square kilometer. Looking at these results from multiple studies worldwide, it can be concluded that green roofs has a positive effect of abundance of variety of different species of pollinators. The green roof vegetation which consists only from sedums, had the positive effect in transitional periods, when sedums bloom. This conclusion is important contribution for decision makers and for the existing roofs which do not have the load capacity for heavy constructions. So, even in that case, the extensive green roofs can have some contribution to the pollinators abundance.

3.1. Examples of rooftop beekeeping worldwide

Various big cities worldwide have the different projects concerning beekeeping at the rooftops of buildings. For the example, the city of Paris, France has a very long tradition of urban beekeeping, dates from 1856. A lot of famous buildings in Paris, such as Notre-Dame cathedral, Museum d'Orsay, Palais Garnier etc. have their own beehives and urban honey production [14]. Also other metropolis such as London has the projects for beekeeping promotion. As a part of the study performs by University of London, a two beehives were installed in the 2013. at the roof top Institute of Advanced Legal Studies (Fig.4), and two more added until 2019. [15]. The facility is used for trainings of beekeepers.

Fig. 4 Beekeeping at the roof top in London (source: [15])

Further, outside the Europe, in the USA, there are a lot of examples of urban beekeeping. One of them is beekeeping at the roof of Fairmont hotel in Washington, USA. Mentioned hotel has the restaurant at the roof top, the "Juniper restaurant" and the produced honey is used for food preparation for the hotel needs [16]. Further, the company "Brooklyn Grange" supports a beekeeping, by organizing the educational program for practical beekeeping at the Long Island city farm, USA (Fig. 5) [17]. Another example from the USA is the company Beacon Capital Partners (Fig.6), who installed the beehives on the roofs of the majority of their buildings worldwide and it is considered as a largest property owners in the USA with urban rooftop beekeeping [18]. Similarly, the example on beekeeping at the Four Season Hotel in Boston is shown in Fig. 5 right.

Fig. 5 Beekeeping at the Long Island city farm (source:[17])

Fig. 6 Urban rooftop beekeeping - Beacon Capital Partners (left), Four Seasons Hotel in Boston (right), source:[18])

3.2. Examples of city rooftop beekeeping in the Republic of Serbia

Interesting example of the urban beekeeping in Belgrade is a mutual project of the company MC Properties, Association MadMed and Serbian Association of beekeepers, where the MC Properties installed 12 beehives at the roofs of two buildings: Usce shopping center and Navigator business center 2, from which 130 kg of honey was produced in four months [19]. Further, the Embassy of France in Belgrade, also has the beehives at the roof top of the Embassy building, as a part of the project "Green embassy" and contribution to the environmental protection goals [20]. Furthermore, the Belgrade Ada shopping mall center also has the beehives at the rooftop, since the center's location is situated near largest green area in the city of Belgrade, Ada Ciganlija [21].

4. POTENTIALS OF URBAN BEEKEEPING

The urban beekeeping practice worldwide dates decades ago, but it easily can be said that it is relatively new concept in the Republic of Serbia and not researched enough. A various examples worldwide and for some cities, such is Paris, a very long tradition and even touristic attraction, speaks in favor of such a way of urban honey production. On the other hand, the lack of knowledge and practical research in this area make a gap between the potential benefits and decisions to be involved practically in the urban beekeeping. Further, the lack of legislations in the area of green roofs and urban beekeeping is one of the biggest issues when it comes to the practical realizations. As it was previously discussed, a benefits of green roofs are numerous, together with the urban beekeeping, but still it is very important that general public get familiar with benefits, but also a possible disadvantages of this concept. One of the most common questions are the questions of costs of green roofs, the quality of honey in urban areas and potential risks for people living nearby. Looking at the building stock in Belgrade, especially the existing buildings from the seventies and eighties in New Belgrade, a great majority of them are built with a flat roof, also a great numbers of existing school buildings have a flat roof. More precisely, there are about 500 school buildings, with the area of 1.100.000 m^2 which majorly have a flat roof. All this data, gives an insight in the possibilities of refurbishment using green roofs and possibilities for the urban beekeeping as well. Off course, a significant funds would be needed for the full renovation of the building stock, but first step must be the intensive research in this field and dissemination of the results in public. According to the available data, the prices of green roofs vary from 58 euro per square meter for the cheapest extensive green roof to up to 233 euro per square meter for the most expensive intensive green roof [22]. Looking at the question of the quality of honey in urban areas, it is proven by various studies that the urban pollution do not impacts negatively to the honey, since the bees has the ability to purify the pollutants and produce the honey without pesticides and metals. This conclusion was also confirmed by the analysis of the Serbian Food testing center laboratory [23]. Moreover, there is the question of potential risks for health of people living near buy the bee habitats. In the past, some cites even forbidden the urban beekeeping. So, there are some requirements for urban beekeeping that should be followed, such as: bees should have an open access to the natural water source, otherwise they could try to find the water where it would not be appropriate for people living nearby, then the number of beehives in urban areas per square kilometers should be no more than 7, more, the hives should be placed where flying paths of bees do not cross the humans paths and all beekeepers must pass the trainings from the authorized organization [12]. After all, it is very important to have awareness of different types of allergies on vegetation and bee sting that inhabitants of the cities could have and, while planning the buildings' reconstruction to bear in mind the importance of selecting the vegetation with low influence on allergies and bee species which have non-aggressive nature.

5. Conclusions

The green roofs as a habitat for bees are used worldwide, but it is still limitedly researched concept. A various big cities worldwide have a tradition and projects for its development. On the other hand Serbia has a strong potential and needs for building stock refurbishment. The large number of existing buildings have a flat roof which is convenient for installation of green roofs. Further, the green roofs have a strong impact to the pollution and urban heat island reduction in urban areas and they represent the significant habitats for pollinators in urban areas. Furthermore, the pollinators contribute to the agriculture development and species diversity, while at the same time beekeeping contributes to the reduction of unemployment and poverty. But, in order to provide a safe habitats for humans and bees together, it is necessary to perform more studies on behavior of bees in urban areas and to provide, by different types of media, peoples' awareness rising on the benefits of green roofs as a habitats for bees. More, it is very important that the experts from fields of architecture, structural and mechanical engineering, agricultural engineers and biologist are involved together into integrated building design from the very start of the project, ensuring that all this important fields of research are covered. Moreover, it is necessary that local authorities are involved in the projects concerning green systems and urban beekeeping, which would further lead to the adoption of the legislation on green roofs and beekeeping in the Republic of Serbia.

Acknowledgement: *The results presented in the paper are obtained through the research supported by the Ministry of Science, Technological Development and Innovation of the RS under Contract 451-03-47/2023-01/ 200105 dated 02/03/2023.*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

OVERVIEW OF THE USE OF CONVOLUTIONAL NEURAL NETWORKS IN PLANT DISEASE RECOGNITION BASED ON THE LEAF IMAGE

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Abstract. *The use of artificial intelligence in modern agriculture is on the rise, due to the fact that it provides a possibility for more efficient production, better decision making and reduction of the costs. This research takes into consideration the use of the convolutional neural networks for diagnosing plant illnesses based on the leaf image. Detection of plant diseases in the early phase can improve the quality of the food products and minimize the loses. Convolutional neural networks are a type of deep learning method that is one of the most used models for solving image recognition, classification and detection tasks. Therefore, it is justified to anticipate that they can be very effectively applied in the agriculture sector. This paper covers plant species that are the most significant for Serbian production. Various models have been presented and analyzed, while highlighting their advantages and disadvantages when applied for solving this task.*

Key words: *Convolutional neural networks, plant disease recognition, artificial intelligence*

1. INTRODUCTION

Today, agriculture faces various challenges as it is necessary to increase food production in sustainable manner due to the expansion of global population while using limited resources such as water and land [1]. Traditional agriculture methods are not capable of coping with the posed demands for few reasons. Firstly, it does not ensure efficient use of resources like water, fertilizer, pesticides and insecticides which may cause harm to the environment and health of the living beings. Secondly, a lack of information and analytics about crop conditions can be noticed, which complicates the decision-making process. Thirdly, traditional agriculture requires a large amount of physical work which is exhausting and expensive. Finally, it relies on subjective assessment during visual examination of field which may result in late detection of crop diseases. In order to overcome the mentioned disadvantages, the idea of applying new technologies in agriculture, known as Agriculture 4.0, appeared and it is constantly developing and improving. The mission of agriculture 4.0 is upgrading agriculture strategies and methods to create optimized value chain by utilizing a wide range of modern technologies that enhance processes at all stages of agricultural production chain [2]. Also, the solutions of the fourth agricultural revolution tend to be eco-friendly and efficient in satisfying requirements of society and consumers [3]. Technologies such as GPS, satellite imaging, sensors and different software enable precise agriculture which refers to optimal management of the resources using chemical means only when it is necessary and in prescribed doses or adequate utilization of agricultural land. In order to obtain all indispensable information that facilitate decision-making process agriculture 4.0 uses Internet of Things, Big Data and sensors. The amount of human hard physical work is reduced by implementing automatization techniques, robotic and artificial intelligence, while efficiency is improved, at the same time. Agriculture 4.0 allows continuous monitoring of crops by combining outputs from sensors, drones, cameras and methods of artificial intelligence which leads to faster detection and solving problems.

When it comes to the monitoring of fields, one of the most important tasks is recognition of plant diseases in the early phase. If disease is diagnosed early, then certain steps can be taken to suppress the illness before it spreads on the whole crop, thus preventing yield loss and preserving product quality. One of the benefits is also saving resources because they are used only on infected areas, which means minimizing consumption of chemicals, time and money. In addition, pollution can be significantly reduced which contributes to the preservation of the environment.

Convolutional Neural Network (CNN) is one of the mostly used methods for detecting plant diseases. It is a type of a deep neural network that is highly efficient in solving computer vision tasks. The main reason that explains this fact is their ability to achieve excellent performance without manual extraction of important features from input data.

This research considers the use of the CNN for disease recognition based on the leaf image for plants that are the most common on the crops in Serbia. This paper is organized in several parts – after introduction, applied methodology for the study is described in the second section, following with the basic information about CNN. The fourth section describes the selection of plants crops considered in the study. Results and discussion are presented in the fifth section, while the sixth section summarizes the derived conclusions.

2. METHODOLOGY

This paper is focused on finding the best possible solution for recognition of plant diseases, for plant species that are the most common in Serbian agriculture by using CNN. Therefore, the first step of the research is analyzing the representation of plant species on crops in Serbia. The second step is finding research papers dealing with the application of CNN for disease recognition, based on the leaf image for plants that bring the highest yield in Serbia. Final, third step is to choose two species that are the most significant for Serbian plant growers, while considering that those species are also frequently analyzed in scientific research. The Scopus database is used in the second step. The main comparison criteria are CNN model's accuracy and number of diseases that can be recognized by the CNN models. Accuracy is the performance evaluation parameter that shows the percentage of correctly classified samples among all samples.

3. Convolutional neural networks

CNNs represent type of deep learning networks that are often used for solving computer vision tasks such as image classification, object recognition, recognition, etc. The architecture of CNN consists of three types of layers – convolutional, pooling and fully connected layer. In convolutional layer a filter made of weight coefficients that should be learned in the training process, slides among input image creating feature map. In pooling layer information from input feature map are reduced in order to lower computational costs and training time, transmitting the most important information to the next layer. The role of these two layers is feature extraction. The role of fully connected layer is making the final conclusion about input sample and generating network's output by applying weights to flatten output from the last pooling layer. They find their application in robotics [4], cybersecurity [5], etc. More information about CNNs can be found in [6].

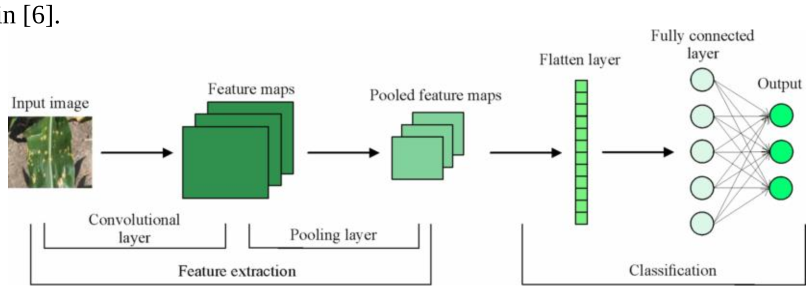

Fig. 1 General architecture of CNN

4. Selection of plant species for the overview analysis

This section deals with the selection of plant species whose diseases recognition by CNNs will be discussed in this study. The selection is made in previously described steps.

4.1. Analysis of the significance of plant species in Serbia

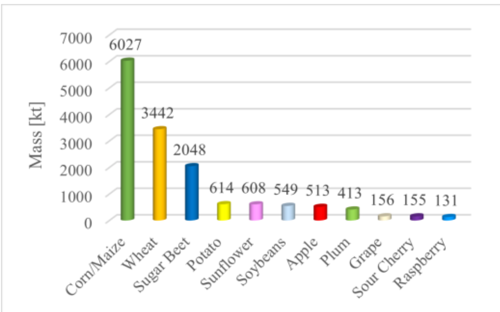

Fig. 2 Bar diagram of crop production in 2021

Data obtained by Statistical Office of the Republic of Serbia are used for plant significance analysis. As it is written in [7], there are given "*the main statistical data on the national social and economic development*", so it is considered that the mentioned plants are the most significant for Serbian economy and therefore, the most commonly grown on crops. Document [8] obtains information about achieved production of wheat and early fruit as well as expected production of late crops, fruits and grapes in 2021. By combining gathered information from [7] and [8] the top 10 yields come from plants: corn (maize), wheat, sugar beet, potato, sunflower, apple, plum, grape, sour cherry and raspberry. It is noticed that there is no data about achieved production of soybeans, while the predicted yield is very high, so soybean is considered as eleventh significant plant. Bar diagram of crop production in 2021 is shown in Fig. 2.

4.2. Representation of suitable plant species in scientific work

In order to investigate the frequency of research about diagnosing plant diseases by using CNNs for plants declared as the most significant for Serbian production, SCOPUS base is used. The name of the plant is entered in the search field together with words disease, leaf, and convolutional neural network. The percentage of found papers is shown in Fig. 3.

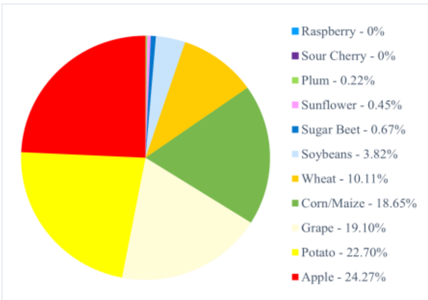

Fig. 3 Percentage of papers on plant diseases diagnosis using CNNs in SCOPUS database

4.3. Selection of plant species for further analysis

As it can be observed, amount of scientific research does not completely match the significance of plant species. There is just one paper that analyzes plum, and only few papers dealing with sugar beet, sunflower. Also, there is no papers that take in consideration raspberry and sour cherry. In further work, papers about diagnosing leaf diseases of wheat and corn using CNN will be analyzed as they have the most yield in Serbia. The second reason is that significant number of research papers about these plants can be found. The criterion for choosing papers is based on the number of citations and applied CNN models.

5. RESULTS AND DISCUSSION

5.1. Recognition of wheat leaf diseases using CNN

The best obtained results from papers about wheat diseases are presented in Table 1. Number of classes includes all classes of diseases and class of healthy leaves that CNN models are trained to recognize. Abbreviation ‘avg’ stands for average accuracy.

Table 1 Accuracies obtained by applying different CNN for recognition of wheat leaf diseases

Plant species	Reference	CNN architecture	Classes	Accuracy [%]
Wheat	[9]	Tairu	4	90.47
		AlexNet		94.04
		LeNet		97.61
	[10]	AlexNet	8	91.54
		LeNet-5		89.15
		Inception-V3		94.31
		ZFNet		92.79
		DACNN		95.18
	[11]	VGG-19	5	79.05
		ZFNet		86.32
		PNN		72.14
		GoogleNet		89.84
		Inception-V4		82.73
		EfficientNet-B7		87.96
		RFE-CNN		**99.95**
	[12]	AlexNet	8	72
		VGG-16		78
		M-bCNN-CKM-2		83
		M-bCNN-CKM-3		91
	[13]	VGG-16	10	97.88
		ResNet50		90.87
		Custom		81.96
	[14]	Custom	3	94.91
	[15]	VGG-16	4	85.25 (avg)
		Inception-V3		92 (avg)
		RenNet50		89.5 (avg)
		DenseNet121		91.5 (avg)
		EfficientNet-B6		88.5 (avg)
		ShuffleNet-V2		88.75 (avg)
		MobileNet-V3		88.5 (avg)
	[16]	Custom	2	93
	[17]	AlexNet	7	87.15
		VGG-16		87.44
		ResNet34		95.05
		ResNet50		96.52
		ResNet101		95.68
		InceptionResNet-V2		96.7
		MobileNet-V1		94.41
		MobileNet-V2		95.23
		MobileNet-V3_small		95.34
		MobileNet-V3_large		96.75
		EfficientNet-B0		96.81
		IRCE		98.76
	[18]	AlexNet	4	84.54

All mentioned models are trained to recognize certain leaf diseases of wheat, except for model in [16] which is trained to classify samples only in two classes – healthy and not healthy. Powdery mildew is the most common disease that can be recognized, as it has been mentioned in every paper other than [14] and [16], following the leaf rust that has not been mentioned only in [9], [14] and [16]. Stripe rust is one of the disease classes in [10], [12], [14], [15] and [18]. Septoria is included in [9], [11] and [14], while the recognition of the bacterial leaf blight can be found in [10] - [12]. Papers [10] and [12] take in consideration classes of mechanical damage, bacterial leaf streak and cochliobolus heterostrophus. Also, brown rust can be found in [9], wheat streak mosaic in [13], stem rust in [18] and tan spot in [13] and [17]. Papers [13] and [17] cover some diseases that are not strictly related to the leaf such as crown root rot, head blight and wheat loose smut, while the paper [13] include also Karnal bunt and black chaff. The highest accuracy of 99.95% is obtained in [11] by using network that included two parallel CNNs to extract the basic features of images, residual channel attention block for optimizing basic features, feedback block for training of those features and another CNN with elliptic metric learning to process and classify samples, named RFE-CNN. However, it should be pointed out that papers [10] and [12] offer models that can classify the highest number of leaf diseases and accuracy of 95.18% obtained by differential amplification CNN from [10] is significantly high. Only CNN from [18] is tested on images taken by mobile device from actual fields and it is stated that images were correctly classified, but other information cannot be found.

5.2. Recognition of maize leaf diseases using CNN

The results from the analyzed papers about detection of maize diseases are presented in Table 2. As previous, number of classes include healthy class as well.

All researches, except [28], offer solution for diagnosing common rust. Only authors in [27] do not include a class of northern leaf blight disease, while there is a type of disease named “big spot”, which is not precisely described. In every paper, with the exception of [19] and [28], exists the class of grey leaf spot disease. CNN architectures from [23] and [28] are trained to recognize curvularia leaf spot. Most classes can be found in [23], where southern leaf blight, brown spot, round spot and dwarf mosaic are included among previous mentioned classes of diseases. The highest accuracy of 99.84% is obtained by using EfficientNet-B0 in [21], while proposed optimized DenseNet achieved 98.06% accuracy, but it has the lowest number of parameters and the shortest training time, which can be significant in terms of real-time application. Study [23] developed improved GoogLeNet model that can classify eight types of diseases and healthy leaf with the accuracy of 98.9%. However, papers [19], [24] – [26] brought closer their models to real-time disease diagnosing usage. In [19] images are taken in real life conditions and sent via Wi-Fi system that uses proposed CNN to classify diseases, which is later displayed on LCD screen. The average accuracy obtained on real-life classification problems is 88.66%, which is high. In study [24] models are also trained under natural environment conditions and the highest accuracy is obtained by proposed TCI-ALEXN, 93.28%. Paper [25] used CNN with OpenMP implementation to achieve accuracy of 84%, which is shown in Table 2. Authors of [26] used ResNet as model with highest accuracy of all deep networks and MobileNet as model with highest accuracy of all lightweight models, on PlantVillage dataset, to train them on dataset collected by mobile device. ResNet achieve highest accuracy of 98.77%, while highest accuracy obtained by MobileNet is 99.11%.

Table 2 Accuracies obtained by applying different CNNs for the recognition of maize leaf diseases

Plant species	Reference	CNN architecture	Classes	Accuracy [%]
Maize	[19]	Custom	3	96.7
	[20]	LeNet	4	97.89
	[21]	EfficientNet-B0	4	**99.84**
		VGG-19		96.36
		XceptionNet		93.52
		NasNet		91.9
		DenseNet		98.06
	[22]	Custom	4	92.85
	[23]	Cifar10	9	98.8
		GoogLeNet		98.9
	[24]	VGG-16	4	89.98
		DenseNet		92.29
		ResNet50		92.84
		AlexNet		93.77
		TCI-ALEXN		99.18
	[25]	Custom	4	84%
	[26]	VGG-16	4	96.76
		VGG-19		97.04
		ResNet		99.48
		DenseNet121		97.47
		DenseNet169		97.67
		DenseNet201		97.99
		Inception-V3		98.82
		InceptionResNet-V2		99.31
		Xception		96.81
		MobileNet		98.69
		MobileNet-V2		98.04
		ShuffleNet		96.08
	[27]	AlexNet	4	No data
		VGG-19		93.33
		ResNet50		97.75
		2-chanel CNN		98.33
	[28]	AlexNet	3	82.74 (avg)
		GoogLeNet		86.29 (avg)
		ECNN		92.92 (avg)

5.3. Advantages and disadvantages of using CNN for diagnosing plant diseases based on leaf image

Application of CNNs for tasks of diagnosing diseases has great advantages, but also some limitations that the researchers are trying to overcome. CNN models bring benefit to the phytopathologist, because even though they can interpret plants conditions and diagnose diseases by themselves, it can help them to confirm their hypotheses and make decision quicker, especially in cases when the disease is not expanded on the whole field [9]. Also, it can help less experienced farmers to detect and diagnose diseases in order for them to take measures and actions for suppressing diseases immediately [9]. The main disadvantage is that there is no model that include all possible diseases [11]. Therefore, when new disease is added to the dataset, the CNN should be retrained with variations in training parameters to achieve the best possible results, which can be time consuming. Of course, datasets could be expanded with new classes of diseases. However, it can bring potential problem, since the different diseases can have similar symptoms, which makes it difficult for the CNN to successfully distinguish between them. The good side of the CNN implementation is that the developed systems can be integrated in mobile devices or embedded systems, making them easy to use [15]. Currently there are some limitations when it comes to the use networks with great number of parameters, as they cannot be run on mobile phone [17]. The solution for that problem is to use the lightweight CNN. Also, some technologies are very expensive [17]. Finally, CNNs can achieve great robustness if they are trained with many samples of data [21] but they do not achieve satisfactory accuracy when they are faced with multiple disease on one leaf [11] and [17].

6. CONCLUSION

Agriculture 4.0 should develop strategies to overcome numerous problems of the traditional agriculture, while making it easier to satisfy the demands of the growing population. This paper offers overview of the usage of CNN for the purpose of diagnosing corn and wheat diseases based on the images of plant's leaf, as it is important to take appropriate steps for their suppression as soon as possible. The most important points of this paper are given in the continuation.

Initially, the amount of production of plant species in Serbia was analyzed. It was shown that corn is unquestionably the most widely grown plant, following with the wheat and sugar beet.

When it comes to research papers based on the application of CNNs for the diagnosing of plant diseases significant for Serbian agricultural production, it can be seen that some plants are not taken into consideration at all. Also, some of them are not thoroughly analyzed in comparison with plants like apple, potato, grape, corn, which are often represented in research papers.

The result of the overview of studies about diagnosing wheat diseases shows that the best performance, with accuracy of 99.95%, is achieved by using custom network, RFE-CNN. This model is trained to classify four wheat leaf diseases and to recognize a healthy leaf. The most effective model in terms of the number of diseases it recognizes is differential amplification CNN with the accuracy of 99.18% and the ability to recognize seven leaf diseases and healthy leaf.

The outcome of this research also shows that for diagnosing three corn diseases and healthy leaf condition, the highest accuracy – 99.84% can be obtained by using EfficientNet-B0, while improved GoogLeNet can classify nine types of leaf images with the accuracy of 98.9%. Some models for diagnosing maize diseases are also tested in real-time, showing that proposed methods can give promising results, but because of real-time conditions, performance of those models cannot overcome performances of CNN models tested and trained on data from laboratory.

Additionally, this paper offers short overview of advantages and limitations of implementing CNN models for real-time usage. It is pointed out that CNNs have great potential to improve agricultural processes, but there is still a lot of shortcomings that need to be exceeded and a lot of space for upgrading existing techniques.

Finally, the main conclusion is that the significance of CNNs in terms of diagnosing plant diseases is on the rise due to the benefits they bring. Nevertheless, much more effort is needed in order to develop an optimal model that can successfully recognize a wide range of diseases. Evidently, there is a lot of space for further improvement, while special attention should be given to the plant species important for Serbian agriculture, such as raspberry, sour cherry, sunflower, etc.

Acknowledgement: *Results presented in this paper are obtained in the research financially supported by Ministry of Education, technological development and innovations of the Republic of Serbia under contract 451-03-47/2023-01/200105 from 03.02.2023, subcontract TR-35043 and TR-35004*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

APPLICATION OF DIGITAL TECHNOLOGIES IN BEEKEEPING

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INVITED PLENARY LECTURE

Abstract:*The honey bee (Apis mellifera L.) is the most important pollinator that participates in the pollination of over 200 species of cultivated plants. With its role as a pollinator in the ecosystem, the honey bee affects the quantity and quality of food for humans. Breeding of this useful insect produces direct bee products such as honey, pollen, royal jelly, wax, propolis and bee venom. As a result of various negative factors, the honey bee population suffers losses. The application of digital technology and machine learning in beekeeping affects the improvement of bee colony research, the prevention of undesirable phenomena and diseases, and the improvement of beekeeping production.*

Key words: *beekeeping, honey bee, digital technologies, bee colony monitoring*

1. INTRODUCTION

The oldest evidence proving the first contact of men with bees about 7000-8000 years old was found on the wall of a cave in Spain and illustrates how people collected bee honeycombs. Over the time the man acquired the skill of breeding honey bee and understood what kind of habitat it needs thus the earliest proof showing authentic beekeeping dates back to the ancient times from about 3000 BC to 500 AD (Kritsky, 2017).

Honeybee *Apis mellifera* L. provides both direct and indirect benefits to people. In the past the man at first only made use of honey and it was the only natural sweetener at that time. Later on the benefits from using other direct bee products in everyday life were recognized what inspired a detailed research of bee life and breeding (Topal et al., 2021) (Nedić et al., 2022).

Honeybee indirect benefit is recognized as its role to carry pollen thus taking part in the process of plants pollination (Plavša and Nedić, 2015). Pollination is considered to be a vital process in survival of terrestrial ecosystem and human species. It is estimated that the world's economic value from pollination amounts to 153 billion euros, i.e. 9.5% of total economic value of agricultural production used directly for human food (Gallai et al., 2009). Honeybee, due to its adaptibility, way of breeding, habitat and availability in relation to other bees occupies a top position regarding its use in crops pollinating throughout the world (Stanisavljević and Nedić, 2008) (Khalifa et al., 2021). It makes extremely efficient visits to flowers and participates in carrying pollen from flower to flower thus contributing about 13% floral visits in all natural floral networks around the world (Hung et al., 2018).

In search of food and water honeybee manifests complex behaviour (Abou-Shaara, 2014). An efficiency in obtaining quality food and suitable quantity of food brings better development and vitality of bee colony while nutritive stress can lead to bees health problems (Branchiccela et al., 2019) (Kratz, 2022).

To humankind honeybee provides direct bee products that are highly important, indirectly affects the provision of food for humans through pollination process, and has positive effects on life environment. Different beehive and external environment factors and their interaction can impact a bee behavior, bee products yield and bee survival (Meikle, 2020).

By introducing digital technology in beekeeping the possibility to precisely continually monitor the process going on inside and outside beehive with bees in real time independently of human observer is being obtained (Andrijević et al., 2022) (Dimitrijević and Zogović, 2022). Sensors powered by artificial intelligence are connected with internet and they can collect a great number of records from a great number of beehives which are then sent to the cloud. Collected information can be analysed and as a result an account about the state in bee community or predictions made on what is necessary to be undertaken in beehive can be produced (Hadjur et al., 2022).

Machine learning, as a subfield of artificial intelligence (AI) provides perception of a number of different parameters in beehive and its environment. It refers to the process of development of algorithms which produce computers that can learn on the basis of data collected by sensors or from data bases. In this way computers are given possibility to recognize certain patterns and make predictions in further operations (Aydin et al., 2022); (Alpaydin, 2020).

The application of digital technologies for monitoring the bee behavior should facilitate and provide data collecting, their analysis and solutions which would serve in understanding bee behavior, their protection, facilitate management of bee colonies and produce higher yields of bee products. This study covers the application of digital technologies in different segments of beekeeping. At the end of the paper, the perspective of their application in beekeeping is given.

2. The Use of New Technologies in Monitoring Bee Activities and Development of Bee Colony

A very complex biology of bee colony and the impact of numerous biotic and abiotic factors on bee colony is a subject of numerous studies. Methodology used in different spheres of studying the life of honeybee and its colonies has been appropriately adapted and tries to be as precise and as uniform as possible (Buchler et al., 2013).

The putting up of the first beehive individual sensors has developed to simultaneous placing of more sensors inside and outside the hive which measure numerous parameters and of their connecting to the system for remote monitoring based on Internet of Things (IoT) concept. Such an approach can provide timely information on the state in bee colony. "By use of machine learning algorithms the computers are given possibility to learn to detect these events without explicit programming" (Marković et al., 2016) (Pešović et al., 2019). Development of multisensory platforms that can simultaneously monitor the mass of a beehive, sounds emitted by bees, temperature, humidity and CO_2 inside hive, as well as climate parameters outside the hive are aimed at collecting a large quantity of information that can indicate the state in bee colony and help preventing decline in their number (Cecchi et al., 2020).

Maintenance of temperature and relative humidity at an appropriate level in a bee colony are vital for its survival. Honeybee actively manages the process of maintaining the temperature especially in the zone of bee brood where ideal temperature should be 35ºC. Humidity in the brood affects the surviving of bee brood, growth of microbes and parasites, concentration of nectar and thermoregulation and usually it ranges between 50 and 60 % (Ellis, 2008). Beehive temperature is an important parameter of health and impact of stress on bee colony along with a relative humidity (RH) (Altun, 2012). Hence the use of sensors for measuring a beehive temperature and RH has, besides scientific application, a commercial application as well (Melicher et al., 2019). Putting up remote sensors on several positions in a beehive provides more thorough information on temperature and RH inside beehive with bees and therefore on the conditions in a bee colony. By measuring a beehive temperature it is possible to assess the strength of bee colony. It has been determined that sensor records for temperature that are the closest to a beehive geometrical centre are also closely connected with the strength of colony (Cook et al., 2022).

Carbon dioxide is an essential gas for collective functioning of bee colony. At high concentrations CO_2 can be harmful for bees (Meikle et al., 2022). A quantity of carbon dioxide can initiate fanning behavior in bees. By placing the sensor in beehive the information on the state of bee colony in beehive can be obtained. Bencsik et al. (2023) used non-dispersive infrared (NDIR) detector to measure a beehive CO_2. The system was based on microcontroller which collected data from the SCD41 NDIR sensor placed in crown boards and queen excluders of honeybee colonies. The same sensor provided collecting data on relative humidity and temperature. The colonies were placed on an automatic BEEP hive scale and the mass of colonies was monitored during research. The research showed that it is possible to assess the size of colony on the basis of the change of measured CO_2, and that its level decreases during several weeks as bee colony dies.

Measuring the mass of beehive with bees over a year is crucial for assessing both the quality of honeybee pasture and productivity of colony, a moment of honey centrifugation and providing adequate food supplies for winter and for the estimation of the health of colonies. This parameter can indicate the incidence of robbing or swarming in a bee colony. The use of the automatic scales equipped with sensors proved to be useful in remote data collecting and furthermore they can be equipped with GSM/GPRS exterior interface for package communication with remote server (Zacepins et al., 2017). The automatic scales are particularly useful in combination with sensors that can make a record of meteorological conditions in different landscapes thus the information that the modifications in weight mostly depends on the period of observation and air temperature were obtained (Czekonska et al., 2023).

The activity of the bees at the entrance of the hive can indicate the strength of bee colony, its value at pollinating activity, diligence at food collecting as well as potential health state of the colony (Cook, 2022) (Kulyukin and Kulyukin, 2023). The affordable price of digital cameras led to installing one or more of them to record and monitor the behavior of the bee at the entrance of the hive (Crawford et al., 2022). By means of video recording and computer vision it is possible to collect data on the count of the bees that enter the hive carrying the burden of pollen (Yang et al., 2018). Digital cameras placed inside the hive, supported by the algorithm of deep learning are used in detecting the level of bees infested by varroa mite (Voudiotis et al., 2022). In order to monitor bee's going in and out of the hive during a certain period of time the counters are put up in front of the hive entrance. In majority of cases those are the multiple gate counters equipped with photoresistors. Installed photosensible counters can be a part of a complex system based on the use of the IoT (Andrijević et al., 2022). Data collected by means of algorithms of machine learning can predict different states in bee colony so that certain apitechnical measures can be undertaken accordingly.

The assessment of the bee colony strength is a parameter valued in commercial beekeeping connected with honey production, general state of the bee colony and used also as one of the performances in selection regarding the choice of colonies. Standard methods encompass the estimation of contents on the frames taken out from bee colony whose performances are being assessed. One of the standard methods is Liebefeld method based on a visual estimation of the number of worker bees, quantity of nests and food on the frames in a hive (Dainat, 2020). There are some other methods that are also based on visual estimation of an evaluator but certain methods require considerable time and upset the bees. The era of digital cameras in conjunction with computer software for image processing has opened the field of their application in beekeeping as well. The early application of digital cameras in estimating the bee colony performances included the use of digital camera, auxiliary stands, image processing software and data analysis. Even with this, at that time innovative technology, the hive frames had to be removed what has disturbed the bees. A care should be taken to regulate the distance between digital camera and the object of observation along with a consistency of lighting (Knopp et al., 2006). However, the method made an advance in use of digital technology in estimating the bee colony performances.

Throughout the time a completely autonomous system for monitoring the image and sound inside the hive with bees as well as the system for warning the owner if the noise of bees in the hive is higher than usual has been developed (Murphy et al., 2015). Installing a digital infrared camera for shooting images inside hive, external thermal imaging camera for monitoring the status and activity of bees, accelerometer and microphone connected to shelf microcontroller node for processing has provided obtaining the relevant information. Taking into account that bees cannot see in infrared spectre the cameras set up inside hive did not disturb them. The system was energy-supplied via solar panels what made it energy-neutral. Such a concept provided to the owner the insight into an array of useful information regarding the state in a hive even when they are placed in remote locations.

Development of utility software in recognizing the content in honeycomb cells has being improved in sphere of beekeeping. Free of charge DeepBee© software is able to automatically detect the cells in the images of honeycombs and classify their contents in seven classes (Alves et al., 2020). For the purpose of counting and differentiating the content in honeycomb cells thirteen convolutional neural network (CNN) architectures have been trained and evaluated. The aim was to successfully differentiate honeycomb cells containing eggs, larvae, pollen, nectar, honey and other. The exactness of recognizing with chosen network accounted for 94.3%. Authors have made CNN models, original code and data sets publicly available.

An advantage of free and open approach to the models has enabled the upgrading of already existing solutions. Thus Capela et al. (2022) determined the size of bee colony by assessment of the mass of adult bees. All beehives were equipped with Beeyard autonomous scale for continual checking the mass of beehive with bees. The resources of brood and food were estimated by taking images and by image analyses by means of DeepBee® image analysis software. Since the software is based on a deep insight the pictures of eggs and larvae suitable for instructing and improving the software accurateness were chosen. After a training course the accuracy of upgraded version was estimated by using 40 random images of bee colonies, by comparing automation output with manually corrected output. The upgraded version had better effect in recognising the content of honeycomb cells. As a result of this study it was concluded that it is possible to adapt software to local conditions in which the bee colonies exist.

3. Use of New Technologies in Monitoring Swarming Behaviour in Bees

Swarming is a specific biological process in honeybee communities resulting in a division of an already existing colony of old bees during which about half the bees with an old queen bee fly out and form a new colony in a new locality and in a new habitat. Another half of that bee colony remains in a beehive with more mature queen bees. This phenomenon most often occurs before a main honey pasture which is predecented by a great activity of queen bee in egg laying. The colony becomes stronger and stronger and there is an abundant number of young bees in the beehive. Due to accumulting the bees in the hive and its confined space a ventillation can be disturbed in which conditions the concentration of CO_2 increases and that contributes to swarming of the bees. In a bee colony a balance between the number of young bees and quantity of brood can be disturbed. Bad weather conditions, inability of collector bees to perform their job and disturbing the chierarchy of jobs in a beehive and its less abundant secreting can make the worker bees start preparing for the process of swarming. The swarming is considered undesirable phenomenon in the technology of honey production. Certain measures are being conducted by beekeepers to detect this phenomenon in the first phase and then prevent it or for a bee colony to be swarmed artificially. If swarming nevertheless takes place and newly created swarm has not been caught by beekeepers this phenomenon can represent a significant economic loss in commercial beekeeping. Because of that the recognising the signs of swarming is very significant in commercial beekeeping. Majority of mentioned causes of swarming can be monitored by use of new technologies.

Acoustic monitoring of animal activities is used in modern livestock breeding. Such monitoring in beekeeping can help control the hives with bees on remote locations. It is possible to separate the activity of bee swarm out of audio signals using a classification of acoustic signals based on deep neuron nets IoT-a (Zgank, 2021).

One of the important signs of swarming state is "vibration" or "shaking" signal at which worker bees move their bodies fast (Grozinger et al., 2014). Use of vibrations and their analysis in discovering swarming instinct was researched by Bencsik et al. (2011). With the help of this non-invasive method by placing the accelerometer on the hive external wall without combinations with time or other measures they have determined the quantity of vibrations which is very specific for swarming process, a few days before a visible swarming. On the basis of the records on vibrations recorded by means of accelerometers placed in hives with bees and using two algorithms of machine learning a successful differentiation of colonies which intend and which do not intend to swarm has been achieved (Ramsey et al., 2020). A level of accuracy of over 90% has been achieved with successfull prediction of swarming up to 30 days before the event.

In addition, audio signals are emitted by queen bees in the season of swarming and they are described as tooting and quacking. It is believed that those signals are important for swarming and that bees can differ those two signals through differences in their time structures. By placing the microfone in hive and their analysis by software the difference between queen piping temporal structures of two honeybee species, *Apis cerana* and *Apis mellifera* have been detected (Yamamoto et al., 2021).

4. The Use of New Technologies in Monitoring a Reproductive Behaviour in Bees

Honeybee queen mates only once, most commonly seven days after birth. Queen bee fly out of the hive and go to so called mating areas – drone congregation areas (DCA), where non-mated queen bees and drones gather together. About 11.750 ± 2.145 drones (Koeniger, 2005) gather in the air flying at mating apiaries but only few of them have a chance to mate with queen bee. By arriving at the DCA the drones form a so called "comet" behind the queen bee in which there are about 30 drones which fly after queen bee and fight for the position. A queen bee mates with 12 to 14 drones on average. Different factors can affect a behaviour of queens such as the age or climate factors (Simone-Finstrom and Tarpy 2018). Number and length of individual nuptial flights of queen bee is variable (Tarpy et al. 2015). Unlike sexually mature drones which often leave the hive in search of a partner the queen bees rarely fly out of the hive in order to mate with drones. Monitoring and studying the behaviour of queen bees and drones for the purpose of mating was an issue of various studies (Williams, 1987) (Williamson et al., 2022), but only with the use of new techniques the essential particulars regarding reproductive behaviour of honey bee have been learned. In standard metodology used in studying this behaviour the marking of individual bees by means of a colour, pheromone traps, micro-dots are used (De Souza et al., 2018).

Use of transporders for radio-frequency identification (RFID) is innovative approach of marking individuals in beekeeping which was used at two mating apiaries in studyng a mating behaviour of virgin queen sisters in the “Ilm-Kreis” district in Middle-Thuringia, Germany (Heidinger et al., 2014). Into the system based on radio waves three components have been integrated and they are antenna, reader and mark (Nunes-Silva et al., 2019). In their research Heidinger et al. (2014) used RFID (mic3-TAG 64RO, carrier frequency: 13.56MHZ, Microsensys GmbH, Erfurt, Germany). Tags dimensions were 1x1.6x0.5 mm and 2.4 mg mass. On account of their dimensions tags are fixed to the backs of non-mated queen bees. Reader module is fastened to the entrance of every nucleus beehive. Reading the coming in and coming out of queen was registered by a reader module (date, time, reader and tag ID number) and data were stored on the host. The data collected were taken off the host followed by the analysis of the number of survived queen bees, general flight behaviour of the queens, lenght and frequency of nuptial flights of the queens. Such a type of research with use of RFID is very efficient for collecting and analyzing the data on mating behavior in queens..

Monitoring the activity of drones *Apis mellifera* L. during mating season, by use of standard methods is very demanding and subject to errors. Ayup et al. (2021) in nortwest Argentina, monitored comparative reproductive behaviour in drones using three methods: direct monitoring, video recording (video camera JVC 40X Full HD) and radiofrequency identification (RFID). In method of monitoring by means of RFID 200 individual drones were marked 200. Each microchip included an identifier that enabled separating the singular activities of drones. This method enabled 24 hour monitoring and understanding the behaviour of drones at dawn and in the morning which up to then has not been displayed. Collected RFID data have confirmed the pattern of activity of drones recorded by a direct monitoring at the entrance into a hive and by a drone congregation area. .

Uzunov et al. (2022) monitored the queen’s reproductive behaviour by free observation and video recording by digital camera. It was observed that queens performed nuptial flights over a period of 1.8 days in Croatia (HR), to 4.3 days in Northern Macedonia (NM) and 1.6 to 2.4 days in Slovenia (SI) on average. On different locations queens had the least number of nuptial flights in SI (Krma 2.3), and largest in NM (Belicki 8.8). This kind of research which use digital video recorders provides detailed insight into reproductive behaviour in honey bee queens, decrease the engagement of researcher and increases the precision of the data obtained. When using an observer service, this activity is time-consuming and fatigue can affect the observer.

4. Conclusions And Recommendations

Honeybee (*Apis mellifera* L.) is an irreplaceable member of natural ecosystem to which it contributes through its pollinating activity by a transport of pollen between the plants. A direct benefit of honeybee is also unique and is reflected in bee products. In the first place, it refers to honey production as an important source of functional food but also of an economically significant product in international trade.

The application of high technological solutions in the field of digital technology and artificial intelligence has been incorporated into many segments in beekeeping area by revealing new details and predictions regarding complex biological processes in bee community.

The application of digital technologies in the future should fulfil the factors which comply with specificities in the beekeeping area. Sensors used for data collecting should be of appropriate size according to the use in hive or on the bees themselves. During the operation of monitoring system it is necessary to achieve the effect of non-invasiveness to bees while sensor units should be "olfactory" acceptable to bees not isolating them by propolis. Installed sensors and the other digital equipment should provide collecting data from the hive zones and the zones around the hive that are deemed important for the studied trait. Taking into consideration a variability of bee colonies in one apiary or on more apiares at different locations, with different environment, it is neccessary to plan carefully the number of monitoring units and take care of presentation of data obtained. In that light the price of singular components and of the entire system for monitoring can be a limiting factor for their application in beekeeping. Installed systems of monitoring the bee colonies should provide an access to remote information. It is very important to endeavour to developing the energy independent monitoring systems. It is necessary to include/develop softwares for the processing of collected data that can be both easily applicable for an average user and whose accuracy regarding the collected and processed data would not be compromised and predictions in accordance with events in real time possible.

The application of digital technologies in beekeeping provides better insight into a honey bee behaviour as well as the perception of the environment impact on bee colony, which can affect its better production performance. Using the capabilities of digital technology will enable timely identification of appearance of negative conditions in bee colony in order to prevent negative effects on bees.

Acknowledgments: We are grateful to the Serbian Ministry of Education for providing grants 451-03-47/2023-01/200116.

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ISAE 2023
The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

USE OF CONSTANT FLOW VALVES (CFV) ON HAND-OPERATED SPRAYERS TO IMPROVE CROP PROTECTION QUALITY

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Abstract: *To achieve high yields and good fruit quality, adequate, timely, and high-quality crop protection is required. Farmers on small farms use hand-operated sprayers for crop protection, which as such are not reliable for high-quality crop protection because the pressure at the nozzle outlet is uneven, resulting in low-quality pesticide application. Since hand-operated sprayers are unreliable, the objective of this paper is to determine the extent to which constant flow valves (CFV) (1 bar, 1.45 bars, and 2 bars) affect the quality of crop protection and thus the cost. The flow rates with the constant flow valves were 240 ml/min (CF valve 1 bar), 303 ml/min (CF valve 1.45 bars), and 331 ml/min (CF valve 2 bars), the factory nozzle 261 ml/min. During the test, the working pressure was determined by the regulator used, the operator's speed of movement was constant at 1.2 km/h, and the distance to the object was 1 meter. The average coverage of the treated area ranged from 5.76% to 35.85%. The average size of droplets ranged from 490.88 µm to 639.72 µm, and the average number of droplets per cm² of surface area ranged from 44 to 102. Based on the results obtained, it was concluded that constant flow valves have an impact on leaf coverage, number and size of droplets, and cost of crop protection, and therefore can be used very effectively for these purposes.*

Key words: *constant flow valve, hand-operated sprayer, pesticides, quality of spraying, coverage of treated area*

1. INTRODUCTION

The protection of cultivated plants includes plant protection from biotic and abiotic factors. In plant protection, the precise application of pesticides implies the proper maintenance of machines and devices for application, the education and expertise of operators, the use of improved methods, and modern and environmentally friendly techniques for pesticide application. Failure to meet one or more of the stated conditions will result in environmental pollution, harmful consequences for human health, as well as an increase in production costs, which can be: direct (excessive consumption of pesticides) and indirect (reduction in product quality and yield) [1]. The main reasons for unsuccessful chemical protection of a crop are primarily the use of inadequate equipment, incorrect spraying technology, uneven and excessive distribution of pesticides, and inadequate working pressure [2].

The most common method of pesticide application in Bosnia and Herzegovina is using hand-operated sprayers, which are available due to their low cost and ease of use. Also, hand-operated sprayers are mostly used for pesticide application on small farms and also for amateur production [3]. Since agricultural farms in Bosnia and Herzegovina are usually small, a large number of agricultural producers (fruit growers and vegetable growers) decide to use hand-operated sprayers, which do not provide the possibility of precise pesticide application. Protecting plants with hand-operated sprayers usually causes oscillation of the working pressure, significantly affecting the output amount of pesticides, droplet size, and leaf coverage. The advantage of sprayers compared to atomizer sprayers is less occurrence of drift, which is more present with atomizers even when there is a slight wind, as well as the simplicity of the construction, which enables easier use even by non-experts [4]. Also, it is common that operators of hand-operated sprayers are not sufficiently familiar with the correct setting and handling of sprayers, as well as with new technologies in plant protection. The appropriate pressure when applying pesticides has a high influence on the costs and efficiency of the application. If the pressure is too low, it leads to incorrect coverage of the leaf surface, incomplete dispersion of the pesticides, and thus ineffective treatment. This can result in re-treatment, which leads to additional costs of resources and time. On the other hand, if the pressure is too high, it can lead to excessive dispersion of the pesticides, which increases the amount of spent pesticides, which also leads to an increase in costs.

The appropriate pressure of the sprayer during the pesticide application enables uniform dispersal of the pesticide, which increases the efficiency of the treatment and reduces the need for re-treatment. This leads to a reduction in the consumption of resources and time, and thus to a reduction in costs. Appropriate pressure on the nozzle of hand-operated sprayers reduces the risk of loss of pesticide due to evaporation, thereby increasing the effectiveness of the treatment and reducing the need for re-treatment. Therefore, the appropriate pressure is the key importance for reducing costs and increasing the efficiency of the pesticide application, which can result in higher profitability of agricultural business. Constant flow valves are new on the market in Bosnia and Herzegovina, and the work aims to determine the influence of the constant flow valve on the amount and distribution of the liquid that is sprayed on the plants. Also, the effectiveness of the constant flow valve in preventing overspray and fluid waste was tested, which included measuring the amount of fluid wasted and the amount not sprayed where needed.

2. MATERIAL AND METHODS

The examination of the effect of the CF valve on the hand-operated sprayer was done in the laboratory according to EN ISO 19932-3 standard in *Willamette* raspberry plantations. Raspberries were treated with a hand-operated sprayer (with and without a CF valve), and testing was done with water. The hand-operated sprayer was used with and without built-in CF valves of 1 bar, 1.45 bars, and 2 bars, brand *Brichmeier*. The treatment of raspberry plantations did the testing (*Rubus ideaus*), using a hand-operated sprayer brand *Koplast*, with a factory nozzle (spray angle 110°, ISO color 01 (orange), flow rate 280 ml/min at a working pressure of 1.5 bars).

The testing of the flow rate and quality of protection was performed in the authorized "Laboratory of Agricultural Machinery" within the Faculty of Agriculture and Food Science, University of Sarajevo. The nozzle flow test was performed by the sprayer testing equipment "*Schachtner type control B20*" using a hand-operated sprayer and applying the EN ISO 19932-3 norm. Measurement of plant protection quality parameters included droplet size, leaf coverage, the number of droplets per unit area, and pesticide consumption. As part of the selected measurement methods, water-sensitive papers and towel papers, dimensions 95 x 110 mm are used (to determine the pesticide amount retained on the plant), and microscope and digital measurement techniques are used to process the results. The leaf coverage was analyzed with water-sensitive papers, and the amount of pesticides retained on the plant was determined by the mass method of paper towel weighing.

In laboratory conditions, testing of a hand-operated sprayer with and without a CF valve was performed to determine mutual differences and avoid the influence of "drift". The hand-operated sprayer was also tested in field conditions of raspberry protection, with and without a CF valve. The collected data were statistically analyzed. Based on the obtained data, an assessment of the application of CF valves was made.

Based on the obtained results, the optimal CF valve, the distance from the object of application, and operator's speed of movement during the pesticide application were determined. Also, based on the examination conducted, a review of the impact of the use of CF valves in raspberry protection on the economic indicators of production was made.

3. RESULTS AND DISCUSSION

To achieve set goals and tasks of the work, it is necessary to analyze the collected data and to make adequate conclusions. The results are presented in several separate sections.

1.1 Nozzle flow

Based on the set goals of the work, the factory nozzle flow and the flow of the nozzle with CF valve (1 bar, 1.45 bars, and 2 bars) as well as the deviation from the declaration norms were determined. The declaration norm of flow for a CF valve of 1 bar was 230 ml/min; of 1.45 bars – 280 ml/min and of 2 bar – 325 ml/min, and for the factory nozzle at a working pressure of 1.5 bar – 280 ml/min. Mathematical operations determined the flow deviation (%) from the declaration norms, as well as the average flow (mean) of the nozzle with and without a CF valve. The lowest flow was at the 1 bar CF valve (240 ml/min), and the highest at the 2 bar CF valve (331.78 ml/min). Also, at the significance level $\alpha=0.05$, a statistically significant difference in flow between all 4 measured flows was determined. Table 1. Shows the statistical parameters of nozzle flow with and without a CF valve.

Table 1. Statistical parameters of nozzle flow and different types of constant flow valves (CFV).

Statistical parameters	Nozzle	CF-valve 1 bar	CF-valve 1,45 bars	CF-valve 2 bars
Average (ml/min)	261,13	240,07	303,21	331,78
Minimum (mil/min)	225	238	280	300
Maximum (ml/min)	320	260	320	360
Deviation from declaration norm (%)	-6,78	4,34	8,21	1,84

Based on the presented data, it can be concluded that the use of CF valves causes an increase in the average flow compared to the use of the factory nozzle, whereby average flow increases with the use of a higher-pressure CF valve. Also, it can be seen that the minimum and maximum flow are within an acceptable range. The deviation from the declaration norm was low in the CF-valve at 2 bars, and the highest in the CF-valve at 1.45 bars. These results can be useful for selecting the appropriate CF valve depending on the target flow values.

Similar studies were also concerned with analyzing nozzle flow deviations, where a higher number of nozzles were analyzed [5] [1]. The nozzle is in good condition until the flow capacity increases by more than 15% compared to the declared value [6]. So, the flow deviations in this case, which ranged from 1.84% to 8.21%, are considered satisfactory. In the published study, it was necessary to replace all old nozzles with new ones because the old nozzles had more than 15% deviation from declaration norms [7]. Some authors found in their research that applying constant flow valves on sprayers achieves a more uniform leaf coverage [8]. Research shows that using CF valves on sprayers reduces the amount of pesticides that are sprayed into the environment, which reduces the risk of negative impacts on the environment and human health. It has also been shown that the use of nozzles with a CF valve achieves a more precise pesticide application and a more uniform leaf coverage.

2.1 Pesticide retention on plants

Except for nozzle flow and deviation from declaration norms, very important is to know how much pesticides are retained on the plants themselves. For this purpose, a paper towel was used, which was placed between the plants. The average amount of pesticides retained on the surface of the paper towel, when treated with the factory nozzle was the smallest 0.100 g, and the largest, when treated with a CF valve of 2 bars was 0.285 g. When applying a CF valve of 1 bar, the average amount of pesticides retained on the paper towel was 0.171 g, and with a CF valve of 1.45 bar, it was 0.257 g.

Table 2. Statistical parameters of the amount of pesticide retained on the plants (towel paper)

Statistical parameters	Nozzle	CF-valve 1 bar	CF-valve 1,45 bars	CF-valve 2 bars
Average (g)	0,1	0,171	0,257	0,285
Standard deviation	0,058	0,049	0,054	0,069
Minimum (g)	0	0,1	0,2	0,2
Maximum (g)	0,2	0,2	0,3	0,4

Table 2. shows statistical data on the amount of retained pesticides for different CF valves (1 bar, 1.45 bars, 2 bars) and the factory nozzle. The average pesticide retained amount increases with increasing pressure, with the highest average pesticide retained of 0.285 g for a CF valve 2 bars. Also, it is noticeable that the differences between the average values of pesticide retained for CF valves 1.45 bars and 2 bars were smaller than between 1 bar and 1.45 bars. Also, the standard deviation for 2 bars was higher compared to the other CF valves, which may indicate greater variability in the amount of retained pesticides at that pressure. However, further research with much larger samples and different conditions is necessary to confirm such results. Similar results show that the smallest pesticide amount on the treated object was at an operator speed of movement of 1.66 km/h and amounted to 0.220 g, the largest at a speed of movement of 0.72 km/h and was 0.82 g, and the optimal amount was on the treated object at a speed of movement of 1.20 km/h and amounted to 0.44 g [4]. At the significance level α=0.05, statistical data processing revealed a statistically significant difference in the pesticide amount retained between a) treatment with the factory nozzle and treatment with CF valves 1.45 bar and 2 bars, b) treatment with a CF valve of 1 bar and the CF valve of 2 bars. The effect of the Cf valve on the amount of pesticides on the plant depends on many factors, such as the pesticide type, the type of plant, the type and pressure of the CF valve, the operator speed of movement, the size and type of the nozzle, etc. However, in general, it can be concluded that the use of a CF valve can be useful in reducing the pesticide amount applied to the plant, thereby reducing the potential risk of negative effects of pesticides on the environment and human health. The pesticide amount retained on the plant, using a hand-operated sprayer, can be increased by moving the operator slower and vice versa. The average pesticide retained amount increases with increasing pressure, with the highest average pesticide retained of 0.285 g at 2 bars. Also, it is noticeable that the differences between the average amount of pesticide retained for 1.45 bars and 2 bars are smaller than between 1 bar and 1.45 bars. Also, the standard deviation for 2 bars was higher compared to the other valves, which may indicate greater variability in the amount of retained pesticides at that pressure. At the significance level α=0.05, statistical processing of the data revealed a statistically significant difference in the amount of retained pesticides between a) treatment with the factory nozzle and treatment with a CF valve of 1.45 bars and 2 bars, b) treatment with a CF valve of 1 bar and 2 bars.

3.1 Leaf coverage with pesticides

The quality and success of plant protection largely depend on the leaf coverage, and the coverage depends on the number and size of droplets. To determine the percentage of leaf coverage, as well as the size and number of droplets, water-sensitive papers placed inside the row of raspberries were used. Using the GIMP software, digital photos of water-sensitive papers were analyzed, where the diameter of the droplets, the number of droplets, and the total coverage of the water-sensitive papers were measured. Statistical analysis of data (diameter of droplets from water-sensitive papers) determined the average diameter of droplets with and without a CF valve. The largest droplets are at the factory nozzle (639.72 μm), and the smallest at the 2 bar CF valve are 490.88 μm (Fig. 1.). Also, one-way ANOVA, at the significance level $\alpha=0.05$ showed a statistically significant influence ($sig < 0.05$) of the CF valve on the droplet size. The post-hoc Tukey test showed statistically significant differences between the droplet size of the factory nozzle and the CF valve of 1.45 bars (sig=0.019) as well as the factory nozzle and the CF valve of 2 bars (sig=0.001).

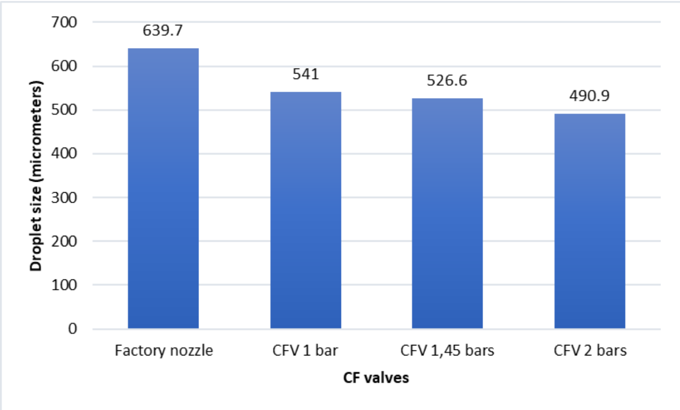

Fig. 1. Droplet size with the application of different CF valves

The smallest average droplet size was 490.88 μm (CF valve 2 bars), and the largest was 639.72 μm (factory nozzle). This means that the average droplet size decreased with increasing pressure and use of the CF valve.

In addition to the above characteristics, which are essential for successful plant protection, the adjustment of spacing and the distance of the nozzles (from the spraying object) play a significant role in the correct pesticide application. In related research, it was established that significant deviations occur in pesticide application if the height and distance of the nozzles are not adapted to the exit angle of the spraying [9]. Other authors found that with increasing pressure at the nozzle, the droplet size further decreased and at a pressure of 3 bars, the average droplet size was 100 μm [1]. Also, another study clearly showed that with an increase in the working pressure, the droplet size decreases [10]. According to a similar study, the smallest average droplet diameter obtained when treated with a green nozzle (marked by ISO color) and at a working pressure of 19.53 bars was 139.29 μm, while the largest average diameter (266.12 μm) determined when treated with a blue nozzle and a working pressure of 1.51 bars [11].

These results are important because droplet size can affect the application efficiency of pesticides and other agrochemicals. For example, smaller droplets can better penetrate the leaf mass and have better leaf coverage, while larger droplets can be more wind resistant and better retained on the leaves. Therefore, choosing the right droplet size can be a key factor in improving the efficiency of pesticide application and reducing costs. These results also show that the use of CF valves can be beneficial in reducing droplet size and better distribution of pesticides, which can result in a reduction in the amount required for application and a reduction in the risk of environmental pollution. In further research, the influence of other factors, such as wind speed or air humidity, on droplet size could be examined, and how these factors can affect the effectiveness of pesticide application. It would also be useful to conduct additional research to determine best practices in droplet size selection and pressure regulation depending on operating conditions, which could be beneficial to farmers in improving efficiency and productivity.

Table 3. Statistical parameters of the droplet number on the treated surface/cm^2.

Statistical parameters	Nozzle	CF-valve 1 bar	CF-valve 1,45 bars	CF-valve 2 bars
Average	43,75	46,75	77,25	102
Standard deviation	5,73	36,77	22,33	11,51
Minimum	37	15	54	94
Maximum	51	82	101	117

Table 3. shows statistical parameters on the number of droplets per cm^2. The smallest number of droplets was when treated with a factory nozzle and was on average 43.75 droplets/cm^2, and the largest number of droplets was when using a CF valve of 2 bars and was on average 102 droplets/cm^2. Also, it can be seen that, per individual sample, the smallest number of droplets was with the CF valve of 1 bar (15 droplets/cm^2), and the largest was with the CF valve of 2 bars (117 droplets/cm^2). It can be seen from the results that the average number of droplets per cm^2 increases with increasing pressure. Also, it is visible that CF valves of 1.45 bars and 2 bars have a higher average number of droplets per cm^2 compared to the factory nozzle and CF valve of 1 bar.

Also, the CF valve of 2 bars has the highest maximum number of droplets per cm^2, while the minimum number of droplets per cm^2 is with the CF valve of 1.45 bars. From these results, it can be concluded that increasing the pressure can increase the number of droplets per cm^2, which could result in better coverage of the treated surface with pesticides, which can be important to achieve a better performance of pesticides. In a similar study, is mentioned that at a working pressure of 2.18 bars, a speed of movement of 8 km/h, and an application dose of 300 L/ha, the lowest average number of droplets per cm^2 was 33.26, and the highest at the working pressure 19.53 bars, a speed of movement of 8 km/h and application dose 350 L/ha was 123.02 droplets per cm^2 [11].

Treating plants with fungicides, the best biological effect is achieved with 80 to 90 droplets per cm^2, and with insecticides 60 to 70 droplets per cm^2 [12]. The group of authors says that a higher number of droplets per cm^2 is achieved by increasing the working pressure [10] [13], and that increasing the working pressure results in higher surface coverage [14].

4.1 Economic indicators of justification for using CF valves

In every production, including agricultural, when the producer chooses to get into, the most important thing is profit. After starting agricultural production, the producer's goal is to reduce costs. One of the cost reductions in agricultural production is the precise pesticide application. In this paper, CF valves used for precise pesticide application were examined. Authors say that in Bosnia and Herzegovina, farmers usually use defective and unadjusted (uncertified) sprayers with defective nozzles, which is reflected in the quantity and poor quality of pesticide application [1]. In fruit production, the number of pesticide applications in one growing season ranges from 5 to 15 times (in exceptional situations, even more) [15]. Some authors indicate that nozzle flow and the number of pesticide applications have a significant impact on the amount of pesticides and thus on the cost of protection [1].

The average price of a CF valve is around € 25. The price of an average and unsuccessful treatment with herbicides is € 50/ha, fungicides € 90/ha, and insecticides € 65/ha. From the above, it can be concluded that the economic justification for using CF valves is unquestionable, the price is lower than the average price of one treatment with herbicides, fungicides, or insecticides. The correct pressure when applying pesticides has a big influence on the costs and efficiency of the application. If the pressure is too low, it can result in insufficient leaf coverage, incomplete dispersion of the pesticides, and thus ineffective treatment. This can result in re-treatment, which results in additional costs of resources and time. On the other hand, if the pressure is too high, it can result in overdispersion of the pesticides, which increases the amount of spent pesticide, which also increases costs. Therefore, the correct pressure is of key importance for reducing costs and increasing the efficiency of the pesticide application, which can result in better profitability of agricultural business.

4. CONCLUSIONS

The tested nozzle and CF valves had deviations from the declared norms, but the deviations were not higher than prescribed by the standard. The factory nozzle had a smaller flow deviation than the declared one, amounting to 6.78%. The CF valve caused the discharge of more liquid than the declared norm, namely: CF valve of 1 bar +4.34%; 1.45 bars CF valve +8.21%, and 2 bars CF valve +1.84%. Based on the statistical analysis, statistically significant differences between all four cases were determined, and with increasing pressure, the flow at the nozzle increased. When it comes to the quality of pesticide application, the most important things are the droplet size, the number of droplets, and the total coverage of the treated surface. The best coverage of the treated surface was with a CF valve of 1.45 bars (35.85%), and the worst one with a factory nozzle (5.76%). Statistically significant differences were also found between a CF valve of 1.45 bars and 1 bar and a factory nozzle, between a CF valve of 2 bars, a CF valve of 1 bar, and a factory nozzle. By analyzing the average droplet diameter, it is concluded that there was a statistically significant difference in droplet size between different nozzles and CF valves. Droplet size decreased with increasing valve pressure and using CF valves. Therefore, it can be recommended to use CF valves with higher pressure to obtain smaller droplets, which can lead to better coverage and more efficient pesticide application.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

REVIEW PAPER ON *VARROA* INFESTATION, DETECTION AND PREVENTION IN BEEHIVES

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Abstract: *The widely recognized insect known as the honey bee (Apis mellifera) has a beneficial impact on both the environment and human life, making it important to protect them not just for ecological reasons but also for the economic and social advancement of countryside regions. Their existence is so essential that the recent decrease in honey bee hives has caused a growing interest in them. One of the reasons for bees' decline in population is infestation with a parasite known as Varroa destructor. In order to effectively treat the V. destructor infestation, it is critical to monitor the amount of infestation in hives. While there is at present no specific sensor for this job, continuous and discrete monitoring of hive infection levels as well as other critical bee colony characteristics, such as temperature and humidity, is wanted. The use of chemicals by apiarists is a method of controlling the infestation that is the most common strategy. Substitute tactics include the use of organic compounds, organic products like essential oils, and biotechnological techniques like mite trapping. Therefore, successful therapy and preventing harsh chemical use can reduce bee mortality and economic losses.*

Key words: *Smart apiculture, Varroa, Honey bee, Monitoring.*

1. INTRODUCTION AND OVERVIEW

What is Varroa? Simply said, *Varroa destructor* is a mite, a parasite that attaches itself to the bee, like a tick on a human being. The most dangerous pests to adult and larvae bees, *Apis mellifera* are Varroa mites. Adult bee body, weight, life expectancy, and resistance to infections are all decreased as a result of mites feeding on bees (Jong et al., 1982; Martin S. J., 1994; Büchler, 2015; Roberts et al., 2017). Varroa mites are from 1.5mm to 2mm wide and one mite approximately weights 0.453mg while one bee weighs around 110mg. Adult female mites spread via phoresy by latching to worker bees and drones. The mites enter into brood cells occupied by mature bee larvae before worker bees seal comb cells with wax, where they ultimately consume the fat tissue and hemolymph of the host larvae (McMenamin and Genersch, 2015; Wallner, 1999). Left unattended, infected honey bee colonies typically die within a year if the mite population grows unnoticed and untreated (Büchler, 2015). While there are several causes that might lead to colony death, Varroa infection (Roberts et al., 2017) and the spread of a wide variety related to bee viruses are often deemed to be the most significant (McMenamin and Genersch, 2015). There is a paradox in the chemical treatment for varroa mites. It is necessary to apply poisonous substances to kill mites, however, these chemicals can also have negative and lethal effects on bees and entire colonies. In order to avoid the accumulation of chemical leftovers and their side effects in bees, honey, and wax while also preventing the development of acaricide resistance, pesticides must be used at their lowest effective dose (Wallner, 1999; Ruijter, 1994). Acaricides with lower leftovers and greater mite monitoring could help decrease significantly the quantity of harmful active ingredients used each season. Thus, we examine studies on mite monitoring advancements, detection, and prevention systems.

2. Early detection of Varroa mites in a beehive as a means of prevention

Szczurek et al. (2020) describes an innovative method that makes use of E-nose technology. Once the infestation affects the chemical makeup of the air inside a hive, it is used to detect varroa. The moment of detection is what determines if this method is effective.

Utilizing Mel or fast Fourier transform (FFT) spectrograms in sound monitoring systems is another effective method for identifying Varroa mites. In particular, threats from the outside, colony anxiety, swarming, and queen loss can be distinguished by using frequency-amplitude over time representations in combination with Support Vector Machine (SVM) and neural network classifiers (Nolasco et al., 2019). Colony collapse can be used as a signal to confirm the presence of the Varroa mite.

Currently, basic field and lab diagnostic techniques are accessible for determining the level of varroa mite contamination throughout complete honey bee colonies. Throughout decades, beekeepers have been measuring the effectiveness of an acaricide treatment by quantifying the dead mites that fall off the bees and brood frames into the bottom board of the hive (Ritter, 1981; Gregorc and Jelenc, 1996). A good correlation exists between the quantity of these dead mites detected in a hive's waste and the mite populations now infesting the colony atop (Liebig et al., 1984). In fact, researchers looked at the relationship between the total amount of mites in honey bee colonies and natural mite mortality. They discovered that the daily varroa mite deaths found on hive bottom planks can be multiplied by 20–40 to estimate the varroa mite numbers in colonies including brood (Harris, 2019). Control is necessary after completing mite assessments and once varroa infestations have risen to 3 mites per 100 bees within a colony (Harris, 2019). The quantity, location, management, and additional stress factors of the hive will all affect the treatment threshold values (Mattila and Otis, 2000). To determine the extent of mite contamination before and after acaricidal treatment and seasonal shifts in the number of natural mite populations, it is essential to preserve data records of the natural mite drop rates inside a colony (Martin S., 1998). Since varroa mite concentrations under 100 mites per colony are unable to be identified by looking at samples of adult bees or brood (Ritter, 1984), bottom plank counts are particularly helpful for calculating overall varroa mites per colony and daily mite deaths (Branco et al., 2006). Nevertheless, bottom board mite count-based mite sampling techniques are time-consuming, more expensive, and may require many days or weeks to determine an appropriate degree of colony infection. The level of mite removal by bees for hygienic purposes may also affect varroa mite numbers (Spivak and Reuter, 2001).

The "sugar shake" is an easy non-destructive technique for collecting varroa mite samples from adult honey bee bodies. The only step in this method is to sprinkle sugar on live bees' body parts. The tarsal pads of varroa mites will quickly become clogged by the powdered sugar, losing stickiness, and becoming permanently detached from host bees (Fakhimzadeh et al., 2011). For mite counting purposes, the sugar shake approach eliminates 77% to 91% of the mites (Fakhimzadeh, 2001; Aliano and Ellis, 2005). The sugar shake technique can retrieve 82% of varroa mites even in heavily plagued colonies (Macedo et al., 2002). Numbers of mites dislodged from adult bees taken from a single brood frame can be used to extrapolate the size of mite populations in the entire colony. Simply counting dislodged mites from more captured bees will result in precise projections of colony infestation (Lee et al., 2010). Therefore, the "sugar shake" method is a quick and accurate way for beekeepers to determine how many varroa mites are present on adult worker bees, drones, and even in entire colony (Macedo et al., 2002; Dietemann et al., 2013). When assessing various mite controls, sugar shake is another helpful sampling procedure (Gregorc et al., 2018). The sugar shake procedure has a few limitations that should be taken into account. While using the sugar shake method, there are a few things to keep in mind. Variations in the size of the honey bee population and environmental factors can affect how well the powder shake method extracts varroa mites from adult host bees. In a warm, moist climate (i.e., 32 °C and 76 RH), the sugar shake method's average effectiveness to remove varroa mites from adult honey bees is only about 66%, which is lower than the 94% achieved in cooler and dryer conditions (i.e., 26 °C and 71% RH) (Gregorc et al., 2017). Several sugar blends work better than others in terms of varroa removal due to differences in sugar quality. For example, a smooth dusting of pure powdered sugar removes 70-80% of varroa mites, which is significantly more than the 50% varroa drop attained using a mixture of powdered sugar and cornstarch. As a result, the efficacy of sugar shakes to eliminate mites may be influenced by the quality of the sugar combined with high humidity (Fakhimzadeh et al., 2011). It's possible that higher temperatures and humidity levels cause granules to coagulate, making sugar coarser and reducing the likelihood of tarsal clogging. Dusting honey bees with sugar is generally regarded as a secure mechanical technique for identifying colony infestations and, in some circumstances, can be used to lessen varroa mite infestation in field colonies (Gregorc et al., 2018).

The application of washing kits, usually homemade, with water or alcohol (70%) functioning as both the washing and collection fluid is a method equivalent to preventing mites from host bees (Toufailia et al., 2014). In hives absence of brood, accurate counts of varroa mites on adults can be made for research or practical beekeeping purposes using either the sugar shake method, water wash, or alcohol wash. About 300 bees are lost when employing an alcohol wash, but there is no apparent effect on the health and productivity of the colony. Alcohol washes, nonetheless will eliminate both mites and the few bees handpicked for sampling. To ensure colony survival and productivity, precise assessments of colony infection acquired with this diagnostic test are essential (Medina and Martin, 1999). Treatments of miticides or alternative therapies may be necessary based on a determined number of varroa mites discovered by sugar shake or alcohol wash. As a result, both approaches can be used to evaluate the efficacy of earlier control procedures. For beekeepers, varroa mite rates between 3 and 5 percent are acceptable. Varroa mite control must be carried out right away when mite counts are greater than 5% (Lindberg et al., 2000; Imdorf et al., 1999). In the United States, a comparable wide range of economic thresholds for varroa mite populations in colonies have been established at values between 5 and 12 percent, while most beekeepers prefer to utilize the lower 5 percent (Harris, 2019). By examining the mite weighs on adult and pupal bees in addition to counting the dead varroa mites within a colony, accurate projections of the size of the varroa mite population can be made. The ability of varroa females reproduction in worker nest cells is a major factor in the dynamics of the varroa mite population (Giacomelli et al., 2016; Bogdanov et al., 1998). Additionally, by combining samples from adult bees and brood, as well as comparing those results with the amount of mites eliminated through chemical treatment, the extent of the mite population can be approximated (Nanetti and Stradi, 1997).

The technology of cloud computing and low-power Wireless Sensor Network (WSN) is in use to monitor the presence of bees exhibiting stress behavior, which includes the presence of the Varroa mite (Kontogiannis, 2019; Edwards Murphy et al., 2015; Bellos et al., 2021). One of this study’s goals is to utilize WSN technology to spot a beehive colony and gather vital data regarding the activities of the surroundings, within a beehive, and regarding the bees’ health. However, as stated by (Kontogiannis, 2019), Varroa mite discovery employing sensors (temperature, humidity, noise level, and gas sensors) may contain numerous false-positive cases since other phenomena like swarming, queen loss, or even starvation may generate Colony Collapse Disorder (CCD) that are mistaken for those caused by the mite.

Var-Gor device is an appealing option for the prompt identification of Varroa mites and its early treatment because of its green and sustainable nature, reliable results, and cutting-edge design (Sevin et al., 2021). Particularly, the Var-Gor technology identifies the mite using picture capture, pattern matching, color categorization, and segmentation filters when an infected bee with varroa enters an unaffected hive. Additionally, the beekeeper's phone receives an alert with a warning.

The researchers from (Mrozek et al., 2021) created an experimental system for real-time bee monitoring utilizing cameras and deep learning techniques. Their idea is based on the Raspberry Pi (RPi) single-board computer platform and intends to analyze bee video streams in order to find varroosis. Additionally, they used two Convolutional Neural Network (CNN) models in two different detection procedures, one for bees and another for Varroa. However, because the camera is outside the hive, it is difficult to detect mites before they become a problem. In the event of an infection, the images of the sick bees are sent to the cloud-based data center for additional analysis, archiving, updating the CNN models, and notifying the appropriate personnel. As the writers of this work suggest an offline system method, it is challenging to apply detection to a solitary RPi device inside the device due to the usage of two different CNN models. Additionally, a CNN trained network that accurately detects bees, for instance, the one the authors of this paper suggest, can be used to provide methods for image processing like edge detection Hough transformations, region labeling, and color masking that correctly recognize the mite on the identified bees.

By manually separating infected from non-infected bees and using a laser to kill the infected ones, the authors of (Chazette et al., 2016) offer a camera-based method of CNN-trained networks. The disadvantage of this method as it is now given is the use of single bee image labels and classifications. Due to the high numbers of bees on each frame, this can perform well at detecting individual bees on the beehive entrance openings or a white backdrop but substantially worse at detecting bees inside the frames, where the mites live. This research suggests using frame images where hand bee labeling and image localization are done before CNN training to solve this issue. Image segmentation and manual region of interest (ROI) identification can produce noticeably better results because certain areas of the image don't contain any information.

A solution to identifying Varroa mite from a small number of poor-quality photos is what the researchers at (Kaur et al., 2022) are attempting to deliver. To distinguish between diseased and healthy bees from normal bee photos, the suggested model incorporates the image enhancement approach CLAHE, the data augmentation method DCGAN, and the optimal classification method CNN. CLAHE stands for contrast limited adaptive histogram equalization, while DCGAN stands for deep convolutional generative adversarial networks. The findings show that the CLAHE approach enhances sharpness and has a good impact on CNN efficiency. Additionally, in the infection recognition scenario, the DCGAN augmentation method showed more promising outcomes than the traditional ones. To conclude, it seems that this vision-based approach is more effective and appropriate for locating Varroa mites on bees.

Furthermore, the researchers of (Bilik et al., 2021) tested the effectiveness of cutting-edge object detectors utilizing datasets labeled with information on sick bees and varroa mites. They next experimented with CNN algorithms to accomplish unhealthy bee detection, including YOLOv5 (Redmon et al., 2016) and SSD (Liu et al., 2016). According to the authors' CNN assessment utilizing F1-score findings, SSD varroa mite identification scored above 70% and Yolo sick bee detection scored 87%. The Deep Support Vector Data Description (SVDD) anomaly detector was tried out by the authors. The SVDD anomaly detector, yet, was unable to simulate the issue. The Jetson Nano can be an element of a detecting end-node device, according to the researchers. The authors' suggestion to use YOLOv5 yields noteworthy outcomes. However, there is no disclosure of detection performance findings. Furthermore, the F1 score metric, that evaluates the model's sensitivity and precision, does not accurately reflect the model's accuracy. Although not a reliable accuracy statistic, the mAP score implies a good accuracy model.

3. Conclusion

In conclusion, the fight against Varroa mite infestations in honey bee colonies is experiencing a transformative phase marked by the integration of innovative technologies. Traditional methods like bottom board counts and daily mite deaths remain valuable, but the multifaceted nature of Varroa mite dynamics demands a more diverse set of diagnostic tools.

E-nose technology, offers a breakthrough by analyzing hive air composition for early Varroa mite detection. The precision of the detection moment is crucial, emphasizing the significance of timely intervention in controlling infestations.

Sound monitoring systems, provide sophistication in Varroa mite identification by distinguishing various stressors and correlating colony collapse events with mite presence. The "sugar shake" method emerges as a simple yet effective technique for quick and accurate Varroa mite assessments on adult bees, drones, and entire colonies.

Washing kits with water or alcohol, offer an alternative for obtaining accurate mite counts on adult bees. Cloud computing and Wireless Sensor Network (WSN) technology present opportunities for real-time monitoring, but challenges like false positives need addressing.

Technological innovations like the Var-Gor device and experimental systems by showcase automation and early detection potential. Vision-based approaches, show promise in efficient Varroa mite identification. Collaboration between beekeepers, researchers, and technologists is essential for refining these methods and ensuring their practicality in real-world beekeeping scenarios. The continuous pursuit of accurate and scalable Varroa mite detection remains crucial for honey bee colony health worldwide.

Acknowledgement: *Special thanks to all our colleagues, family and friends for trusting and believing in our work.*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

CASE OF STUDY FOR DRAFT FORCE MAP SMOOTHING IN PRECISION AGRICULTURE

UDC 631.331

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Abstract*. There are many physical and chemical properties of soil that can be measured and mapped. Such maps can be very important decision-making tools in precision agriculture. However, unlike yield maps and crop scouting maps, all other maps show a lower degree of reliability in terms of decision utility. Soil compaction is the most representative feature of the production plot from the domain of physical and chemical soil properties. This paper first presents an experiment designed to measure soil compaction, and then a mapping of the results in a commercial software. The test field with an area of one hectare was reduced to a control limit of 60 meters in width and 120 meters in length to ensure the uniformity of speed and other parameters. The resolution of the draft force measurement as an indicator of soil compaction was 50 Hz. This resulted in the existence of missing data on the draft force map itself, because several draft force values were related to one spatial coordinate manifested as longitude and latitude. The paper further shows the procedure of data smoothing and generation of complete maps without missing spatial data.*

Key words*: draft force, strain transducers, missing data, smoothing.*

1. INTRODUCTION

The experimental field covered an area of one hectare. Pre-crop was winter barley. The sowing rate was 220 kg/ha. The vegetative period lasted from 30.10.2021. until 16.7.2022. In this period, on the February 23, 2022, fertilization with ammonia-nitrate 33.5 with a norm of 200 kg/ha was carried out, and after that, chemical crop protection on 12.5.2022, with the insecticide Polux at the rate of 0.25 l/ha and the fungicide Escorta plus at the rate of 1.0 l/ha. The average yield of barley was 6.7 t/ha.
After the barley harvest, soil sampling was carried out in the field in order to examine its chemical composition, as well as electromagnetic sounding of the soil, to map its electrical conductivity (Fig. 1). Soil analysis showed that the pH value is 7.27, the P_2O_5 concentration is 21.6 mg/100g, the K_2O concentration is 21.2 mg/100g, and the humus

content is 3.56%. The soil EC is a measure of how easily an electric current flows through the soil.

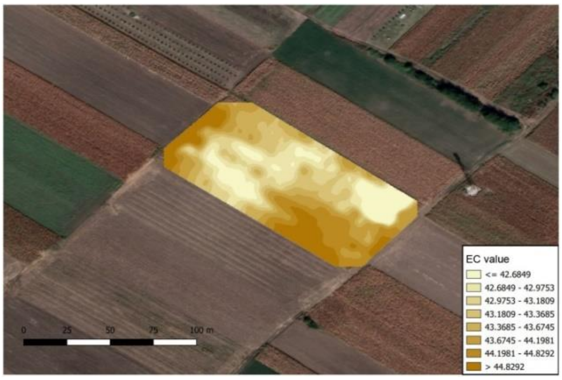

Fig. 1 A smooth surface map of soil EC for a sample field.

Soil EC responds to the amount of salt in the soil as well as indicates the soil's composition - the amount of sand, clay, organic matter, and water content. The soil electromagnetic conductivity map suggests relatively good soil conductivity and relatively low variability of this conductivity across the sample field.

2. Draft force measurement installation, measuring on the field and map

Draft force is variable along each pass and across the field width. The reason for this is the inhomogeneous soil structure [1-5]. Sensors for measuring force during plowing must have the necessary sensitivity to record all the variables, but they also need to be robust enough due to the specific working conditions. Finally, before the actual measurement, it is necessary to successfully perform sensor calibration [6-8]. For mapping purposes, four strain transducers were used in the experiment presented in this paper (Fig. 2).

Fig. 2 View of the strain transducers from the inside of the lower levers

The sensors are connected to an acquisition device that collects draft force data. The plowing speed was constant at 8 km/h. The plowing depth was 30 cm. GPS coordinate data is collected by software, directly in the computer and processed also by software. After measuring the draft force during plowing, the obtained yield map was formed using GIS software, and it contained some defects in its basic representation (Base Map, Fig. 3).

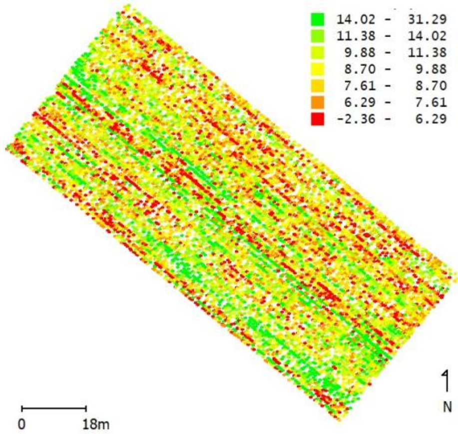

Fig. 3 Draft force base map with flaws

The map clearly shows passages with lower soil resistance, as well as resistance variability. The research question is: Can the map be smoothed by interpolation, and does this change the appearance of the Contour Map?

3. Interpolation procedure of non-existing map points

The tractor coordinates are recorded only while the tractor was working with active tool attached to the back of the tractor. These coordinates are read from successive lines of the input file. Once the change in the trend of growing or dropping of X axis coordinate values is detected, the tractor is considered to have changed the direction of movement. The beginning and ending coordinates for each row are stored in separate vectors. The GPS coordinate system is translated, so that, separately for latitude and longitude, the beginning digits that are common for each GPS coordinate are removed. Based on the beginning and ending coordinates of the first tractor row, the coordinate system is rotated, so that both coordinates have the same Y value.

The rotated coordinates are calculated using the following source code lines:

```
x= x*cosinus - y*sinus;
y= x*sinus + y*cosinus;
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Further, all coordinates between the starting and the ending point of the first tractor row are updated by linear interpolation between these two points, so that the tractor movements is modeled as if it has driven parallel to the x axis. The same interpolation was performed for each tractor row, with certain differences in the Y values of coordinates for other tractor rows. All resulting coordinates are then compared to those originally obtained by the GPS and then truncated and rotated. Following analysis was performed on top of these two sets of coordinates:

1) Minimal and maximal Y values of original coordinates for each tractor row were stored for each tractor row.

2) Minimal and maximal distance between two GPS readings were stored for each tractor row.

Based on the analysis, following conclusions were driven, respectively:

1) The tractor rows didn't overlap at any point

2) The uncovered GPS regions were approximately the same for each tractor row.

After the transformation of the coordinates, with the help of SMS Advance software, a new draft force map can be generated, with significantly improved characteristics (Fig. 4.)

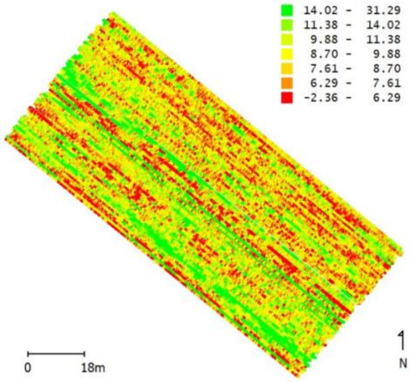

Fig. 4 Draft force base map without flaws

4. CONCLUSIONS

The observed shortcomings of the soil resistance measurement procedure and the value of the results using a manual penetrometer suggest an indispensable need for a soil resistance measurement procedure using a continuous method in real time. The thus obtained data on soil resistance can be further used for scientific purposes from the aspect of observing and monitoring the process of soil degradation, but also for the application of variable soil treatment ("site-specific"), that is, the application of precision agriculture. Analysis of the resulting maps revealed that interpolation of coordinates can be a useful method for filling in missing spatial points on maps [9,10]. The soil compaction maps can provide two types of information: the values of soil cone penetrometer resistance; the field areas and the depth where eventually soil compaction occurs. In this way, the preservation of the natural fertility potential is ensured, the soil is monitored and can be protected from further degradation, the environment is preserved, but it is also possible to improve the production in the fields through the reduction of energy consumption. The difference between the maps generated using 7 (Fig. 5) or 3 (Fig. 6) zones is small, especially in the second case.

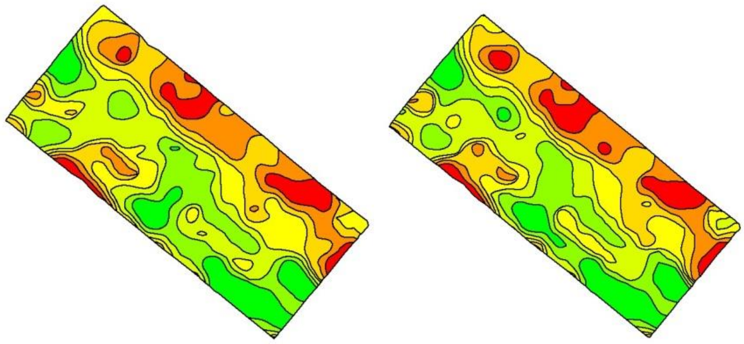

Fig. 5 Contour maps of draft force: seven zones, without smoothing, after smoothing

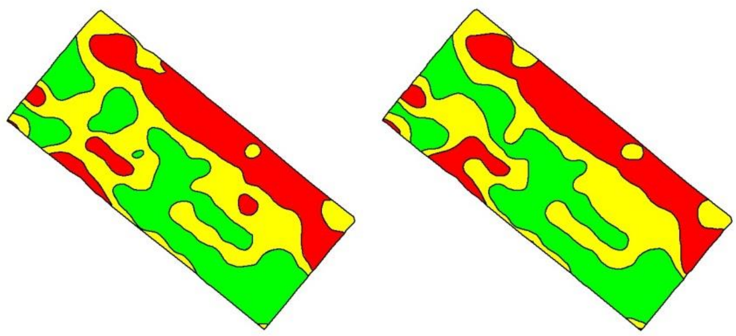

Fig. 6 Contour maps of draft force: three zones, without smoothing, after smoothing

The considerations in this paper have shown that the minor shortcomings of commercial programs do not significantly affect the formation of organizational zones throughout the production plots. A layer containing a zoned draft force can be a useful and important link in the chain of decisions about the location-specific application of inputs in precision agriculture.

Acknowledgement: *The results presented in the paper are obtained through the research supported by the Ministry of Science, Technological Development and Innovation of the RS under Contract 451-03-47/2023-01/ 200105 dated 02/03/2023.*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19^{th} – 21^{st} Oct 2023, Belgrade–Zemun, Serbia

TECHNICAL AND TECHNOLOGICAL PARAMETERS OF THE PROTECTION ZONE PROCESSINGIN PERENNIAL PLANTATIONS

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Abstract:*Maintaining modern intensive plantations requires the latest practical and theoretical knowledge, the application of which achieves top-quality production results. In recent years, more and more attention has been paid to both energy efficiency and environmental aspects as the ultimate goal of the sustainability of each production. The sustainability of a process can limit reaching the maximum of said process. In the technologies of soil maintenance in perennial plantations in recent years, it becomes imperative that the chemical treatment of the soil, immediately adjacent to the plant and within the row, be replaced by mechanical processing. This need is primarily aimed at minimizing the use of pesticides in order to respond to the environmental requirements. Regular land cultivation is a technically complex problem. The given area is made up of up to 25% of the total land area of the plantation. The paper presents the results of testing a rotary harrows with a deflection, which in one pass achieves the processing of a part of the inter-row surface and half of the protective zone. The results of the research show that the optimal speed of movement of the aggregate carried out in the plantation of the orchard is 1,56 m/s, and in the plantation of the vineyard 1,23 m/s. Productivity of aggregates in the orchard 0,24 ha/h, in the vineyard 0,19 ha/h. Fuel consumption in the vineyard 7,2 l/ha, and in the orchard 6,8 l/ha. Productivity of the aggregate is largely conditioned by the technical solution of the aggregate and the technology of plantation cultivation*.

Key words: *rotary shredder, soil cultivation, perennial plantation, aggregate productivity*

1. INTRODUCTION

High-quality processing of perennial crops also implies the rational engagement of human labor and mechanized means. The modernization and development of agricultural techniques, especially information and communication technologies, have significantly improved the technological processes of processing [10]. The application of modern fruit growing technologies is, above all, related to the implementation of new techniques and mechanization in the production process, regardless of the fruit type [12]. Procedures and measures of soil cultivation in plantations, in addition to climatic and soil conditions, are also conditioned to a considerable extent by cultivation technology [15]. Modern fruit and vineyard plantations are characterized by the so-called dense planting, it greatly affects processing procedures.

The lifespan of the plantations, the size of the yield as well as the quality of the fruits, are largely determined by the technology of tillage [3]. Maintenance of soil in perennial plantations during its exploitation is a technically complex job that requires the engagement of a large amount of energy [4]. In conditions of dry fruit growing, where there is no infrastructure and availability of water resources for irrigation, mechanical soil cultivation is a mandatory agrotechnical measure [17]. This processing is carried out both in the space between the rows and in the protective zone. Processing of the protective zone is a far more complex technological procedure and involves the use of far more complex machines and devices [14]. In addition to processing the surface of half of the protective belt, a larger surface is often processed, so that the processed surfaces overlap. Overlapping processing avoids finding an unprocessed and weedy surface due to poor machine guidance.

The mechanization of this process is realized by a machine-tractor aggregate of the appropriate energy potential [11]. Attached machine in a aggregate with a tractor consisting of a tractor equipped with a attached machine that has the ability to move the working elements when encountering a plant and return to the intermediate space with its own processing time. The use of appropriate tillage enables the reduction of costs and ecological preservation of the soil [5]. High-quality mechanical soil cultivation, in addition to improving the physical properties of the soil, destroying weed vegetation, ensures sufficient accumulation and rational use of moisture [2].

Mechanical cultivation in perennial plants loosens the soil, achieves areation, increases volume, increases absorption of moisture, so that optimal conditions for the development of the root system of perennial plants are provided in the zone of the root system of perennial plants. For those conditions of fruit growing, it is necessary to perform high-quality basic and supplementary equipment in order to sufficiently accumulate and rationally consume moisture in the soil [1], [6] . The working depth of the part of the machine that processes the protective zone is directly dependent on the depth of the roots of the planted plants. The working elements of the machine that process the inter-row space at a greater depth can be basic or supplementary.

With a quality choice of technological procedures and adequate mechanization, it is possible to achieve greater economic and energy efficiency while preserving the ecological environment and soil [8]. The transition from conventional to new technological procedures in primary agricultural production should be handled, with the obligatory presence of expertise and research work [9] . The use of modern technologies in soil cultivation should create prerequisites for achieving sustainable agricultural production, which is largely made up of fruit-growing and viticulture production. The integration of aggregates for the simultaneous cultivation of regular and inter-regular plantings contributes to the reduction of soil compaction [7]. The obtained results in concrete production conditions indicate the possibility of saving energy and increasing the productivity of aggregates in soil works.

2. MATERIAL AND METHODS

According to the set goal, the aggregate consisting of the tractor »McCormick x2.40« and the rotary harrow with deflection »Rinieri EL brand 140« was tested. The measurement was carried out in real conditions of fruit production at »OD Radmilovac-Table I« in a peach orchard with the following parameters:

- speed of movement (obtained as the quotient of the path covered on a pathway of a certain length m and the time for which the tractor covers that path),
- slippage of drive wheels based on the actual and theoretical speed of movement of the aggregate
- hourly fuel consumption (obtained by volumetric method - measuring cylinder)
- specific fuel consumption (calculated method)
- volumetric mass of soil (of Cilindri Kopecki)
- fuel consumption per unit area (obtained as a quotient of hourly consumption and productivity of the given aggregate),
- torque on the tractor's PTO shaft. Control of TD2 transmitter measurements was performed with a Tektronix 2230 oscilloscope.
- analysis of the soil structure of cultivated land (done using the *Savinova* method)
- Presence of sedge vegetation after processing (visual)
- productivity of aggregates (based on chronography)

Table 1. *Technical characteristics of the tested aggregate*

Technical characteristics of the tractor	**McCormick x2.40**	**Tech. characteristics of the rotary harrow with deflection**	**Rinieri EL brand 140**
Engine power [kW]	40	Number of working bodies	2
Number of rotations at max. of power [min-1]	2800	Working grip/operation [cm]	65
Mmax./nMmax [Nm/ min-1]	160/1400	Deflection of the working assembly [cm]	50
Specific fuel consumption [g/kWh]	225	Processing depth [cm]	10
Energy supply in comparison with construction mass [kW/t]	24.24	Deflection speed of the working assembly [m/s]	0.75
Specific mass without ballast [kg/kW]	41.25	Transmission type	Hydrostatic
Specific mass with ballast [kg/kW]	44.25	Method of aggregation	Carried
Mass without ballast [kg/]	1650	Mass [kg]	320

Fig. 1 Tractor “McCormick x2.40”

Fig. 2 Rotary harrow “Rinieri EL brand 140”

Fig. 3 Formed aggregate

Fig. 4 Tested aggregate in progress

List of symbols:

Eha – tech. energy consumption [kWh/ha]
Fv - traction force [kN]
kt – spec. ground resistance [N/cm2]
Mmax – max. [Nm]
nMmax – rotation speed at Mmax [min-1]
Pv – traction power [kW]
q – spec. ef. tractor fuel consumption [g/kWh]
Qe – hourly consumption of mechanical work [Nm]
Q – hourly fuel consumption [l/h]
Qha – fuel consumption per unit area [l/ha]
v – movement speed [km/h]
Wh – performance [ha/h]
φ - adhesion [-]
λ - sliding [%]
η – coefficient of beneficial effect [-]

2.1. Test conditions

The dominating type of soil, on "Table I" in Radmilovac, is the arable land [13]. From the Display in Table 2, it can be seen that the processing conditions were partly difficult, considering that the processing process was carried out in a dry period. The analysis of the data in Table 2 shows that the soil moisture was significantly reduced and that the soil belongs to the heavier category based on volumetric mass.

Table 2. *Soil moisture and volumetric mass*

Serial number	Measurement place	% moisture	Volumetric mass *(d/cm^3)*
1.	Area	14,41	1.374
2.	Depth 5 cm	15,36	1.483
3.	Depth 10 cm	15,15	1.426

2.2. Energy parameters of aggregates

The implementation of agrotechnical measures during the maintenance of perennial crops, such as processing that engages a significant amount of mechanical work, which directly affects the economy, is measured with energy parameters. The rational consumption of energy is achieved first of all by good design of the tractor-machine aggregate as well as the conditions defined by the technology of growing plants, which achieves the necessary adaptability of plants for machine processing. The lack of adaptation of plants is projected on the appearance of more frequent downtimes as a great limitation of technological speeds and in some cases the impossibility of using processing machines.

The results obtained from the field tests of the tractor-machine aggregate are shown in Tables 3 and 4. The engagement of the power of the tractor engine depends to the greatest extent on the type of soil, the quality of the previous process and the number of rotations of the tractor PTO shaft.

Table 3. *Energy parameters of aggregate operation in supplementary processing of orchards*

S. number	**M** *(Nm)*	**n** *(o/min)*	**Pv** *(kW)*	**v** *(km/h)*	**Fv** *(kN)*	**Qha** *(l/ha)*	**Wh** *(ha/h)*	**Eha** *(kWh/ha)*	**Qe** *(MJ/h)*
1.	92	495	5.68	1.22	1.44	8,21	0.19	29.89	20.44
2.	86	501	5.72	1.38	1.48	7.35	0.20	28.60	20.58
3.	85	500	5.27	1.49	1.35	7.11	0.21	25.09	19.58
4.	87	503	5.33	1.56	1.38	6.8	0,24	22.20	19.18
5.	91	420	5.07	1.22	1.12	7.38	0.21	24.14	18.25
6.	100	390	6.12	1.09	1.54	8.95	0.20	30.60	22.03

The obtained data show that the optimal speed of movement of aggregates was carried out in the orchard plantation in variant 4 and was 1.56 m/s. At the same time, the torque had a value of 85 Nm, and the number of rotations was 502 rpm. In the vineyard, the optimal speed was in variant 2 and was 1.23 m/s, with torque. Aggregate productivity in the orchard was 0.24 ha/h, in the vineyard 0.19 ha/h. Fuel consumption in the vineyard was 7.2 l/ha, and in the orchard 6.8 l/ha.

Table 4. *Energy parameters of aggregate operation in supplementary cultivation of vineyards*

S. number	**M** *(Nm)*	**n** *(o/min)*	**Pv** *(kW)*	**v** *(km/h)*	**Fv** *(kN)*	**Qha** *(l/ha)*	**Wh** *(ha/h)*	**Eha** *(kWh/ha)*	**Qe** *(kJ/h)*
1.	87	501	5.96	1.13	1.48	9.61	0.14	42.57	21.45
2.	83	502	6.02	1,23	1.52	7.20	0,19	31.68	21.67
3.	82	500	5.53	1.17	1.41	9.32	0.15	36.86	19.91
4.	85	498	5.81	1.23	1.24	8.62	0.18	32.27	20.91
5.	93	490	5.32	0.96	1.15	9.36	0.16	33.25	19.15
6.	97	485	6.43	0.93	1.58	10.32	0.19	33.84	23.14

Aggregate productivity is largely determined by the technical solution of the aggregate and the technology of planting. The low torque values are the result of more intensive preprocessing in both cases, which led to a relatively low engagement of driving energy. In addition, the relatively low speed of movement of aggregates is a condition of lower productivity of aggregates in the processing of both plantations. Higher aggregate productivity in the orchard was achieved due to higher movement speed due to greater distance between plants in the row. Lower technological speed in the cultivation of vineyards was due to the insufficient distance between the vines. Observations made during the experiment lead to the conclusion that there is also a certain inertness of the hydraulic system, which, after detecting plants as an obstacle, carries out the drift-deflection of the working elements.

2.3. Processing quality

One of the basic indicators of the quality of aggregate work during processing is the achieved content of individual structural soil aggregates. By analyzing the obtained values in table 5, it can be concluded that the processing quality is satisfactory. At the same time, it can be stated that there are significantly present and significantly fine aggregates of around 5 and less than 5 mm, which can be explained by the fact that during processing the soil was with reduced moisture.

Table 5. *Performance quality indicators of the tested aggregate*

Aggregate dimensions (mm)	Measurement I		Measurement II	
	Mass (d)	Participation of individual fractions in the sample (%)	Mass (d)	Participation of individual fractions in the sample (%)
>50	-	-	-	-
25-50	170	3.41	180	3.30
19-25	560	11.22	200	3.67
16-19	440	8.82	270	4.95
9,5-16	510	10.22	480	8.81
5-9,5	1730	34.67	820	15.06
1-5	750	15.03	2600	47.71
>1	830	16.63	900	16.51
Total amount	4990	100	5450	100

Another important quality parameter is the intensity of the destroyed weed vegetation, which was mostly represented by narrow-leaved weeds with shallow roots, which facilitated the processing process. The fact that tillage with rotary harrows is accompanied by worse destruction and covering of weed vegetation in the tested tillage achieved satisfactory results, which was also contributed to by the orderly tillage that preceded the planting maintenance procedures.

3. CONCLUSIONS

Carrying out the process of mechanical processing in the protection zone of perennial plantations represents a great technological advance in the management of modern intensive plantations. This procedure greatly reduces the participation of human labor, which increases productivity and significantly reduces the costs of maintaining plantations.

The high-quality application of machines for processing the protective belt needs to be sufficiently adapted to the plantings, which primarily refers to the layout that defines the distance between rows and between rows. In addition, proper training of the operator of the aggregate is required.

Tests of the roto harrow in the given conditions showed that the layout of the grape vines due to dense planting did not allow higher technological speeds, which resulted in a relatively lower output than designed.

Further research should more fully cover the testing of the hydraulic system, which would determine the required force detected by the feeler when encountering the plant, as well as the speed of operation of the hydraulic system, which moves the working element during the tour of the plant and returns it to the intermediate space. The obtained results of the parameters in practical conditions would give the possibility to reduce the inertness of the system, which was manifested during the testing of the machine, through technical improvements.

Acknowledgement: *The work is granted by the Ministry of Education, Science and Technological Development of the Republic of Serbia - project number TR 31051: "Improvement of biological processes in the function of rational use of energy, increase of productivity and quality of agricultural products", within the framework of the contract for the realization and financing of scientific research work in 2021 between the Faculty of Agriculture in Belgrade and the Ministry, contract registration number: 451-03-9/2021-14/200116. Present study has not received any additional specific grant from funding agencies in the public, commercial, or not-for-profit sectors.*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

THE VERTICAL GREENHOUSE. A CONCEPT OF FUTURE AGRICULTURE

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Abstract. *This paper provides a comprehensive overview of vertical greenhouses highlighting the importance of vertical greenhouses today, their advantages and disadvantages, their construction technology, the types of crops that can be grown in a vertical greenhouse, the challenges, and limitations they face and their main construction details. An analysis of their future use in agriculture is also referred. The main advantages of vertical farming or vertical greenhouses are a) Efficient use of space b) Increased crop yield, c) Reduced water use, d) Protection from pests and diseases, e) Energy efficiency. The design and construction of vertical greenhouses involves careful consideration of construction materials, lighting and ventilation systems, irrigation and nutrient supply systems for vertical cultivation, and automation and control systems. Vertical greenhouses face challenges and limitations that must be carefully considered. High initial investment costs, technical complexity, limited crop diversity, dependence on artificial light and climate control, and the need for skilled labor and specialized knowledge are key factors that can affect the successful operation of vertical farming. However, with advances in technology, continued research and increased awareness, these challenges can be overcome, leading to more efficient sustainable and diverse crop production in vertical farming systems.*

Key words: *vertical farming, vertical greenhouses, urban agriculture, sustainability, land saving, energy saving*

1. INTRODUCTION

In view of global challenges such as the intense urbanization, climate change, the food crisis, etc., the need for innovative agricultural solutions has become more critical than ever. Among these solutions vertical greenhouses have emerged as a pioneering concept that has enormous potential to transform modern agriculture. A vertical greenhouse, also known as a vertical farm, is a specialized agricultural structure that uses vertical space to grow crops in multiple stacked layers. Unlike traditional horizontal farming, where crops are located on vast tracts of land, vertical greenhouses take advantage of limited space in densely populated areas [1]. By utilizing height rather than surface area, these structures maximize the yield of the land and enable year-round crop production, making them highly adaptable to urban environments [1] [2].

The concept of vertical farming can be traced back to the early 20th century, when the idea of growing in multi-level structures was first proposed. However, the principles behind the technique have been known for many centuries. The Babylonian Hanging Gardens, dating back to about 2,500 years ago, are the first case of vertical agriculture known today [3]. In the 16th century a more modern type of vertical farming appeared by French and Dutch farmers creating their own microclimates with walls, while the whole idea of integrating the green on a building wall was firstly introduced and patented many years later by a professor, Stanley Hart White in 1938 [4].

However, only in the last few decades advances in technology, such as artificial lighting, hydroponics and automated systems, allowed the systematic and practical application of vertical greenhouses. Driven by the need to address concerns about the food crisis, the need to reduce environmental impact and increase local food production, researchers and entrepreneurs have begun pioneering vertical greenhouse systems in various regions around the world, and even discussing the feasibility to integrate the vertical farming on skyscrapers [5].

This paper provides a comprehensive overview of vertical greenhouses aimed at understanding them from the average citizen to the expert scientist. In the chapters that follow, reference is made to the importance of vertical greenhouses today, their advantages and disadvantages, their construction technology, the challenges and limitations they face, and it concludes with an analysis of their future use in agriculture.

2. Advantages and Importance of Vertical Greenhouses

Vertical greenhouses play a critical role in modern agriculture by addressing key challenges the industry faces. One of the main advantages of vertical greenhouses is their ability to optimize land use [2]. As urbanization continues to encroach on arable land, vertical farming offers a solution by utilizing limited space more efficiently. By layering crops, vertical greenhouses can produce significantly higher yields per square meter of land, compared to traditional growing methods (Fig. 1). Furthermore, they allow crop production all year round, overcoming the limitations imposed by seasonal changes and adverse weather conditions. By creating controlled environments, these structures provide precise control of temperature, humidity, lighting and nutrient supply. This ensures optimal growing conditions, resulting in consistent crop production regardless of external factors. The ability to produce fresh, locally sourced food all year round enhances food security and reduces reliance on long-distance transport and imports of agricultural products (Fig. 1) [1] [6] [7].

They promote sustainability in agriculture. These systems minimize water use (Fig.1) through advanced irrigation techniques such as hydroponics or aeroponics, reduce the need for synthetic pesticides and fertilizers, and use energy-efficient technologies. By incorporating renewable energy sources and adopting sustainable resource management practices, vertical greenhouses can significantly reduce the carbon footprint associated with food production [8].

They represent a transformative approach to modern agriculture, offering increased land yield, year-round crop production and sustainable practices. As the world faces the challenges of urbanization, climate change and the food crisis, vertical greenhouses have emerged as a promising solution that has the potential to revolutionize the way we grow and consume food. By maximizing space, optimizing the use of resources and providing a sufficient supply of fresh agricultural products, they help create resilient and sustainable food systems for the future.

Water usage per Kg lettuce	Crop yield per m² of land (lettuce)	Food Km In Transportation
VERTICAL		
1 L	80 - 120 Kg	70 Km
GREENHOUSE		
20 L	41 Kg	800 - 1600 Km
OPEN FIELD		
250 L	3.9 Kg	3200 Km

Fig. 1 Comparison of water usage, crop yield and food transportation between open field, greenhouse and vertical farming cultivation [6] [7].

Therefore, the main advantages of vertical far are:

a) **Efficient use of space**: They maximize land use by using vertical space instead of relying solely on horizontal land expansion. By layering crops, these structures can significantly increase production capacity per unit area. This efficient use of space allows vertical greenhouses to thrive even in densely populated urban environments where land availability is limited [6].

b) **Increased crop yield**: They are designed to optimize growing conditions for crops. By providing controlled environments with precise control of temperature, humidity and lighting, these structures create ideal conditions for plant growth. As a result, vertical greenhouses can achieve higher crop yields compared to traditional growing methods. The ability to stack crops vertically ensures that each plant receives enough light, nutrients and space, promoting optimal growth and maximizing overall greenhouse productivity [6] [9].

c) **Reduced water use**: Water scarcity is a growing concern in agriculture. Vertical greenhouses address this challenge through efficient water management systems. Advanced irrigation techniques, such as hydroponics or aeroponics, allow precise water delivery directly to plant roots, minimizing water wastage [1]. In addition, they often incorporate water recycling systems, capturing and reusing runoff water, further reducing overall water consumption. This water-saving approach makes them more environmentally sustainable and less dependent on traditional soil-based irrigation methods [6].

d) **Protection from pests and diseases**: They provide a controlled and closed environment that offers protection from pests, diseases and harsh weather conditions. The controlled environment mitigates the risk of pest infestation and reduces the need for chemical pesticides. In addition, the physical barrier provided by the greenhouse structure prevents external pests from entering, reducing the potential for crop damage and yield loss. This creates a healthier and safer environment, leading to improved quality and reduced crop losses [9].

e) **Energy efficiency**: They incorporate energy-efficient technologies to minimize energy consumption and reduce greenhouse gas emissions. These technologies include LED lighting systems that provide targeted and energy efficient lighting for plant growth. In addition, automated air conditioning systems optimize energy use by adjusting temperature, humidity and ventilation settings based on facility requirements. The integration of renewable energy sources such as solar panels further enhances the energy efficiency of vertical greenhouses, reducing their dependence on conventional energy grids and promoting sustainable practices.

3. STUDY AND CONSTRUCTION OF VERTICAL GREENHOUSES.

Designing and building a vertical greenhouse requires careful consideration of various factors to ensure optimal functionality and productivity. This chapter delves into the key aspects involved in the design and construction of vertical greenhouses, including the selection of building materials, lighting and ventilation systems, irrigation and nutrient supply, vertical growing systems, and automation and control.

3.1. Selection of Building Materials, lighting and ventilation systems

The choice of suitable construction materials is decisive for the construction of a vertical greenhouse. They should possess properties such as strength, insulation and light transmission. Common options include glass, polycarbonate or acrylic panels for the walls and ceiling. These materials provide insulation, allow adequate light penetration, and offer structural integrity. The choice of materials also depends on factors such as climate, budget and energy efficiency.

Lighting plays a vital role in vertical greenhouses, especially in environments with limited natural sunlight. Whilst glass and transparent building materials offer the possibility to the sunlight to enter the greenhouse, this in many cases is not adequate for optimum plant growth. Supplemental lighting systems, such as LED lights, are commonly used to provide the required light spectrum for optimal plant growth [10].

Ventilation systems are also vital to maintaining proper temperature, humidity and air circulation within the greenhouse. Natural and artificial ventilation, exhaust fans, and climate control systems help regulate these environmental factors, ensuring optimal growing conditions [11].

3.2. Vertical farming systems, irrigation and nutrient supply systems

Vertical growing systems within the greenhouse define how crops are arranged and grown. Common approaches include hydroponics, aeroponics (Fig. 2), or stacked trays [12]. Hydroponics involves growing plants in nutrient-rich water without soil, while aeroponics suspends plant roots in a moist droplet environment. Stacked trays use multiple layers to maximize vertical space. The choice of vertical cropping system depends on factors such as crop type, available space, and resource efficiency considerations [11]. Efficient water management is essential for vertical greenhouse operations. Automated irrigation systems, such as drip irrigation or hydroponic systems, deliver water directly to plant roots, minimizing waste and optimizing water use. These systems can be integrated with nutrient delivery systems, such as fertilization, to provide plants with essential nutrients in a controlled and precise manner, while aquaponics (Fig. 2) is another system which can be integrated for nutrient supply [12]. Monitoring systems can also be used to measure soil moisture levels and nutrient concentrations, ensuring optimal plant health [13].

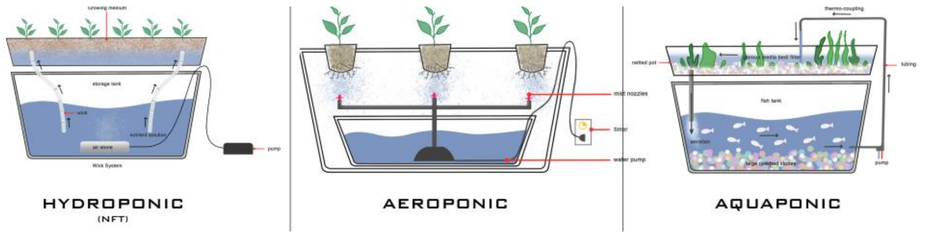

Fig. 2 Hydroponics, Aeroponics, Aquaponics

3.3. Automation and control systems

Automation and control systems upgrade greenhouse operations, improve efficiency and reduce labor requirements. They can monitor and control factors such as temperature, humidity, lighting, watering and nutrient supply. They include sensors, actuators, and electronic control systems that adjust environmental parameters based on predetermined parameters or real-time data. Automation enables precise control, reduces human error and optimizes the use of resources, resulting in improved productivity and crop quality [14].

4. CHALLENGES AND LIMITATIONS OF VERTICAL GREENHOUSES

While vertical greenhouses offer many advantages, they also come with some problems that need to be considered. This chapter examines some of the key challenges and limitations associated with vertical greenhouses, including high initial investment costs, technical complexity of vertical farming systems, limited crop diversity, reliance on artificial light and climate control and the need for skilled labor and specialized knowledge [15].

4.1 High initial investment cost

One of the main challenges of vertical greenhouses is the high initial investment required for installation and infrastructure [16]. Vertical farming systems often include advanced technologies such as LED lighting, air conditioning systems, and automated irrigation, which can significantly increase initial costs [17]. In addition, the creation of multi-level structures and the installation of specialized equipment can be expensive. However, it is important to note that as technology advances, the cost of vertical greenhouse systems is gradually decreasing, and the payback period is continuously decreasing.

4.2 Technical complexity of vertical farming systems

Vertical farming systems involve a higher level of technical complexity compared to traditional farming methods. Incorporating technologies such as hydroponics, aeroponics and automation systems requires specialized knowledge and expertise. Maintaining ideal growing conditions, monitoring nutrient levels, managing lighting and ventilation systems, and dealing with technical problems require constant attention and technical know-how. Adequate training and expertise are essential for the effective operation and management of vertical greenhouses [18].

4.3 Limited variety of crops

Vertical greenhouses, because of their compact and controlled environment, may have limitations in terms of the variety of crops that can be grown. Some crops with extensive root systems or tall growth habits may not be suitable for vertical growing systems. While leafy greens, herbs, tomatoes and other grape crops, strawberries, small fruits and sprouts, microgreens as well as edible and ornamental plants are successfully grown, the variety of crops that can be grown in vertical greenhouses is narrower compared to conventional growing [19]. However, ongoing research and advances in vertical farming techniques are expanding the range of crops that can be grown vertically.

4.4 Reliance on Artificial Light and Climate Control

They rely heavily on artificial lighting systems to make up for the limited natural sunlight. While LED lights are energy efficient and offer customizable light spectrums, the energy consumption associated with artificial lighting can be significant. In addition, maintaining precise control of temperature, humidity and air circulation requires robust climate control systems. Dependence on artificial light and climate control adds to operating costs and requires careful management to ensure sustainable and cost-effective production.

4.5 Need for skilled labor and specialized knowledge

The operation and management of vertical greenhouses requires a skilled workforce with expertise in areas such as crop cultivation, plant nutrition, irrigation, lighting, and climate control. The complex nature of vertical farming systems requires trained professionals who can monitor and optimize growing conditions, address technical issues and implement efficient production practices. Recruiting and retaining a skilled workforce with specialized knowledge in vertical greenhouse operations can be a challenge, particularly in areas where this expertise is limited.

5. Future of Vertical Greenhouses in Agriculture

The future of vertical greenhouses in agriculture holds great promise as a sustainable and efficient solution for food production. This chapter explores the potential for expansion and innovation, the integration of vertical greenhouses with other agricultural technologies, the role in addressing food security and sustainability challenges, collaboration with urban planners and architects, and the implications for farmers, consumers and policy makers.

5.1 Opportunities for expansion and innovation

Vertical greenhouses have the potential for significant expansion and innovation in the agricultural sector. As technology continues to advance and costs decrease, the adoption of vertical farming systems is likely to increase. They can be applied in a variety of settings, including urban areas, where land availability is limited. In addition, the development of compact and modular structures allows for scalability and adaptability, making it possible to adapt vertical greenhouses to different environments and growing conditions.

5.2 Integration with other sustainable agricultural and energy technologies

Vertical greenhouses can be integrated with other agricultural technologies to create more efficient and sustainable agricultural systems. For example, the integration of renewable energy sources such as solar panels or wind turbines can help reduce energy costs and reduce dependence on conventional energy networks. The use of advanced sensors, data analytics and artificial intelligence can enable real-time monitoring and optimization of crop growth parameters, leading to improved resource management and higher yields.

5.3 Role in addressing the challenges of food security and sustainability

They have the potential to play a critical role in addressing food security and sustainability challenges. With the world's population projected to reach 9 billion by 2050, vertical farming can help meet the growing demand for food in a sustainable manner. By maximizing land use, reducing water consumption, minimizing pesticide use, and optimizing resource efficiency, vertical greenhouses can help mitigate the environmental impact of agriculture while increasing food production in a controlled and resource-efficient manner.

5.4 Cooperation with Urban Planners and Architects

Integrating vertical greenhouses into urban landscapes requires collaboration between agricultural professionals, urban planners and architects. They can be integrated into building designs, turning urban spaces into multifunctional structures that combine food production, recreational spaces and green spaces. Collaboration between these disciplines can lead to innovative urban agriculture concepts such as rooftop gardens (Fig. 3), vertical farms embedded in residential or commercial buildings, and community-based agricultural initiatives. Such a case, is the architectural project by Romses Architects, “The Harvest Green Project” (Fig. 4) which was awarded in an architecture competition focused on structures designed to guide greener development. Vertical farm designs like this one may play a role in the fight against world hunger -- if such ideas can be successfully transferred from sketches and models to life-size structures.

5.5 Contributions for farmers, consumers and policy makers

Vertical greenhouses can enable the participation of various stakeholders in the agricultural sector. For farmers, vertical farming systems offer opportunities to diversify their crops, increase their income streams and reduce their reliance on traditional farming methods. Consumers benefit by having access to fresh, local farm produce year-round, reducing the carbon footprint associated with long-distance transportation. Policymakers play a vital role in supporting the adoption of vertical greenhouses through the development of favorable regulations, incentives, and funding programs that promote sustainable agriculture and urban agriculture initiatives [21].

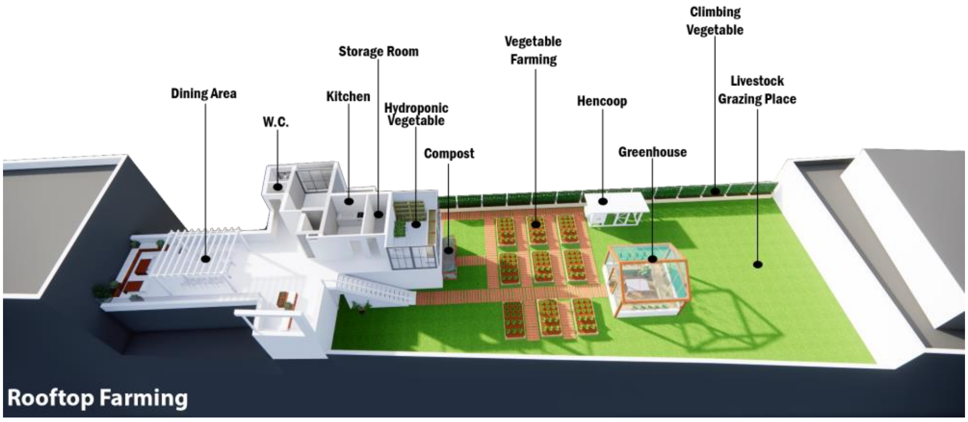

Fig. 3 Mixed – Use Urban Buildings – Rooftop gardens

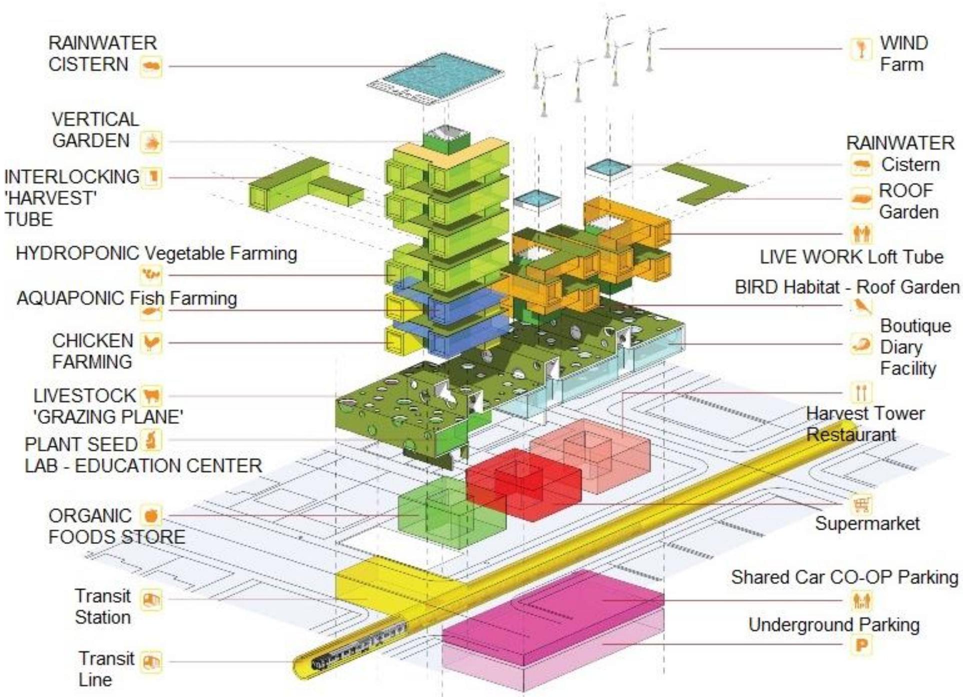

Fig. 4. The Mixed-Use Development – The Harvest Green Project [20]

6. CONCLUSION

The last decade, vertical greenhouses have emerged as a transformative technology in modern agriculture, offering numerous advantages and opportunities for sustainable food production. Throughout this research, we have explored various aspects of vertical greenhouses, including their benefits, design and construction, challenges and limitations, and future implications. A recap of key points highlights the potential of vertical greenhouses to address the challenges faced by traditional growing methods. These structures allow for efficient use of space, increased crop yields, reduced water use, pest and disease protection, and energy efficiency. Design and construction considerations such as the selection of building materials, lighting and ventilation systems, irrigation and nutrient supply systems, vertical farming systems, as well as automation and control systems contribute to optimal crop growth and resource management.

However, it is important to recognize the challenges and limitations associated with vertical greenhouses, such as high initial investment costs, technical complexity, limited crop diversity, reliance on artificial light and climate control, and the need for skilled labor and specialized knowledge. Addressing these challenges requires further research, innovation and collaboration between agricultural practitioners, researchers, policy makers and industry stakeholders. Continued advances in technology, plant science, and engineering will contribute to the optimization and cost-effectiveness of vertical farming systems. In addition, interdisciplinary collaboration can lead to the integration of vertical greenhouses with other sustainable agricultural practices, urban planning and architectural design.

Reflecting on the importance of vertical greenhouses for the future of agriculture, it is evident that they offer a sustainable and efficient solution to the growing challenges of food security, environmental sustainability and urbanization. Vertical greenhouses have the potential to revolutionize the way food is produced, creating opportunities for local, decentralized and environmentally controlled agriculture.

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INNOVATIVE APPROACHES FOR PROLONGING THE POSTHARVEST FRESHNESS IN THE FRUIT SECTOR

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Abstract *Edible films and coatings encompass thin edible layers that can either be peeled away or ingested along with food items. Edible active packaging involves utilizing edible polymers combined with natural antioxidants. Edible coatings have demonstrated their efficacy as a primary packaging solution by effectively retarding the ripening process, maintaining nutritional attributes, and curbing quality deterioration through the reduction of various inherent mechanisms such as gas exchange, respiration, and transpiration rates. In this paper we present recent advancement in the augmentation effectiveness of edible coatings and films through the infusion of active natural elements with demonstrated antioxidant and/or antimicrobial characteristics. These packaging materials are classified as active due to their capacity to interact with fresh fruits, constantly eliberating bioactive components. This integration of active agents within biopolymer matrices not only enhances the fruits resistance to oxidation but also impedes the proliferation of foodborne pathogens. Consequently, these packaging innovations offer supplementary safety measures for food products, even in conditions where refrigeration is absent.*

Key words: *fruit sector, postharvest technology, films and coatings, bioproducts*

1. INTRODUCTION

In the last decade, many new concepts and solutions for modern food packaging have appeared. Consumers (increasingly aware and demanding) expect fresh, preservative-free and best quality food on the market. In addition, the recently observed dynamic development and progress in trade in a diverse range of commodities, including food, and their distribution modalities, e.g. such as the internationalization of markets and new trends (e.g. online shopping), impose high demands on the packaging industry, including food. The idea behind traditional packaging is to guarantee food products the longest possible shelf life. On the other hand, the task and purpose of active packaging is to extend the shelf life as much as possible and to guarantee the safety of the food and to maintain the typical (characteristic) organoleptic properties of a certain assortment, while maintaining the best possible, i.e. originally, quality and nutritional value.

In the context of continuous improvements in living standards and notable changes in consumer consumption patterns, the impact of the fruit industry on the global economy has seen remarkable growth in recent decades. This transformation can be attributed to evolving consumer preferences and paradigm shifts in how goods are consumed (Aday et al, 2020) . As people's aspirations and expectations have evolved, the fruit industry has adapted to meet these demands, leading to a significant and remarkable increase in its economic importance worldwide.

Consumer demand for natural, safe and healthy food options, along with increasing environmental awareness, has seen significant growth in recent years. A pivotal aspect in improving both the safety and quality of food is its packaging. However, the widespread use of synthetic plastics in packaging has led to environmental pollution and recycling challenges. To address this issue, the research and development of biodegradable and active packaging has become a societal imperative, requiring dedicated research and development efforts.

Food spoilage originates from various factors, including microbial contamination and various physical, chemical and biological processes. Microbial activity can induce significant changes in product quality and raise significant food safety concerns, particularly when pathogens enter the product (Diab et al 2001). Within the spectrum of food preservation methods aimed at combating spoilage mechanisms, the use of active packaging materials to counteract microbial or oxidation processes represents an interesting approach for extending the shelf life of products. Such active materials are based on polymers that serve as carriers for antimicrobial or antioxidant agents. These materials promise to reduce food spoilage, especially when using biodegradable polymers, thus reducing their environmental footprint (Rosenthab, 2018). Also, the use of active biopolymer coatings and films can function as controlled release systems for active compounds on the food surface. This dual action not only extends the shelf life of food, but also aligns with environmentally friendly principles.

In the context of current advances in the study of postharvest fruit quality and safety, this review focuses primarily on strategies that rely on the molecular foundations of quality preservation and antioxidant pathways in fruits. It also explores safe substances that synergistically manage fruit aging and improve antioxidant capacity in the post-harvest phase (Ponce A.G., 2008). In addition, the review looks at possible targets that could be manipulated to regulate pathogenicity and toxin production in fungal pathogens.

2. EDIBLE COATINGS OVERVIEW

An effective approach to preserving the storage quality of fruit involves the use of active coatings. These coatings play a vital role in retarding overcooking and senescence by effectively controlling humidity, solution levels, and gas exchange (Ncama K., 2018). Recently, the focus has shifted to the use of natural active films and coatings, mainly derived from edible biopolymers such as proteins, polysaccharides and lipids (Krochta

J.M. (2002); Perdones A., (2012). Chitosan (CS), a positively charged polysaccharide, has gained wide traction for the creation of edible films and coatings.

Antimicrobial coatings are designed to inhibit the growth of bacteria, fungi and other microorganisms that can spoil fresh produce or cause foodborne illness. By preventing or slowing microbial growth, coatings can help maintain the quality and freshness of fruits and vegetables for a longer period of time (Otero V. et al., 2014).

These coatings also act as a barrier between the product and the external environment. They can help reduce the exchange of gases and moisture between the product and its surroundings, which further helps preserve the freshness and quality of the items. Some antimicrobial coatings can also help retain essential nutrients in fruits and vegetables. The extended shelf life and reduced microbial activity can help prevent nutrient degradation, ensuring consumers receive more nutritious and healthier products ()Nair et al., 2020).

It is worth noting that the application of antimicrobial coatings on fresh produce is subject to regulation and approval by the relevant food safety authorities in different countries. Manufacturers must ensure that these coatings are safe for human consumption and do not introduce harmful substances into the food.

3. CHITOSAN- AN EXAMPLE OF EDIBLE COATING

Chitosan, a unique pseudo-natural cationic polysaccharide, boasts versatile applications due to its distinctive properties, including protein recovery flocculants and depollution agents. Its solubility in acidic aqueous solutions makes it suitable for various systems like solutions, gels, films, and fibers (Talon et al., 2017).

Possessing attributes of non-toxicity, biodegradability, biocompatibility, and resistance to microbes, chitosan is currently garnering significant interest. Extensive scientific evaluation of its capabilities on a grand scale is currently underway to uncover its potential applications across various domains (Kona Mondal et al., 2022;). Chitosan is thought to exhibit the capacity to hinder the proliferation of numerous bacteria and fungi. In these processes, its polycationic nature allows the bio-derived polymer to interact with negatively charged components and subsequently adhere to the surfaces of bacteria (Youssef et al., 2014).

Chitosan is widely used in the food industry, including in the design of biodegradable films and coatings, due to its capacity to immobilize enzimes via its antimicrobial attributes and even as a dietary supplement with hypocholesterolemic effects (Jianglian, et al., 2013, Duan et al., 2019) .

Therefore, in the area of development of films or coatings, chitosan offers numerous benefits such as antimicrobial, antioxidant and emulsifying properties, as well as good compatibility with other biopolymers and lipids (Duan et al., 2019). This versatility enables chitosan to create films that can be tailored to a wide range of food-related uses. Beyond its inherent antimicrobial capabilities, chitosan can serve as a carrier for bioactive substances, effectively managing microbial contamination in fresh or processed foods (Talon et al., 2017). This approach of incorporating antimicrobial substances into edible films or coatings can prove more effective than directly adding antimicrobial agents to the food. The rationale lies in the gradual and selective migration of active compounds from the packaging onto the food surface (Elsabee and Abdou, 2013).

In the realm of natural antimicrobials, various essential oils have demonstrated antibacterial and antifungal attributes against a substantial array of pathogens and spoilage microorganisms. Notably, many of these compounds have earned FDA approval as flavoring agents and are widely adopted in the food industry. Consequently, integrating essential oils into food products presents an avenue to confer antimicrobial functions. Nevertheless, these compounds do have certain limitations, notably their high volatility and the potential to strongly impact sensory perception. As a result, their application is constrained for a significant portion of food-related scenarios.

Table 1. Examples of chitosan based solutions for horticulture sector

Other film compounds	**Product**	**Main effect**	**References**
None	Papaya Litchi	Decrease in respiration rate	Ali et al., 2011; Lin et al., 2011
Lemon essential oil	Strawberry	Control of fungal decay	Perdones et al., 2012
Bergamot EO	Grape	Reduction in weight loss	Sánchez-González et al., 2011
Waste Green Algal Biomass Extract	Tomato	Improved physicochemical properties	Kona, 2022
Banana peels extract	Apple	Visual appearence	Zhang, W.; Li, 2020

CONCLUSIONS

Further research should be conducted in the upcoming years to enhance the advancement of better extraction and isolation technologies. These technologies aim to more effectively reclaim high added-value materials from postharvest fruit and vegetable byproduct. Additionally, the utilization of these materials to uphold the quality and prolong the shelf life of postharvest produce necessitates consideration of potential effects on food safety and the sensory characteristics of the products.

It's important to note that the effectiveness of antimicrobial films can vary based on the type of microorganisms targeted, the film's composition, and the specific fruit being protected. Therefore, it is crucial to validate the efficacy of antimicrobial films for each intended application and ensure compliance with relevant food safety regulations.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

DIGIBEE: DIGITALIZATION OF BEEKEEPING – DEVELOPMENT OF A BEEHIVE MONITORING SYSTEM AND IMPLEMENTATION OF AUGMENTED REALITY FOR HAND-FREE INSPECTION

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Abstract: *In the past years Smart Beekeeping systems (SBS) have been developed and implemented successfully, most of them are still on an experimental level, covering a wide scope of parameters relevant to beekeepers, implementing IoT protocols of data transfer for remote monitoring of the beehives. As of now, little attention has been paid to the fieldwork situation of the beekeeper – a perspective that inspired the authors to prototype DigiBee as a demand-driven SBS. Besides implementing standard beehive monitoring devices and corresponding user front-end software, the main focus of DigiBee lies in the use of Augmented Reality during fieldwork. This allows proper recording of beehive conditions and documentation which helps the beekeeper in inspection and decision making as well as satisfying legal aspects concerning German food legislation. Thus, a user-friendly, hands-free system has been developed that efficiently supports the beekeeper in performing field monitoring of their beehives.*

Keywords: *sustainable beekeeping, digital monitoring, real-time data visualization, Augmented Reality application, STEM education*

1. INTRODUCTION

Food security and biodiversity conservation were long believed to be primarily a challenge to face in the global south [1]. Global observations of insect populations over the past 30 years, however, provided compelling evidence for massive losses in insect biomass as well as species diversity, alongside alarming trends in land use changes and land use conflicts as a worldwide threat [2]. In response, various investigations offered new approaches to the food-biodiversity nexus [3, 4, 5, 6], more recently with a growing focus on smart agriculture [7].

Smart Agriculture, often referred to as Precision Agriculture or Digital Agriculture, harnesses the power of cutting-edge technologies to optimize various aspects of farming. This multidisciplinary field integrates advancements in sensors, data analytics, robotics, artificial intelligence (AI), and the Internet of Things (IoT) to enable more efficient, sustainable, and resilient agricultural practices (ibid.). Smart Agriculture holds the potential to not only increase agricultural productivity but also to reduce the environmental footprint of farming and improves the quality of life for farmers [8].

Among the many perspectives on food security, honey production deserves particular attention. While bee pollination substantially increase the yield of crops and harvesting efficiency [9], honey production is also considered to be among the highest ranking food processing activities with regard to carbon dioxide emissions – particularly due to the need for inspection, typically by car or truck [10]. These observations made honey production a key item of interest of Smart Agriculture, in the area of Smart or Precision Beekeeping [11].

Numerous Smart Beekeeping systems (SBS) have been developed and implemented successfully at experimental level (ibid.), as Do-It-Yourself (DIY) manuals [12, 13, 14, 15], or as commercial products [16, 17, 18], covering a wide scope of parameters relevant to the beekeeper and implementing IoT protocols of data transfer for remote monitoring of the beehives. In these solutions, however, little attention has been paid to the field work situation of the beekeeper – a perspective that inspired the authors to prototype DigiBee as a demand-driven SBS. Besides implementing standard beehive monitoring devices and a corresponding user front-end software, the main focus of DigiBee lies in the use of Augmented Reality (AR) during field work. According to beekeepers' experience, proper inside inspection and documentation of beehive conditions as well as retrieval of a beehive's meta data and history is disproportionately time consuming and cumbersome constantly having honey-stuck hands – although necessary nonetheless according to German food legislation (B. Heuvel 2021, pers. comm.). This unfortunate situation called for the development of a user-friendly, hands-free field system that supports the beekeeper in solving the monitoring tasks.

This paper describes the evolution of DigiBee and first experiences with the technology. In Material and Methods, the principal steps in the SBS development along with a bill of materials is documented. Results and Discussion provides details on the assembly of the SBS, its data flow and database architecture. The Conclusion summarizes the first experiences, lessons learned and an outlook on work packages to be implemented in the future.

2. MATERIAL AND METHODS

2.1. System overview

Figure 1 shows the operational and communication flow of the proposed system. The flow is a simple representation of an open-loop SBS. The system can be split into 3 sub-systems: *data acquisition* where a microcontroller (MCU) is connected to a set of sensors installed in a beehive, retrieving data on weight, temperature, humidity, sound and vibration; *data storage* where the MCU transmits the data to a Database; and *data* *visualization* where dashboards display the time-stamped data. Additionally, an AR implementation has been added to facilitate hand-free field inspection of the beehive.

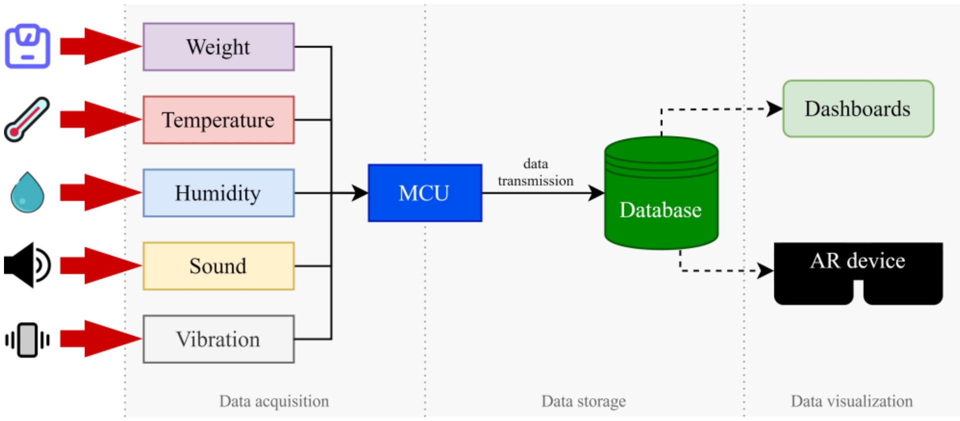

Figure 1. Smart beekeeping system

The hardware elements proposed for the Data acquisition sub-system are documented in the following sub-section.

2.2. Hardware elements for data acquisition sub-system

To measure the desired parameters of a beehive, a set of sensors is needed, along with a suitable microcontroller and a fitting power supply. For the sake of easy replication, the components were chosen based on price, weather resilience, accuracy, and ease to program. Table 1 shows the components of this subsystem, the featured devices with their corresponding specifications, their function; and in the case of the sensors, additionally their respective measurement ranges.

Table 1. List of components for data acquisition sub-system

Component	Function	Range	Notes
4-wires Load cells + HX711 24-bit analog-to-digital converter [19]	Weight sensor	up to 80kg in total	Easy to install
SHT40 [20]	Temperature sensor Relative humidity sensor	-40 to 125 °C 0 to 100%	Better resistance to environmental stress factors, durability and accuracy compared to the also popular DHT22 or DHT11 sensors
Micro ElectroMechanical Systems microphone ADMP401 [21]	Sound sensor	100Hz to 15kHz	Wide range of measurement Small dimensions
Piezoelectric ceramic chip [22]	Vibration sensor	-	Voltage signals are adjustable using a resistor in parallel [23]
NodeMCU ESP32 [24]	MCU Data transmission	-	Wireless fidelity (WiFi) connection Low power consumption Ease to program
18650 Li-Ion 3200mAh battery cells [25]	Power supply	-	Rechargeable battery cells

2.3. Database and dashboarding

The database used was InfluxDB [26], which is a database that organizes and stores the data that have been registered over time, helping the beekeeper keep track and analyze the data of each individual beehive.

In order to visualize the data, InfluxDB's native dashboarding feature was used. This feature allowed the creation of customized dashboards directly in the InfluxDB platform, thus enabling real-time monitoring and visualization of the data without the need for external tools.

2.4. Augmented Reality implementation

The implementation of AR consists of the identification of objects based on markers, where a device scans a Quick Response (QR) code, decodes it and displays the encrypted content. In the context of beekeeping, AR glasses were chosen to overcome the difficulties beekeepers face doing any on-site recording due to their suit and the contact with honey and beeswax which asks for a hands-free device.

The AR glass used is the DreamGlass Lead Pro [27]. This is a standalone Android-based device with a built-in 13MP RGB camera, microphone, and WiFi connection. It has 5300mAh Lithium batteries for a 3.5h usage time. In order to develop this application, Unity [28] was used. This game engine provides a versatile and powerful platform by offering tools for (user interface) UI design, camera integration, scripting, and deployment across multiple platforms.

3. RESULTS AND DISCUSSION

This section provides details on SBS assembly and its installation, data storage and dashboarding, as well as a pilot test of the AR glasses application. The system was developed, installed in an unpopulated beehive, and tested on an indoor environment for a period of three days.

3.1. Data acquisition sub-system

3.1.1. Weight measurement

For weight measurement, a scale platform was designed using 4 bending beam load cells – also known as *bar load* cells – with a measuring range of up to 20kg each. As shown in Figure 2 a), the load cells have been connected in parallel and arranged in an *H shape* together with the HX711. Figure 2 b) shows the assembled platform using 4 wooden pieces, measuring 50cm x 6cm x 2cm each. The separators needed between the load cells and the wooden pieces were designed and 3D printed. Metallic or wooden pieces can be used as an alternative. Heat shrink was used to protect the wires from damage and facilitate the handling of the lines. The assembled weight sensing platform was calibrated using a known weight of 60kg.

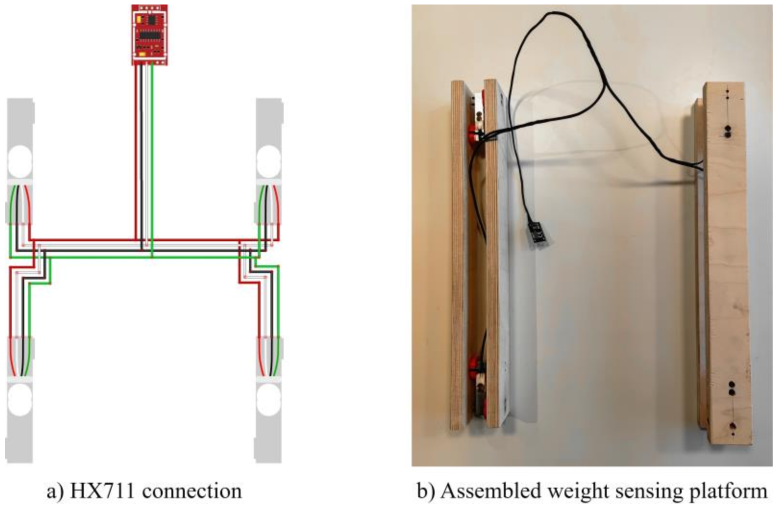

Figure 2. Weight sensing platform

3.1.2. Temperature, humidity, sound, and vibration sensors

The SHT40, ADMP401, and the piezoelectric ceramic chip were soldered to one perforated circuit board. Wires were soldered to the board with male pin headers as terminals to facilitate the connection to the ESP32. Heat shrink was used to protect the wires from damage and facilitate the handling of the lines.

3.1.3. Microcontroller and data transmission

The ESP32 board was attached through female pin headers to a perforated circuit board. Additional female pin headers were soldered to the circuit board to provide an easy connection to the sensors.

The Integrated Development Environment (IDE) used to program the ESP32 was the Arduino IDE [29]. It was programmed to collect and process the data from the sensors and, by using WiFi connection, it establishes communication to the InfluxDB database, using the InfluxDB Client library [30], and transmits the data every 15 minutes.

3.1.4. Power supply and enclosure

The three batteries were connected in series. They power up the VIN pin of the ESP32 board. The power lines for all of the sensors are taken from the 3V3 and GND pins from the ESP32 board.

Figure 3 shows the enclosure of the temperature, humidity, sound, and vibration sensors. A pattern of holes was added to the digital design, taking into consideration proper sizing and number: large enough and in sufficient quantity to read the desired environmental conditions, while small enough to prevent the bees from entering and having direct contact with the sensors, as those would be covered by the bees with wax.

A second enclosure contains the MCU and batteries. Its design must be weather resilient to prevent humidity from entering the circuit and at the same time provide easy opening to change the batteries or connect more sensors.

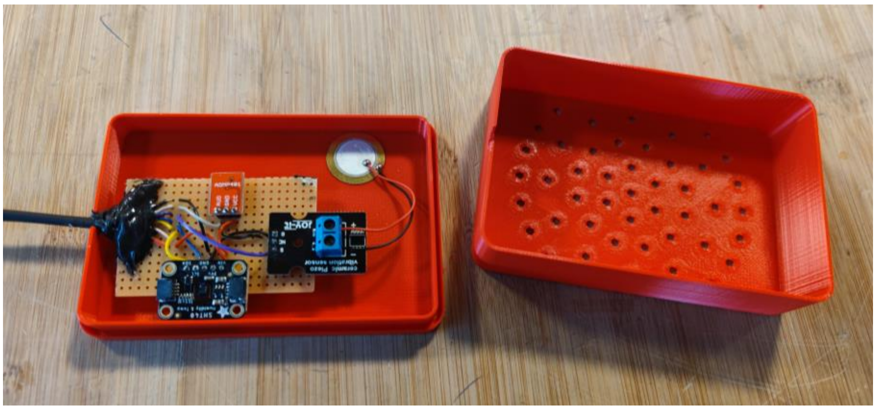

Figure 3. Temperature, humidity, sound, and vibration sensors in enclosure

The enclosures were designed and 3D printed in polyethylene terephthalate glycol (PETG). This material was chosen due to its higher durability and resistance against environmental conditions, compared to the popular polylactic acid (PLA).

3.1.5. Installation of the data acquisition sub-system

Figure 4 shows the position of the three groups of hardware components of the data acquisition sub-system [31]. The temperature, humidity, sound, and vibration sensors are placed on the inner cover of the beehive. The MCU and the batteries were placed on the brood chamber, outside the beehive. The elements were fastened with hot glue.

Figure 4. Data acquisition sub-system installed on beehive (left) collecting data of temperature, humidity, sound, vibration (top-right), and weight (bottom-right) with MCU (center right)

The resulting sub-system was easy to install since only one person was needed and no extra tools were used. This sensor system is non-invasive since it does not involve contact with the beehive body where the queen bee resides.

The weight sensing platform was placed under the beehive's bottom board, other models might feature a beehive stand with the platform placed underneath. The arrangement of the weight sensing platform was chosen to suit different beehive models and sizes. For DigiBee, a simple, easy to replicate set of sensors was preferred in contrast to the mechanical system proposed by OpenHiveScale [13], which measures the weight of an object by quantifying the amount of force it exerts on a spring or a system of levers.

Considering the requirements requirements with regard to environmental resilience, a commercial IP68 enclosure can be used as an alternative to the 3D-printed casing.

In practice, beekeepers operate hundreds of beehives simultaneously (B. Heuvel 2021, pers. comm.), resulting in more than 1,000 sensors to retrieve data from. In contrast to the WiFi protocol used for mobile data transfer in the DigiBee prototyping, the transmission of the data data for such a real-world scenario can be addressed using the Long Range Wide Area Network (LoRaWAN) [32].

3.2. Database and data visualization

Figure 5 shows the dashboards of the data monitored for three days whereby weight data is measured in kilograms, temperature in degree Celsius, relative humidity as percentage. The microphone signal output is a varying voltage; when it detects no sound the audio (AUD) output will be approximately one-half the power supply voltage which is 3.3V; larger amplitude measured indicates louder sound, and a smaller amplitude indicates quieter sound. The piezoelectric signal output is a varying voltage; when it detects no sound the signal output will be 0V, larger amplitude measured indicates higher, and a smaller amplitude indicates lower vibration. The sensibility may be adjusted varying the value of a resistor connected in parallel to the piezoelectric.

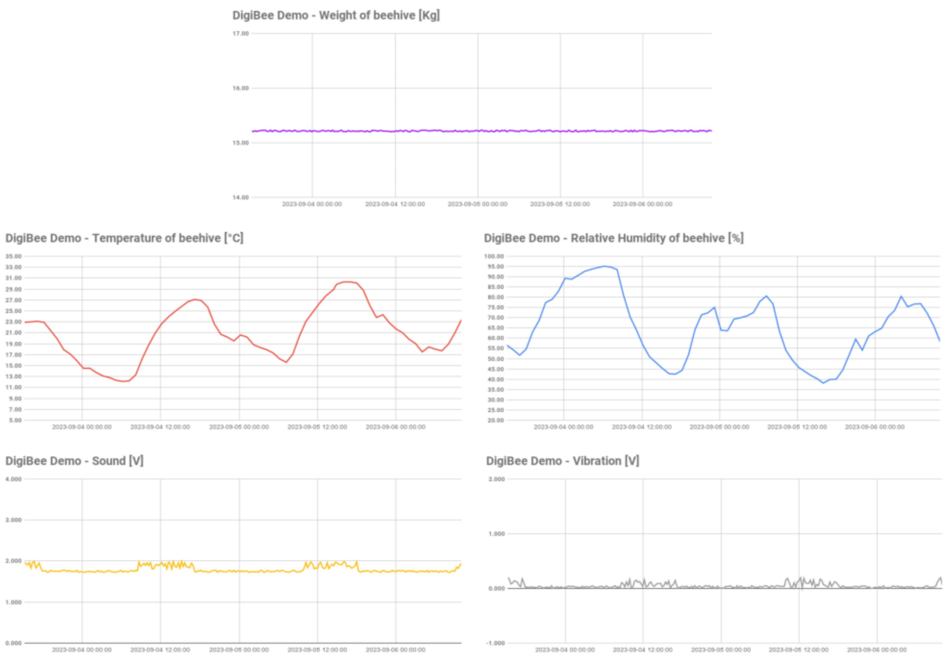

Figure 5. Visualization data of weight (top), temperature (center left), humidity (center right), sound (bottom left) and vibration (bottom right) over a 3-day-period

The resulting dashboards provide an efficient means to gain insights from the collected data facilitating informed decision-making for beekeepers and optimize productivity. Whereas the InfluxDB's built-in dashboarding feature is suitable for a simple integrated solution, it is designed primarily for storing and querying time-series data. On the other hand, Grafana [33] is a tool optimized for analytics and interactive visualization of data. Thus, for the integration of more complex dashboards, alert systems and notifications, the Grafana environment will be given preference in future improvements.

Along with a growing number of data sets from populated beehives, a corresponding increase of disruptions in honey production is expected. Among other factors, these may be caused by a) toppled over beehives, b) missing bee queens, c) Varroa mite infestations, or d) hornet attacks (B. Heuvel 2021, pers. comm.) [34, 35]. It is reasonable to assume distinct patterns in the sensor data from each of these situations, the analysis of which will be subject to the training of a neural network. Over time, such AI will be able to not only trigger an alert on the beekeeper's mobile device once a disruption occurs, but also to compute probabilities for their prediction.

3.3. AR implementation

A QR with the encrypted text "Beehive 1" was created with a QR Code Generator [36], printed and placed on the beehive. Figure 6 shows the AR glasses been worn to scan the code, as well a screenshot of the Game window of Unity.

On the UI Scene of Unity an output text was used to display the particular beehive's identification. Another output text was used to display the data of the beehive. A script is responsible for connecting to the device camera, decoding the marker and, depending on its content, extracting the specific data from InfluxDB.

Figure 6. AR implementation test

Despite presumed substantial savings from fewer on-site inspections and disruptions of bee activity, the investment in professional AR lenses may be financially prohibitive for small scale beekeepers. Thus, the Unity program used in the Dreamglass Lead Pro case might be adapted to Android or iPhone operating systems (OS) with the intention to run the DigiBee AR on considerably cheaper and more common devices.

4. CONCLUSIONS

DigiBee is a Smart Beekeeping system, designed for the specific demand of professional beekeepers in their daily field work. Besides standard remote monitoring, DigiBee addresses the practical problems regarding on-site inspection, documentation and metadata retrieval by implementing the use of AR lenses. The chosen AR device, Dreamglass Lead Pro, features an embedded camera and microphone, offering proper technical endowment for the current development focus on data visualization as well as for future technical enhancements. Future work is directed at detecting distinct disruption patterns gained by sensor data and recordings history of beekeepers that will be subject to training of a neural network that will not only trigger an alert on the beekeeper's mobile device once a disruption occurs but also compute probabilities of disruption to open room for a predictive maintenance.

Acknowledgement: *This paper is part of the research done within the project "DigiBee: digitization of beekeeping as a test field for remote sensing, augmented reality and artificial intelligence", with financial support from the European Regional Development Fund (ERDF) and The State Government of North Rhine – Westfalia. The authors would like to thank professional beekeeper Bernhard Heuvel for his valuable insights on the challenges of beekeeping, as well as Harley Nelson Lara Alonso from Bonn-Rhein-Sieg University of Applied Sciences, and Jovana Kovacevic from University of Belgrade for their technical contributions on the AR implementation.*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

PLANT-IT: A SMART CITY APPLICATION FOR GREENING THE URBAN SPACE WITH CITIZEN'S PARTICIPATION

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Abstract (bold). *This paper presents a smart city application that aims to strengthen green spaces in the city through the public contribution of citizens. Research from several experts has shown that as urban agglomerations become larger and more compact, green spaces disappear. This fact is crucial as we are already in front of rapid urbanisation and unprecedented climate stress is expected in many cities. Green spaces can boost the resilience of cities to heat waves, floods, landslides, and even coastal erosion, and in addition they enhance sustainability by improving air quality, protecting biodiversity, and mitigate urban heat island effect. Through this application there is a great potential for collaboration between experts (i.e. agricultural scientists, botanists, landscape architectures, urban planners), citizens and municipal authorities in order to expand the urban green and enhance the quality of life in cities. The 'Plant it' apps is founded to create awareness among citizens to become city gardeners and contribute to the work of the municipality to make all neighborhoods better with some small green corners in public and private spaces (private gardens, balconies) as well. Users can also upload a picture of their plants to the platform by scanning them to update and be informed about them, talk with other users exchanging ideas as well as find green spaces in each neighborhood to plant a flower or a tree. Users collect points with each planting where they can be redeemed.*

Key words (bold): *urban greening, smart cities, participatory design, greening app*

1. URBAN GREENING

With more than half of the world's population currently living in cities, urbanization is an inevitable worldwide trend [1] and while cities give unmatched prospects for innovation, cultural interchange, and economic progress, they also pose formidable obstacles, foremost among them the environmental effects of urbanization's rapid growth [2]. Habitat degradation, air and water pollution, and an increase in greenhouse gas emissions are frequently consequences of the rising demand for space, resources, and infrastructure in metropolitan areas [3]. As a result, urban planning concepts must be reevaluated as cities grow in order to ensure that they are both sustainable and improve the quality of life for their residents. The exploration of an app based on participatory urban planting in creating greener, healthier, and more sustainable cities, is based on the fundamental proven benefits of urban greening – a multifaceted approach focused on nature-based solutions.

1.1. The Essence of Urban Greening

A broad definition of urban greening includes a variety of actions taken to introduce and incorporate natural components into urban settings [4] while it has been defined as establishing, through public landscaping and urban forestry, a constructive link between city dwellers and the environment [5]. Under its commonly applied definition, projects like tree planting, green roofing, urban parks, community gardens, and sustainable landscaping are just a few examples of how it is applied, with its main goal being to establish a peaceful coexistence of the built and natural environments in cities [6].

1.2. Evolution of Urban Greening and Environmental Imperative

Urban greening has changed substantially throughout time as a result of the rising awareness of its advantages and the urgent need to reduce urbanization's negative consequences. From an early emphasis on aesthetic improvement and beautifying initiatives to a now comprehensive approach and a focus on health and wellbeing by facilitating access to green spaces, urban greening is currently essential to fighting climate change and creating urban resilience, while economic factors highlight its potential to boost regional economies [7]. Therefore, the integration of urban greening into comprehensive urban planning and development initiatives has further accelerated this evolution, resulting in cities that are not only aesthetically pleasing but also environmentally, socially, and economically vibrant.

In fact, research does not fail to show us that the sustainability of the environment is greatly aided by urban greening that comes in the form of community woodlands, green roofs, landscapes around buildings, street trees, urban parks and gardens, wetlands, and all kinds of permeable pavements [8]. Furthermore, it shows that by lowering surface temperatures through evapotranspiration and shading, the impact of the urban heat island effect is significantly decreased [9], while the green infrastructure that results from its implementation improves stormwater management, lowering the danger of flooding and enhancing water quality [6, 10]. Furthermore, by capturing carbon dioxide, urban vegetation acts as a carbon sink to lessen the consequences of global warming [11, 12].

1.4. Economic and Social Benefits

Beyond the benefits to the environment, urban greening has a favorable impact on the social and economic structure of cities as well, as the availability of green areas promotes greater physical and mental health as well as better and happier communities [13]. Additionally, green spaces provide possibilities for entertainment, socialization, and cultural enrichment, while investments in urban greening can also improve property values, stimulate the economy, and create employment opportunities, making them a wise financial decision for communities [14].

2. Smart Cities - Design of Digital Applications

2.1. Smart and Intelligent Cities

The need to deal with problems such as the climate crisis, the urban heat island effect, and the quality of life within urban areas, has led many cities to find more "intelligent" ways to manage them. "Knowledge" is an important factor in the global economy while high technology is evident in every area of people's lives. The concepts of “the city”, “knowledge” and “technology” are interconnected, co-exist and make up "smart or intelligent cities". Huge efforts by public and private organizations and authorities have been done, exploiting the evolution of the Information and Communication Technology (ICT) sector, and nowadays there are many digital applications that already exist under the framework of “smart and intelligent cities” around the world. The value of smart cities lies in their ability to combine three forms of intelligence: the human intelligence of the urban population, the artificial intelligence of digital networks and applications, and the collective intelligence of city’s organisations and institutions [15].

Barcelona and Santander (Spain), Amsterdam (Netherlands), Viena (Austria), and Helsinki (Finland) [16] are only few examples of Intelligent - Smart Cities that apply this new planning paradigm to drive urban renewal more efficiently towards sustainability. Smart city applications offer many advantages to citizens, such as access to continuously updated information on the urban environment, information on smart city services, making suggestions, direct communication with public authorities, participation in online consultations, etc. [17]. In many cases, citizen’s participation and engagement in smart city applications, from the design to the implementation stage, play also one of the most important roles concerning the economic viability of the applications and the results in the urban system. Smart Amsterdam, which follows the Living Lab approach with public and private collaborations and user’s involvement, tests different initiatives to determine which ones will be realized on a large-scale.

2.2. Designing process for a smart city application

Having in mind all the above, this paper’s main objective is to introduce and present a prototype of a smart city application which involves experts, citizens and public authorities towards the enhancement of urban greening to tackle environmental, economic and social problems in cities such as quality of life, urban heat island effect and climate change impacts. The creation of the concept of the application was based on the planning roadmap for new services design for smart cities [18], as illustrated in Figure 1.

The development of the prototype followed an iterative process with four steps. Step 1: Analysis of other similar smart city applications, Step 2: Detailed presentation of the application’s main concept, Step 3: Development of the interactive prototype that demonstrates the application’s core functionality and Step 4: Development of the application’s website that presents the application’s features and added value in the local environment. Although this is a typical application development process, the creation of the application’s concept considered the specific needs for a smart city service, including the definition of its main users and stakeholders, data sources and required data transformations, and expected results in the urban fabric/ecosystem.

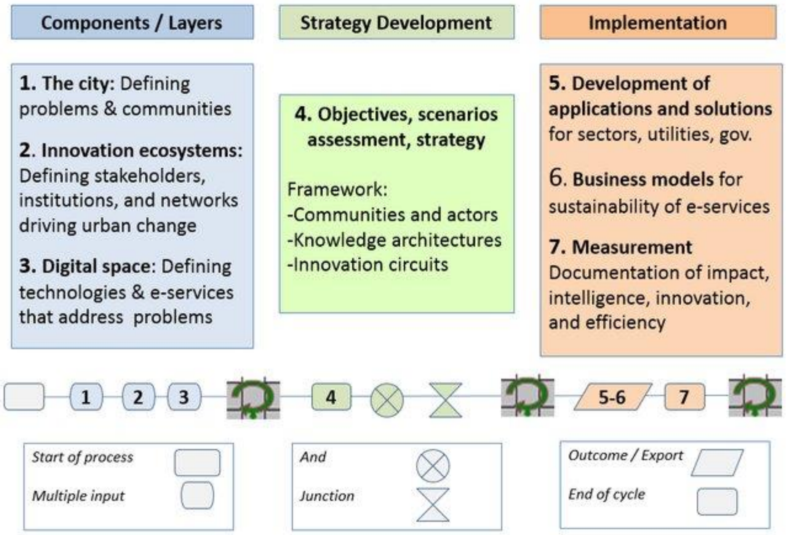

Fig. 1 A roadmap for intelligent city planning: Three stages and seven steps, © N. Komninos [18]

The development of the interactive prototype was based on the principles of user experience (UX) design. According to the Interaction Design Foundation, the user experience design is the process that design teams use to create products that provide meaningful and relevant experiences to users [19]. UX design involves the design of the entire process of acquiring and integrating the product, including aspects of branding, design, usability, and function.

The iterative approach was based on state-of-the-art tools that allow the collection of feedback in each step of the development process. Miro [20] is used for the presentation of the application's main concept, Figma [21] for the interactive prototype and WordPress [22] for the website. Through these tools, selected audience gave feedback that improved the outcome of each step.

3. The Plant-It App design and Prototype development

The Plant-It smart city app was designed and a prototype was developed under the framework of the undergraduate course "Digital Cities-Applications' design and development" of the School of Architecture-Aristotle University of Thessaloniki-Greece. The intended outcomes of the course are the students to: (a) understand the technological dimensions of the new paradigm of urban development and planning: smart cities, (b) comprehend the technical basis of the convergence of the main three systems of intelligent/smart cities: urban, digital, innovation, (c) get familiar with the logic and stages of digital city application design, and (d) get introduced to the web technologies used for the development of the applications.

3.1 Problem and context definition

It is widely known that contemporary urban centers have a huge lack of green spaces and plants. All these high buildings and big constructions and infrastructures have decreased public as well as private green spaces within cities. This situation not only has immediate consequences on the microclimate of the city area, but also on the economic and social prosperity of the cities’ community, as described previously. The creation, expansion and maintenance of urban green depends mainly on the initiative and available financial resources of municipal authorities, making it a pure top-down activity, without any community involvement.

Considering all these problems that exist on the urban fabric, this application aims at the enhancement of green urban spaces by citizen’s participation and their collaboration with the community, and to strengthen the ecological consciousness of citizens. Through this application, citizens in an interactive way contribute to the improvement of the microclimate of each neighborhood of the city and to its “green image”. With the cooperation of citizens and the municipality, green spaces and plantings are created in various parts of the urban fabric, thus combating the heat island phenomenon and all the problems related with the lack of green urban space. In addition, users are motivated by collecting points to buy more plants and trees for both public and private use. With the frequent activity of the citizens, the municipality is forced to take more responsible care of the city's image. Additional free information is also provided to users by the scientific team of the application. On a financial level, the city's florists are given an incentive to cooperate with the application in order to increase their sales.

Urban green concerns both public and private urban space. At the public level, specialist scientists such as landscape architects, botanists, agriculturalists and urban planners collaborate with the aim of improving the green image of the city, by creating green spaces in all neighborhoods. Citizens through the application locate a free space to do their planting and contribute to solve problems within their neighborhood. Another important purpose of the application is the frequent update of citizens from articles and publications from the municipality about the actions it carries out in their city.

On a private level, the application helps the citizens to know more about plants. At the same time, it gives them motivation to plant more often in the yard, on the balcony, on the roof, and even on the walls. The benefits of private plantings can be huge for the neighborhood microclimate. It brings together citizens with common interests, such as gardening and their love of plants, to exchange ideas and collaborate. All these actions have as a direct result the strengthening of the ecological consciousness of the citizens.

3.2. Similar applications and technologies

There are many similar applications that use new technologies in order to strengthen green urban areas. The creation of “Plant it” was inspired from “Picture This”, an application that provides an online library for plants. By using this, users can find the sickness of their flower or vegetable, get notified for the plant watering and get advised from expert’s text about any question they have. There are numerous similar public and private initiatives around the world such as the “National Park City Foundation (https://www.nationalparkcity.org/ and https://community.nationalparkcity.org/) which involves the community and help make a difference to improve city life for nature and people alike. This movement consists of crowdfunders, an advisory board, friends and other supporters. In Greece, smart city applications regarding gardening can also be found. One of them is the page of "potizo.thessaloniki.gr" (https://potizo.thessaloniki.gr/) that citizens can adopt free a tree and take care of it. Finally, the "Green City App" (https://www.thegreencity.gr/) which is the biggest reward program of recycling, is an application through which, users collect points with every recycle the carry out and redeem them in a collaborated business.

3.3. Features and operation of the application

The main features of "Plant-it" app are:

Scan & Learn: Scan your plant in the garden or on your balcony for information such as disease, watering or any other question you have. Scientists give you answers to become a better gardener in your home and city and make your gardening easier.

Find a flower shop: You can check the flower shops near your neighborhood and find products in lower price or cash your bonus you gain by planting a flower in a city corner. You can also get informed about some products in best prices only by using the app and add your favorite flower shop.

Find an empty space: Find a green space near your home or work or any space of your interest and plant a flower or tree and gain bonus by scanning your plant. You can also check the 'green percentage' in different point in town or add a new space in the map and the administration will evaluate if this is suitable for planting.

Post & Collect points: Find a space for gardening and take a photo of the flower or tree you plant. Each upload adds points in your personal profile so you can buy a flower from a flower shop. Your community gains points too with every planting and then a tree can be planted somewhere in your town.

Features of the "Plant-it" app, totally include a) blogs from experts, b) posts from friends, c) landscaping, d) chat, e) favorites, f) find green spaces, g) post your plantings, h) find a flower shop, i) collect points.

After visiting the website, finding the available barcode and downloading the application, the user will be asked to enter the email and a password. Then the home page will appear, as illustrated in the app's sitemap (Fig. 2).

The application has four main pages. On the home page they can find the scanner, where they scan any plant and receive all the available information in the application library (Fig. 3). Furthermore, there are available scientific articles of experts, as well as publications of the municipality and citizens. Next page is the chat, where users communicate with others online, exchanging information and images (Fig. 4). The plantings are being done by clicking on the Plant It category, where the map of the exact area appears to choose green space and a list of cooperating florists to buy the plant. After the planting is done, they can post a photo (Fig. 5). Finally, there is the profile where the user's personal information, points, posts and favorites show up (Fig. 6).

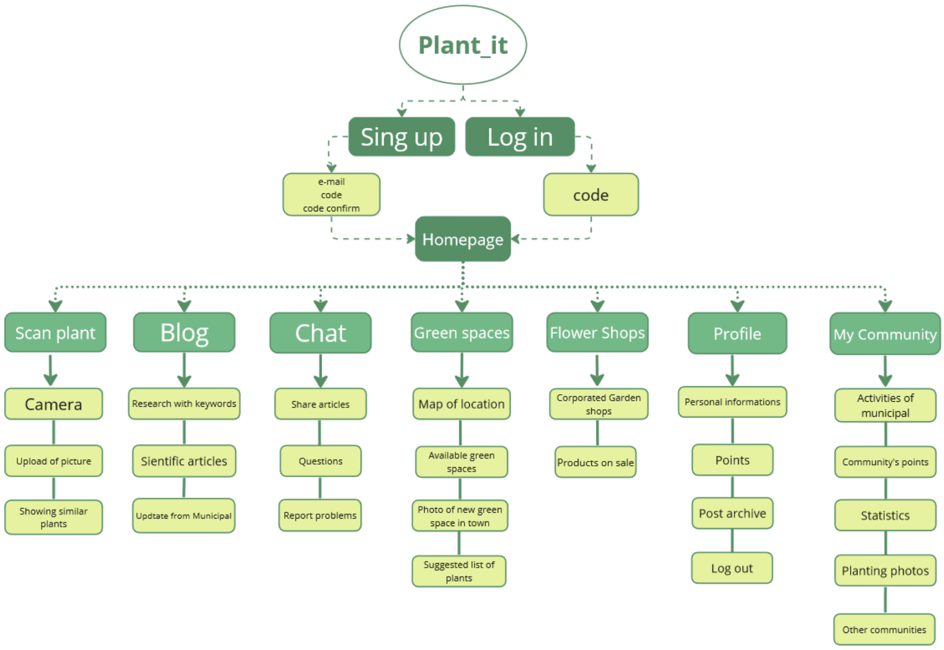

Fig 2. Plant-It sitemap

Fig. 3 Home page

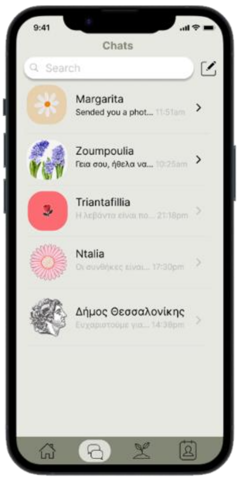

Fig. 4 Chat

Fig. 5 Plant it

Fig. 6 My profile

3.4. Data sources, sustainability and intended results on the urban system

When the user enters the application, it is given access to the location in order to show the nearest available spaces for planting, and also, he writes his personal information such as username, age, residential city. There are also available maps from internet showing free green points for planting marked from municipality. In addition, municipal has access to all functions of the application in order to carry out necessary updates and upload his actions. Last but not least, the scientific team provides encyclopedic knowledge.

This application is a free program of the municipality for citizens. However the incomes come from the flower shops, who give a small fee to be promoted on the app and the app keep a small commission from their sales they do for the city gardening. The advertisements that appear when using the application are also a big source of income.

As far as the intended results by the implementation of the "Plant-It App" is concerned, first of all, the application aims to expand the green spaces in the city. The expansion and maintenance of the urban green is realized by inspiring all stakeholders to build a strong-connected community. Through their active action, citizens create 'Green breathes' between the buildings increasing the percentage of green in the urban environment, and thus improving the biodiversity and the microclimate of their neighborhood; the carbon dioxide and other air pollutants are reduced, birds and other species can find their new habitat within the city. This has as a direct consequence on the improvement of the quality of life of the residents, enhancing their socialization and productivity as well; every resident and child benefits from playing, exploring, socializing and other recreational activities within their neighborhoods. The municipalities benefit from inspiring their citizens to give their support and become city-gardeners and thus reducing their operational costs. Another problem that can be solved is the phenomenon of Urban Heat Island, a big problem that exists in many city centers. The actions offered by the application contribute to the improvement of the image of the city by creating eco-friendly and sustainable neighborhoods. All these functions reinforce the cooperation of citizens, experts and the municipality to create a prosperous urban environment for the whole community.

4. FUTURE STEPS

The Plant-It application introduced in this paper needs further actions in order to be fully implemented. Until now, according to the planning roadmap for new services design for smart cities, which is inspired by strategic planning principles and includes three stages, subdivided into seven different steps overall (Fig. 1), there are some actions and steps to be carried out. First of all, in order to realize the main objective of the application, the community of all actors of change identified (public bodies, citizens, flower companies, scientific experts) must be inspired, built and engaged. From the third, the implementation, stage, the prototype has been created, but the development of the application, the business models, and the methodology and criteria for monitoring and documentation of the level of intelligence, efficiency, sustainability, and quality of life in the city still need to be conducted.

The application can evolve in the future, in a manner to be adapted from other cities or/and neighborhoods as well, and by adding even more solutions and functions. For example, watering of plants by an interconnected network with automatic irrigation and rainfall tanks, with sensors and state-of-the-art equipment may enable micro-water management on the city scale. Finally, statistics provided by the app, concerning the urban green percentage and mapping, may also facilitate research on its impact on citizens wellbeing and productivity, as well as other environmental matters (air pollution, biodiversity, urban heat island effect, climate change) and other complex problems within overpopulated cities.

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TEST RESULTS OF SEEDERS WITH PNEUMATIC APPARATUS FOR MAIZE SOWING

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Abstract. *Optimum layout and the appropriate number of maize plants per area unit are the essential prerequisites for successful production. By maize sowing with precision seeders, significant savings in seed and working time are achieved, and proper and uniform seeds distribution of by depth, length, and width, enables better germination, sprouting, and higher yields. Understanding the importance of correct sowing becomes even more important considering the fact that mistakes made while sowing cannot be corrected later with other agrotechnical measures. The paper presents the test results and quality assessment of the Vaderstad Tempo T6 and Sola Prosem K8 maize seeders. The trial is aimed to determine the work of the mentioned seeders for wide-row sowing when sowing maize seeds in the production conditions of the observed area. The seeders worked in similar test conditions, and the corn sowing was done in the vicinity of Pancevo, in the Banatsko Novo Selo location. Tests and evaluation of the quality of seeders were performed according to ISO standards 7256/1 and 7256/2. The obtained results show that with the seeder type A-Vaderstad Tempo T6, the sowing of maize achieved better quality, bearing in mind that higher values of the QFI index (quality of feed index) were achieved, above 96%.*

Key words: *seeder, pneumatic device, seeds distribution, sowing, QFI index, maize.*

1. INTRODUCTION

Maize takes the leading place in terms of yield and is one of the most represented crops in the world [1, 3]. In Republic of Serbia, maize is grown on 1,020,337 ha, with an average yield of 5.90 t ha^{-1} [19]. In the production of maize, sowing is one of the most important operations because mistakes during sowing cannot be corrected later by other agrotechnical measures. The quantity of seed sown in a row and the distance between seeds are important factors in production, which have an impact on the uniform growth and development of plants and a stable yield. High-quality sowing implies a proper layout of seeds in depth and length with minimal damage to the seeds [12]. Maize can be sown with seeders with different sowing devices (mechanical or pneumatic) at a distance of 70 cm between rows. This distance can be bigger, but it is not good to increase it, because maize is sown in high densities of the assembly, so the more the distance between the rows for the same assembly increases, the distance between the plants in the row decreases. This increases plant competition and reduces the optimal use of vegetation space. Pneumatic seeders are widely used due to their advantages over mechanical seeders, such as better quality of work, more accurate dosing with lower seed damage, and better control and adjustment. When using mechanical seed meters, heterogeneous seeds can clog the delivery mechanism and damage the seeds, resulting in too few seeds being distributed to the soil, while imprecise metering devices can create unwanted skips or multiples within the row [18]. In addition to the sowing device, the uniformity of the seed distribution in the row is also influenced by the speed of sowing, the setting and functionality of the seeder, the terrain, pre-sowing preparation, and the shape and size of the seed material. The ultimate objective in precision maize seeding is to have the highest yield and this can be achieved by having a certain number of plants in a unit area [24]. The pneumatic seed metering mechanisms are responsible for capturing and ejecting the seeds uniformly, operating with variable seed size without damaging the seeds (which affects germination), should be robust, and use established and proven technology [14]. The precision sowing trend is a development of technology for sowing maize. The advantage of planting maize with precision seeder includes saving seeds, fewer working hours, and achieving more uniform spacing in the row and depth of planting, for these reasons it follows that the crop will be uniform in height and strength, which is a prerequisite for high yields [5, 22]. Precision sowing has been a major drive of agricultural engineering research for many years; however, most of the research and development work has dealt with seeders for agronomic crops [8]. The correct distribution of seeds horizontally and vertically enables better germination and sprouting of maize and increases the yield [9, 13, 16]. The quality of maize sowing is the most significant factor that affects a high and high-quality yield and is expressed as a percentage of the achieved sowing spacing according to the standards ISO 7256/1 and 7256/2 [4]. Numerous field and laboratory methods have been developed for testing and evaluating the performance of seeders [10, 11, 15]. Since locating the sown seeds is difficult and requires a lot of time, the quality of the sowing is measured and calculated only after the crop has sprouted, since the achieved assembly is the main factor of successful and profitable production [17]. Seeders that are traditionally used for sowing maize have the function of copying the terrain, but the height of the seed ejection is conditioned by the construction of the sowing mechanism and the feeder itself [20]. The development and improvement of sowing devices are conditioned by the requirements for a wider range of continuous dosing, increasing the performance of seeders and the precision of the distribution of seeds of different sizes [6]. Sowing quality means required vertical (depth) and horizontal (spatial) spacing of seeds in the soil with minimal damage to the seeds. The spatial distribution of seeds (horizontal spacing) is given by the distance between the rows and the spacing of the seeds in a row [7]. The share of achieved distances of 0.5 - 1.5 with the seeder with overpressure is higher compared to the seeder with negative pressure 81.43 to 88.57 compared to 68.89 - 77.78% [21]. The pneumatic seeder with negative pressure achieved a very good quality of maize sowing in field conditions, bearing in mind that in the group of 0.5 - 1.5 required spacing, there were 94.34 - 97.64% of plants (QFI index), with values of open spacing > 1.5 from the theoretical (MISS index) in the range of 1.27-2.59, while the sowing depth was in the range of 5.40-5.65 cm [2].

The objectives of the research were to determine the quality of work of the tested seed drills depending on the defined parameters and to point out the advantages or disadvantages in the tested conditions.

2.MATERIAL AND METHODS

In the production conditions of South Banat - Banatsko Novo Selo during the year 2023 (44°58'05.1"N 20°45'33.4"E) tests of seeders with a pneumatic seeding device were carried out during maize sowing. The distribution of maize seeds along the length and depth was examined, depending on the defined parameters, with the Vaderstad Tempo T6 planter, which was designated as type A, and the SOLA Prosem K8, which was designated as type B. For sowing, seeds of the maize hybrid Pioneer P9911 and DEKAL 5092 with germination of 95% met the basic conditions of seeds in terms of germination and dimensions [23]. The planned layout was 73,000 plants ha^{-1} (row spacing 19.5 cm).

Table 1. Technical characteristics of tested seeders and test condition

Parameters		Seeder type	
		A Vaderstad Tempo T6A	B SOLA Prosem K8
Number of rows	[/]	6	8
Inter-row distance	[cm]	45 - 80	40-75
Working grip	[m])	4.20	5.60
Transport width	[m]	3.20	4.70
Weight of empty seeder	[kg]	2200	1920
Volume of the seed bunker	[*l*]	70	50
Type of seeder apparatus	[/]	Pneumatic, overpressure	
Type of deposer	[/]	Disc	
Power needed	[kW]	>80	>88
Auto pilot	[/]	T - TrimblGFX-1060; S - Vederstat	T – Trimbl GFX-1060
Sowing date	[/]	29.04.2023.	
Soil type	[/]	Czernozem	
Length of the plot	[m]	385	
Pre sowing tillage	[/]	Plowing, harrowing with heavy harrow 2 x	
Previous crop	[/]	Maize	Sunflower
Maize hybrid	[/]	Pioneer P9911	DEKAL 5092
Sprouting of the seeds	[%]	95	95
Theoretical in-row distance	[cm]	19,5	19,5
Planned sowing depth	[cm]	5-6	5-6
Planned layout	[plants ha^{-1}]	73.000	

The technical characteristics of the tested seed drills and test conditions are shown in Table 1. The data shown in Table 1 indicate that the examined seeders worked in similar production conditions, as well as that the sowing was done on the same type of soil. The quality of the work of the examined seeders was related to determining the spacing of the seeds in the row and the achieved sowing depth. The values of the achieved movement speed and other indicators were read in the tractor cabin from the display because the tractors were equipped with ISOBUS technology for the advanced exploitation of agricultural machinery. The layout of seeds in a row was evaluated based on ISO standards 7256/1 and 7256/2. It is expressed through qualitative indices, namely: MULT index (multiple indexes) - represents the percentage share of realized seed spacing in a row that is < 0.5 cm from the theoretical spacing, QFI index (quality of feed index) - represents the percentage share of realized seed spacings in a row that are >0.5<1.5 cm from the theoretical and MISS (miss index) which represents the percentage share of achieved seed spacings in a row that are > 1.5 cm larger than the theoretical spacing. Bearing in mind that finding the sown seeds is difficult, that it requires a lot of time, and that there is a high probability of the seeds being stretched, the quality of sowing is measured and calculated only after the crop has sprouted. The sowing depth was also checked after crop emergence, taking into account soil settlement. All values during the trial were read in 5 repetitions. The trial was performed in a completely random plan variant, and the obtained results were processed using the Microsoft Office Excel 2007 package.

Vaderstad Tempo T6A SOLA Prosem K8

Fig. 1. Tested seed drills for sowing maize (Photo by S. Barać)

3. RESULTS AND DISCUSSION

Tables 2 - 3 show the results of the realized longitudinal layout and depth of maize sowing according to the tested variants, depending on the defined parameters. Based on the obtained results, it can be noted that there was a significant influence of the defined parameters on the values of the qualitative indices, that is, on the quality of the longitudinal distribution of maize seeds in the row.

Thus, the highest average values of the MULT index (proportion of achieved seed spacing in the row in the group <0.5 compared to the theoretical) were obtained when sowing with a Type B seeder (SOLA Prosem K 8) and yielded an average of 3.43% at the speed of movement sowing aggregate of 7.83 km h^{-1}, while the lowest values of 1.05% were measured when sowing maize with a seeder type A (Vaderstad Tempo T6A) at a velocity of 11.97 km h^{-1}. Observed according to the investigated variants, the values of the MULT index were within the limits of 1.05 - 1.35% for the seeder type A, with velocity of 11.97 or 8.72 km h^{-1}, while for the seeder type B they were within the limits of 1.83 - 3.43%, velocity of 10.11 or 7.83 km h^{-1}. Analyzing the influence of the defined parameters on the achieved values of the QFI index (percentage of achieved seed spacing in the row in the group >0.5<1.5), it is observed that the highest average values of 96.29% were achieved when sowing maize with type A seeder at the velocity of the sowing aggregate of 8.72 km h^{-1}, while the lowest values of 89.10% were obtained when sowing maize with a type B seeder at the velocity of 10.11 km h^{-1}. The values of the QFI index according to the examined variants varied in the range of 92.11 - 96.29 % at a velocity of 11.97, i.e. 8.72 km h^{-1} for the seeder type A, while for the seeder type B they were within the limits of 89.10 - 93.24% at velocities of 10.11 or 7.83 km h^{-1} (table 2).

Tabela 2. Indexes of the achieved longitudinal distribution of seeds in the row of tested seeders

Seeder type	Velocity	Theoretical sowing distance	Achieved qualitative indices of seed layout in a row (Average)					
			MULT index		QFI index		MISS index	
	[km h^{-1}]	[cm]	≤0.5	Variation	>0.5<15	Variation	≥1.5	Variation
A	8.72	19.5	1.35	0.61- 1.83	96.29	95.27 - 98.67	2.36	1.25 - 3.17
	9.58		1.16	0.51 - 1.60	92.89	89.70 - 95.96	5.95	5.11 - 7.31
	11.97		1.05	0.55 - 1.43	92.11	88.87 - 93.90	6.84	6.59 - 9.11
B	7.83	19.5	3.43	2.24 - 5.61	93.24	95.20 - 98.67	3.33	3.80 - 6.01
	9.03		2.03	1.23 - 2.83	91.35	89.77 - 95.96	6.62	6.33 - 9.41
	10.11		1.83	1.00 - 2.55	89.10	88.87 - 93.91	9.07	8.03 - 10.08

When it comes to the values of the MISS index - the share of open spaces >1.5 of the theoretical, the highest values were measured with the seeder type B (SOLA Prosem K8) and amounted to an average of 9.07% at a velocity of 10.11 km h^{-1}, while the lowest values of 2.36% were achieved when sowing maize with a seeder type A at a working speed of 8.72 km h^{-1}. Analyzing the values of the MISS index for the examined seed drills, it can be concluded that those of the type A seed drill were within the limits of 2.36 - 6.84%, the velocity of 8.72 and 11.97 km h^{-1}, while the type B were within the limits of 3.33 - 9.07%, the velocity of 7.83 and 10.11 km h^{-1} (table 2).

The results of our research coincide with the statements made by other authors in their research [2, 4, 7, 12, 17, 21, 24].

Bearing in mind the obtained results, which are shown in Table 2, it can be noted that the seeder type A (Vaderstad Tempo T6A) achieved very good results in terms of the quality of sowing and the distribution of seeds in a row, which according to the ISO standard qualifies it to be included in the group of very good seeders bearing in mind that the value of the QFI index was in the range of 91.72 - 96.29%. When it comes to the seeder type B (SOLA Prosem K8), it is noticeable that this seeder also achieves good results in the regime of lower operating speeds because the QFI index was within the limits of 91.65-93.94% (velocities up to 9 km h^{-1}), while the results achieved at higher velocities than the above classify it as a moderately good seeder because the QFI index is 89.33, velocity 10.11 km h^{-1}, which leads to the conclusion that higher operating speeds are a limiting factor, where the optimal velocity for this seeder is in the range of up to 9 km h^{-1} for the observed area.

When it comes to the values of the MISS index, it can be stated that significantly lower values were obtained when sowing with a seeder type A (Vaderstad Tempo T6A) compared to a seeder type B (table 2). This is primarily explained by the fact that on the type A seeder, the owner subsequently adapted the device for additional covering of the seeds, because after passing the seeder and cutting the soil with the discs, open furrows remained, so the additional device ensured quality covering and covering of the seeds by embracing soil above the furrow with the seed, which was not the case with the type B planter.

Table 3 shows the results of the impact of changing the velocity on the realized depth of the maize sowing when sowing with the test seeders. Based on the obtained results, it can be seen that the velocity of the type A seeder was within the limits of 8.72 - 11.97 km h^{-1}, while the speed of the type B seeder was within the limits of 7.83 - 10.11 km h^{-1}.

When it comes to the achieved seeding depth compared to the planned one, it can be observed that with the increase in velocity, the achieved seeding depth decreased, but the decrease was within the defined criteria.

Table. 3. Velocity and achieved maize sowing depth

Seeder type	Velocity [km h^{-1}]	Planned depth [cm]	Achieved seeding depth Statistical indicators				
			Mean	σ	*Cv*	*Min*	*Max*
A	8.72	5-6	5.82	0.36	5.95	5.29	6.34
	9.58	5-6	5.37	0.65	12.08	4.15	6.02
	11.97	5-6	5.06	0.33	6.54	4.55	5.48
B	7.83	5-6	5.51	0.33	5.91	4.98	5.82
	9.03	5-6	5.10	0.57	11.29	4.02	5.73
	10.11	5-6	5.02	0.25	5.04	4.55	5.30

The largest seeding depth of 5.82 cm was measured when sowing maize with a seeder type A at a velocity of 8.72 km h^{-1}, while the smallest sowing depth was measured when sowing with a seeder type B at a velocity of 10.11 km h^{-1} and was 5.02 cm (table 3).

The results of our research are in agreement with the statements made by other authors in their research [2, 3, 4, 8, 13, 14, 15, 17].

4. CONCLUSION

Based on the obtained results, it can be concluded that the tested seeders operated in similar production conditions and that maize was sown on the same soil type. The defined parameters had a significant impact on the values of the qualitative indexes, that is, on the quality of the longitudinal distribution of maize seeds in the row. The highest average values of the MULT index were obtained when sowing with a type B seeder (SOLA Prosem K 8) and they were an average of 3.43%, while the lowest average values of 1.05% were measured when sowing maize with a type A seeder (Vaderstad Tempo T6A). The highest average values of QFI index of 96.29% were achieved when sowing with seeder type A, while the lowest average values of 89.10% were obtained when sowing maize with seeder type B. The lowest average values of MISS index of 2.36% were achieved when sowing with seeder type A, and the highest when sowing with seeder type B and amounted to an average of 9.07%. Seeder type A (Vaderstad Tempo T6A) achieved very good results in terms of sowing quality and seed distribution in a row, which according to the ISO standard qualifies it to be classified in the group of very good seeders, bearing in mind that the value of the QFI index was within the limits of 91.72 - 96.29. Seeder type B (SOLA Prosem K8) at a lower mode of working velocity also achieved good results because the QFI index was within the limits of 91.65-93.94 (working velocities up to 9 km h^{-1}), while the results achieved at higher working velocities at speeds above those classified as moderately good seed drills because the QFI index is 89.33, working velocity 10.11 km h^{-1}, which leads to the conclusion that higher working velocities are a limiting factor, while the optimal working velocities for this seeder are in the range of 9 km h^{-1} for the observed area. When it comes to the achieved seeding depth compared to the planned one, it can be observed that with the increase in movement speed, the achieved seeding depth decreased, but the decrease was within the defined criteria. The highest sowing depth of 5.82 cm was measured when sowing maize with a type A seeder, while the lowest sowing depth was measured when sowing with a type B seeder and it was 5.02 cm.

Acknowledgement: *This study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, Project No 451-03-68/2020-14/200116).*

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EFFECTIVENESS OF INSECTICIDES IN THE CONTROL OF CEREAL LEAF BEETLE *(OULEMA MELANOPUS)* USING AN UNMANNED AERIAL VEHICLE

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Abstract: *Modern management of sustainable agriculture requires fast information about the condition of cultivated plants and a quick response to unwanted phenomena such as the appearance of pests in crops. According to the areas on which it is grown wheat occupies the first place in Serbia while the European Union is the world's largest producer of wheat. However, the technology of wheat production is demanding, especially in extreme climatic conditions such as large oscillatory changes in temperatures and rainfall during the year. The appearance of insects in wheat crops can cause significant crop damage and yield reduction, especially if protection measures are not implemented in a quality manner, in a timely manner, i.e. in the initial stages of insect development. A pest that can cause a significant reduction in wheat yields is the cereal leaf beetle (Oulema melanopus). The cereal leaf beetle feeds on leaves that remain bitten in the form of stripes while the larvae bite only the upper layer, which leads to the appearance of white elongated lines. Due to the decrease in leaf mass, there is also a decrease in the yield of wheat. In Serbia, chemical protection of wheat is most often applied using field sprayers, which recently often show insufficient effectiveness in protecting wheat. Modern pesticide application techniques involve the use of unmanned aerial vehicles (UAVs). Their main advantage compared to conventional field sprayers is the achievement of higher performance as well as better distribution of pesticides on the targeted surface, which results in greater efficiency and flexibility. The aim of this research was to examine the effectiveness of insecticides in controlling the cereal leaf beetle using two different techniques, unmanned aerial vehicles and field sprayer. The insecticide that was used in this research with an unmanned aerial vehicle showed a good efficiency, namely 3 DPT - 49.86%, that is, 72.17% - 9 DPT.*

Keywords: *unmanned aerial vehicle (UAV), knapsack sprayer, cereal leaf beetle, efficiency chemical protection, modern techniques, insects.*

INTRODUCTION

Wheat (*Triticum aestivum*) is one of the main agricultural crops used in the food industry of Serbia, and also one of the most important food products worldwide. According to the data of the Republic Institute of Statistics, the total area sown under wheat in Serbia for the year 2022 was 665,718 ha, which is 6.1% more than in 2021 (RZS, 2023), while in Europe in the mentioned period the areas under wheat amounted to 62,823,491 ha (FAOSTAT, 2023). Ensuring high and stable wheat yields is one of the important factors for solving the problems of poverty and hunger in the world. During the growing season, wheat is attacked by a large number of pathogens and pests. The grain leech (*Oulema melanopus*) is one of the most economically significant insect pests that can directly affect the yield and quality of wheat grains (Milovac and Franeta, 2016). Damage is caused by adult insects and larvae feeding on the leaves of winter wheat. The greatest damage occurs if the flag leaf is damaged, which according to data from the Netherlands can result in a yield reduction of up to 95%, while that percentage is slightly lower in Central Europe (70%) (Császár at el., 2021). In the case of a stronger attack of this pest, there may be damage in the form of smaller or larger oases on the plots, and eventually drying of the entire list mass. Mass reproduction of grain leech is favored by wet and warm weather.

Suppression of grain leech can be carried out by various preventive agrotechnical measures, which include the cultivation of resistant varieties, the destruction of plant residues by deep cultivation of the soil, the application of crop rotation, as well as the optimal application of nitrogen fertilizers. However, the most common way to control grain leech is the application of chemical measures, which include the use of insecticides. These measures act on both the adults and the larvae of this pest. The damage threshold for adults is from 8 to 15 larvae per m^2, while for larvae the damage threshold is from 5 to 10 larvae per m^2, i.e. 1-2 larvae per plant (Milovac and Franeta, 2016). Of the insecticides for these purposes, compounds from the parathyroid group are most often used. The timely and high-quality application of insecticides is of great importance for the successful control of grain leech. Suppression of the imago is carried out when its number reaches the specified damage threshold in order to prevent massive egg laying. However, the use of insecticides is usually aimed at controlling the larvae when they are in the younger larval stages. Insecticides are applied using agricultural sprayers, which can be backpack sprayer, tractor-mounted boom sprayer and self-propelled. Nevertheless, based on the conducted tests of sprayers used in our country, it was shown that they largely do not meet the prescribed technical parameters. Malfunctions that occur on these sprayers, which significantly affect the quality of pesticide application, are the flow of the pump and nozzle, as well as the correctness of the manometer. The flow rate of the pump and nozzle is often either higher or lower than prescribed, most often due to the long use span of the sprayer (Bošković et al., 2019). On the other hand, manometers often show pressures that deviate from the set values (Bošković et al., 2021). According to the agricultural census from 2012, the percentage representation of sprayers older than ten years in relation to the total number of sprayers in the Republic of Serbia is 82% (RZS, 2012), which indicates the stated problem of sprayer weariness. In addition to the correct selection of appropriate pesticides, it is necessary to pay attention to the adequate time of application and its correct application that is, the selection of appropriate technical systems for application (Pajić et al., 2019).

In recent years, the unmanned aerial system (UAV) for crop protection has developed rapidly in the world, not only technically but also in the field of practical application. Also, the safety and accuracy of UAVs has improved significantly with the introduction of obstacle avoidance and terrain tracking technology. As one of the main advantages of pesticide application using unmanned aerial vehicles, an increase in work efficiency of about 0.8 - 2.8 ha h^{-1} is stated (Zhang et al., 2021). Another important advantage of such a system is the absence of operator exposure to the harmful effects of pesticides.

Previous research has mainly focused on examining the influence of the operating parameters of the UAV on the effectiveness in controlling diseases and harmful insects such as aphids, while there is almost no data on the effectiveness of insecticides applied by UAV in the control of grain leech. The objective of this study was to investigate the effectiveness of insecticides in controlling *O. melanopus* using an UAV.

MATERIAL AND METHODS

The experiment was conducted at the location of Busije (Zemun municipality) (GPS: 44° 54′ 58″ N, 20° 13′ 34″ E, altitude: 66 m). Basic tillage was done on the plot to a depth of 20 cm, with the addition of NPK mineral fertilizer formulation 6:24:12 in the amount of 300 kg ha^{-1}. After the basic one, additional tillage of the soil was done, followed by pre-sowing preparation and finally the marking of the experimental field. Wheat sowing was done with a pneumatic seeder, on October 21st, 2022. The sowing rate was 240 kg ha^{-1}, while the pre-crop was corn. The wheat variety was Sofru-RWA. The wheat crop was supplemented with mineral fertilizers three times during the experiment.

In the experiment, a total of six treatments were set up in which the effects of two insecticide application techniques were examined, i.e. the application of insecticides using an UAV at different heights and speeds, as well as the application of insecticides using a conventional tractor sprayer. Table 1 shows data on treatments and applied technical systems.

Table 1. Overview of treatments tested in the trial

Treatment	Technical system	Work parameters
T1	UAV	h= 1 m; v= 3 m s^{-1}
T2	UAV	h=1 m; v= 5 m s^{-1}
T3	UAV	h= 2 m; v= 3 m s^{-1}
T4	UAV	h= 2 m; v=5 m s^{-1}
T5	Field sprayer	b = 21 m; v=5 m s^{-1}
T6A** and T6B	Control	Without chemical protection

*h – flight height; v – movement speed; b – spray width

**A – control for an unmanned aircraft; B – control for the field sprayer

The experiment was set up according to a partially adapted EPPO method (EPPO STANDARDS, 2005) for testing the effectiveness of insecticides in controlling grain leech (*Oulema spp.*) on winter wheat grains (PP 1/236 (1)). The size of the experimental field was 10,200 m^2, while the area of one experimental plot was 1,200 m^2 (20 m x 60 m). A buffer zone of 10 m was left between treatments as a protective zone to avoid the occurrence of drift effects (Wang, 2019). The insecticide used in the experiment was Deltamethrin (Decis Expert, 100 g l^{-1} a.i., Bayer, Germany) in the amount of 0.075 l ha^{-1} with the addition of the wetting agent Inex (fatty alcohol ethoxylate 20.3%, polydemethylsiloxane 1.0%) in the amount of 1 ml per 1 l of water. The treatment rate was 30 l ha^{-1} for the UAV, or 200 l ha^{-1} for the field sprayer. Treatments were carried out in the flowering phase of wheat (BBCH 61), more precisely with a field sprayer on May 9th, 2023, and with an UAV on May 16th, 2023.

The field sprayer (Kubota - iXtrack T3) used in the experiment has a working width of 21 m and a tank volume of 2,600 l. Lechler IDKT 12005 sprayers were used on the field sprayer. The working parameters of the sprayer were: speed of movement 5 m s^{-1}; system operating pressure 0.8 MPa; treatment rate 200 l ha^{-1}. The UAV sprayer (DJI T30, Shenzhen DJI Innovation Technology Co., Ltd., China) used in the experiment has a working width of 6 m and a tank volume of 30 l. The Jeet XR11001 nozzle was used on the UAV sprayer. The operating parameters of the UAV sprayer were: flight speed (v = 3 m s^{-1}; v = 5 m s^{-1}); flight altitude (h = 1 m; h = 2 m); system operating pressure 0.5 MPa; treatment rate 30 l ha^{-1}. Table 2 gives a detailed description of the technical characteristics of the UAV. The flight parameters of the unmanned aerial vehicle (altitude and speed) in the test were optimized based on previous research.

Table 2. Technical characteristics of the unmanned aerial vehicle

Characteristics	**Parametres**
Dimensions (mm)	2858 × 790 × 2685
Number of sprayer	16
Tank capacity (l)	30
Working width (m)	4 – 9 (5)
Type of the sprayer	TJeet XR11001
Flow (l/min)	7,2
Droplet diameter (µm)	130-250
Flight time with empty tank (min)	20,5
Flight time with full tank (min)	7,8

Effectiveness of insecticides - The effectiveness of insecticides was determined based on the number of grain leech larvae in the treatments. Assessments of the number of larvae were performed in three terms: immediately before treatment (NPT), three days after treatment (3 DPT) and nine days after treatment (9 DPT). In all evaluation periods, 100 upper leaves of wheat were examined by random selection within the experimental plot and the number of grain leech larvae was determined. The effectiveness of the insecticide was determined according to the Henderson-Tilton formula.

Figure 1. Unmanned aerial vehicle in operation

Meteorological conditions - During the experiment, meteorological parameters were monitored, which included the measurement of temperature and air humidity (Voltcraft DL-140TH), as well as wind speed (Testo 410i Smart Probe). The mentioned devices were placed at the height of the flight of an UAV, i.e. at 1 m and 2 m above the crops, in order to be in harmony with the height of the flight of of an UAV (table 4 and 5).

Yield monitoring - The analysis of yield parameters (morphological characteristics and yield) was carried out in laboratory conditions by taking 20 samples in five repetitions, a total of 100 samples from each experimental plot, where the sample was represented by wheat plants from an area of 1 m^2**.**

RESULTS AND DISCUSSION

Table 3 shows the values of average temperature and amount of precipitation for April, May and June 2023 for the area of Busija. Based on these data, it can be seen that during the month of May there was slightly more precipitation with optimal air temperatures, which favored the accelerated development of grain leech.

Table 3. Average values of meteorological parameters for the period April - June (2023)

	April	**May**	**June**
Average temperature (ºC)	11,2	17,4	21,8
Amount of precipitation (mm)	79	92,8	75,6

*****(RHMZ)

Table 4. Values of meteorological parameters at the time of treatment with a field sprayer

Date	**Temperature (℃)**	**Wind speed (m/s)**	**Air humidity (%)**
16.05.2023.	22	3	85

Tables 4 and 5 show the mean values of meteorological parameters that were monitored during chemical treatments. During the period of chemical protection with an UAV, the temperatures were slightly higher than the recommended temperatures for chemical protection, but the wind speed was optimal for the application of the mentioned insecticide. The meteorological parameters that were monitored during chemical protection with the filed sprayer were within the limits recommended for the performance of chemical protection and the successful adoption of insecticides.

Table 5. Values of meteorological parameters at the time of performing the treatment with an UAV

Measurement hight(m)	Temperature (℃)	Wind speed (m/s)	Air humidity (%)
1	30,2	0,96	44,9
2	30	1,05	46

Table 6: The numerosity of grain leech larvae NPT, 3DPT and 9DPT and the effectiveness of the applied insecticide (May 2023)

Treatments	Evaluation time	Average number of larvae per leaf	Efficiency (%)
T1 (UAV) (h= 1 m; v= 3 m s^{-1})	**NPT**	**1.57**	**-**
	3DPT	**1.06**	**49,86**
	9DPT	**0.67**	**72,17**
T2 (UAV) (h= 1 m; v= 5 m s^{-1})	**NPT**	**0,96**	**-**
	3DPT	**0.78**	**39,67**
	9DPT	**0,45**	**69,43**
T3 (UAV) (h= 2 m; v= 3 m s^{-1})	**NPT**	**0,94**	**-**
	3DPT	**0,82**	**35,22**
	9DPT	**0,43**	**70,17**
T4 (UAV) (h= 2 m; v= 5 m s^{-1})	**NPT**	**0,8**	**-**
	3DPT	**0,76**	**29,46**
	9DPT	**0,38**	**69,02**
T5 Field sprayer	**NPT**	**0,87**	**-**
	3DPT	**0,96**	**25, 05**
	9DPT	**1.0**	**36,34**
T6a control for UAV	**NPT**	**0,75**	**-**
	3DPT	**1.01**	**-**
	9DPT	**1,15**	**-**
T6b control for field sprayer	**NPT**	**0,72**	**-**
	3DPT	**1,06**	**-**
	9DPT	**1,3**	**-**

The number of grain leech larvae in control treatments immediately before treatment (NPT) ranged from 0.72 to 0.75 per plant. In the other investigated treatments, the number of larvae in the assessment before treatment was between 0.87 and 1.13 larvae per plant. The results of the experiment indicate that the application of insecticides using an UAV gave better effects in suppressing the grain leech compared to the application with a field sprayer. Thus, in the 3DPT evaluation, the efficiency of deltamethrin applied by means of UAV at a height of 1 m and a speed of movement of 3 m s^{-1} (T1 treatment) was 49.86%, while the 9DPT efficiency was 72.17% (Graph 1). In the second treatment where deltamethrin was applied using a UAV at a height of 1 m and a speed of 5 m s^{-1} 3DPT achieved an efficiency of 39.67%, while 9DPT efficiency increased significantly and reached 69.43%. The same insecticide applied using a UAV at a height of 2 m and a speed of 3 m s^{-1} (treatment T3) 3DPT had an efficiency of 35.22%, while after the second assessment, i.e. 9DPT, the efficiency was 70.17%. In the treatment where deltamethrin was applied by UAV at a height of 2 m and a speed of movement of 5 m s^{-1} (T4 treatment), the efficiency ranged from 29.46% (3DPT) to 69.02% (9DPT). On the other hand, application with a field sprayer was significantly less effective in controlling *O. melanopus* compared to application with an UAV vehicle in both evaluation periods. Thus, the efficiency of deltamethrin applied with a field sprayer in the 3DPT evaluation was 25.05%, while the 9DPT efficiency was only 36.34%, which indicates that there is a problem with this technical system.

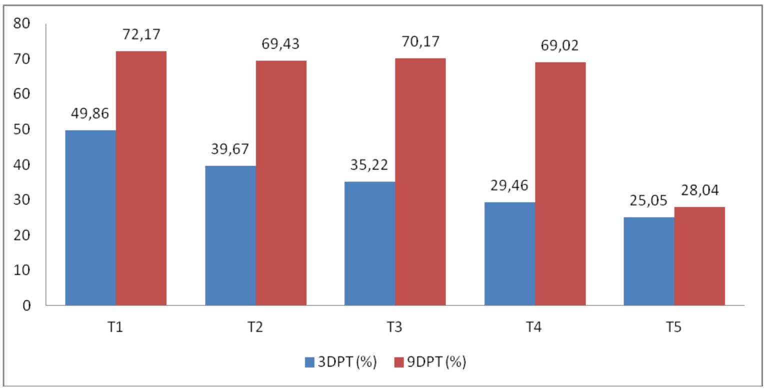

Figure 2. Effectiveness of insecticide applied by different technical systems

Many studies have shown that the application of pesticides using UAV has achieved good effectiveness in controlling harmful insects. Thus, Lou et al. (2018) found that the effectiveness of insecticides in controlling aphids was 63.7% and 61.3%, respectively, in controlling mites on cotton when the flight height was 1.5 and 2 m. Also, Wang at el. (2019) state that the effectiveness of insecticides in controlling aphids on wheat applied by UAV system is about 70.9%. On the other hand, Malschi (2003) states that the effectiveness of deltamethrin in controlling *O. melanopus* ranged from 93-96.6%. Trials conducted in 2008, 2009 and 2010, the effectiveness of insecticides from the pyrethroid group in controlling grain leech ranged from from 70.3 to 87.2% (Kaniuczak, 2013).

In general, the effectiveness of the applied preparationwas not satisfactory, so that, from a practical point of view, its application does not ensure complete protection of the wheat crop from grain leech. As one of the reasons that can contribute to a slightly lower efficiency are the favorable meteorological conditions that contribute to the rapid and unhindered development of grain leech during the spring. In addition, one of the reasons stated can be the intensive application of agrotechnical measures, first and foremost, supplementing with mineral fertilizers in order to ensure a high yield, which at the same time influence the intensive development of the pest. However, the effectiveness of the insecticide can be affected by the technical parameters of the treatment device itself, such as droplet size, distribution, deposition, drift, etc. For now, the mentioned parameters have not been tested for the devices that were used in the trial, so it is necessary to test the mentioned parameters in the following period. In their research, Zhang et al. (2021) proved that the height and speed of flight affect the uniformity of droplet deposition. In addition, for UAVs with multiple rotors (multi rotors), the influence of height and flight speed on the width and speed of droplet penetration was investigated, and it was proven that the flight speed significantly affects the effective width of the drone. Also, the best deposition of droplets at the base of rice plants was at a flight speed of 5 m s^{-1} and a height of 1.5 m. In order to achieve better effects in controlling pests in wheat crops, Wang et al. (2019) suggest the use of larger droplets as well as a higher rate of treatment. Finally, the potential development of resistance of grain leech populations to insecticides may be the reason for the poor efficiency. Considering the long history of application of parathyroid-based compounds in wheat crops, it should be investigated whether there has been a change in the sensitivity of *O. melanopus* populations to the mentioned group of insecticides.

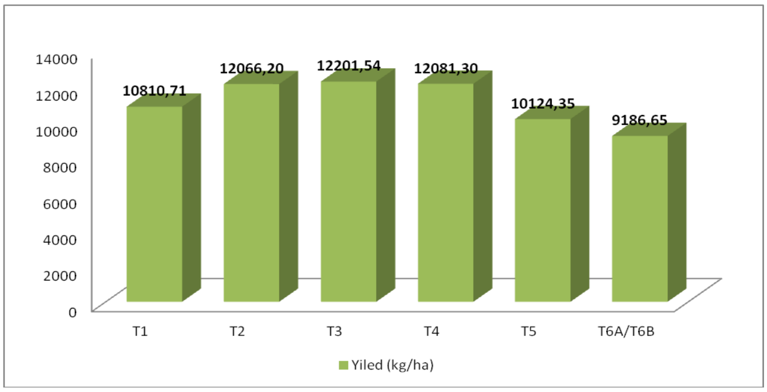

Figure 3. Wheat yield by treatments based on grain mass calculated at 14% moisture

In terms of yields (Figure 2), a significant difference can be observed in the yields achieved in the treatments where chemical protection was performed compared to the control (T6A/B). The highest yield, 12201.54 kg ha^{-1} was achieved in the T3 treatment, while the lowest yield was measured in the control and was 9186.65 kg ha^{-2}, i.e. in the T3 treatment the yield was higher by 24.7% compared to the T6A/B treatment. After the control, the lowest yield was achieved in the T5 treatment, 10124.35 kg ha^{-1}. In treatments T2 and T4, approximately the same yield was achieved, 12066.20 kg ha^{-1} and 12081.30 kg ha^{-1}, respectively, which is 23.86% and 23.95% more than in the control treatments. In treatment T1, the yield was 10810.70 kg/ ha^{-1}. The reason for the lower yield achieved in treatment T1 may be a slightly higher number of larvae immediately before treatment compared to the other treatments, which resulted in greater damage to the leaf and reflected on the yield itself.

CONCLUSION

The results of the research in this study show that there is a tendency for the efficiency of pesticides to increase with the application from the UAV system, but that it is first necessary to examine the influence of the operating parameters on the final efficiency. The above results show that the application of insecticides using an UAV achieved better effects in protecting wheat from grain leech compared to the conventional application using a field sprayer. In order to achieve the best protection effects, it is necessary to choose the appropriate operating parameters of the UAV system depending on the type of crop and the phenophase of development, then the type and developmental stage of the harmful agent and the conditions of the external environment.

According to our results, the best effectiveness in suppressing grain leech larvae was achieved by applying insecticides using an UAV at a height of 1 m and a flight speed of 3 m s^{-1}. Also, it can be concluded that the better efficiency of the insecticide was achieved at a flight speed of 3 m s^{-1}, while the height had no significant effect. However, the obtained results are applicable only for the type of UAV used in this research. Different types of UAVs may have different characteristics (such as single and multi-rotor UAVs), which may affect the quality and effectiveness of chemical protection, therefore systematic research should be conducted to determine the optimal combination of parameters. Future research should be focused on the relationship between the operating parameters of the UAV system, the crop structure and the air current of the UAV system and their influence on the effect of deposition and distribution of droplets.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

MOBILE SMARTFARMOWL – A PROJECT SUPPORTING THE PROCESS OF DIGITALISATION FOR GERMAN FARMERS

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Abstract. *Many German farms are using tools like apps, digitally supported animal welfare or application maps for their farm machines. Nevertheless it has to be stated that most of the farm processes are still operated in a non-digitalised way. On the other hand politics asks more and more for a reduction of chemical plant protection or fertilizer in outdoor work resulting in new regulations which have to be fulfilled by the farmers. This demand for a smaller environmental impact and footprint can be implemented focusing on the individual demands of livestock and field plants and by using tools of digitalisation and state of the art agricultural machines. In order to support farmers on their transformation process towards more digitalisation, the project Mobile SmartFarmOWL has been started in spring 2021. Its main goal was to support farms and farmers in their transformation process for outdoor work and is accomplished by training, consulting, processional networking and a basic starter kit of data. The project core team is composed of the Federal Chamber of Agriculture, a regional business development council, SME companies and the University of Applied Sciences and Arts Ostwestfalen-Lippe and complemented by 60 farms and 15 agricultural SMEs in the region Ostwestfalen-Lippe, which is part of the federal state of North Rhine Westphalia in Germany. This paper describes the initial situation and the approaches and tools developed by the project team to support the farmers and SMEs on their way towards the application of more digitalisation. Furthermore, some products like training courses and preliminary results with respect to the acceptance of the proposed tools and the ways the farmers have made use of the training, consulting and data support are presented. The impediments of digital transformation for farmers in the outdoor work business is discussed briefly. As the projects ended in June 2023, a recommendation will be given for future work both from the project and the farmer's point of view.*

Key words: transformation process, digitalization, e-learning platform, agriculture

1. INITIAL SITUATION AND OBJECTIVES

Despite the fact that Germany is known as an industrial country, approx. 50 % of its area is used for agriculture. This holds also for the federal state Northrhine Westphalia (“NRW”) which includes the highly populated Ruhr region as well as several rural parts. Ostwestfalen-Lippe („OWL“) as a part of NRW is characterized [1] by a successful automation industry, research institutes and higher education institutions, but also known for its wood and furniture and food industry. Most of the companies are SME. A basis for the latter is the regional agriculture which contributes considerably to the food and ressources production. The primary sector in OWL plays with a contribution of 0.9 % an above-average role if compared to the federal state NRW or Germany and also the part of employers is above-average. The landscape is characterized by heterogeneity. Mountain regions up to 400 m above sea level divide the region into several areas with different soil types, elevation structures and micro climate and therefore the agriculture can grow a variety of field crops, vegetables and fruits. The annual precipitation is approx. 1000 mm near the mountain ranges and 750 mm in the regions shaded by the mountain ranges. The prevailing types of landuse are agriculture (67 %) and forest (21 %). The size distribution (Figure 1) of the approx. 7.000 farms in OWL is comparable to the federal state [2]. The value chain of the region related to agriculture is accomplished by Agricultural machinery makers, agricultural traders, a variety of food processing companies and biogas plants.

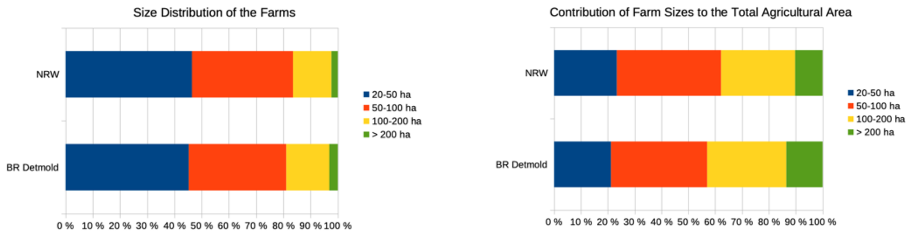

Figure 1: Distribution of the farms in the German region of Ostwestfalen-Lippe (OWL), left, and contributions of the darm sizes to the total agricultural area (right).

The strategy of the region OWL[3] includes, e.g. the transfer of digitalization into SME, the establishment of networks of competences, the safeguarding of skilled employers and the transfer and communication of successful solutions for the before mentioned fields of action. The project Mobile SmartFarmOWL aimed to contribute to the OWL strategy in these fields of action by focusing on farm related digitalization and the conditioning of the farmers to use digital workflows. This is achieved by

- the introduction and advancement of digital farming processes
- provision of material for self-regulated learning
- provision of agricultural data starter sets
- organization of professional networking events for farmers and farm related companies
- offering farm specific agricultural consulting based

As a consequence, the project was more a transfer than a research project.

The structure of the following paper includes a description of the methods applied in the project, the implementation of the above mentioned goals and the results achieved by the implementation and finishes by a short discussion.

METHODS AND COURSE OF ACTION

The chamber of agriculture of the federal state NRW is – among other duties – responsible for agriculture related consulting and monitoring and therefore closely cooperates with the farms in OWL. Therefore they opened a call for farmers to participate in the project. Approx. 100 farmers responded to this call and were invited to an initial information event and online survey, finally 60 of them expressed their interest for the participation (for their locations see Figure 2). In order to regulate the bilateral duties, each farmer signed a contract. One of the main objectives of this contract was the definition of the data ownership. According to the contract, the field related data acquired by the project team is owned by the farmer and the farms grants the right to analyse the data to the project team. The process of signing the contract with all participating farmers was lengthy, but made the data handling process clear and easy to implement.

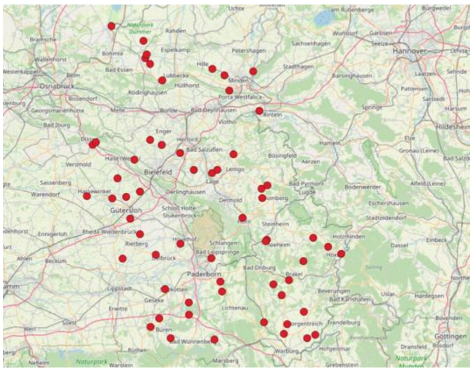

Figure 2: Distribution of the participating farms in the regions Ostwestfalen-Lippe. All farms are within a radius of appriox. 50 km.

In order to prepare a draft for the project's implementation, an online survey was used to ask for data characterizing the individual farms and farmers including, e.g.

- area of arable and grass land
- cultivated crops
- focus of the production (e.g. animal, crop production, biogas plants)
- restraints, e.g. conservation areas, areas with hillslopes or nitrate pollution
- machinery in operation
- digital processes and software
- higher educational qualification
- age of the managers
- preferred advanced training offering
- topics for an advanced training
- preferred method of learning

The results were analysed in order to plan the data acquisition, the agro consulting and the advanced training courses. For the online training, the didactical design was worked up and formed the basis for the online courses. A screenplay template for the newly created videos was developed in order to create a consistent user experience and a quality monitoring was established for the ensemble of the advanced training materials.

As the first year of the project was affected by the Corona pandemic, the project activities and trainings had to be adopted to the corresponding constraints. Instead of the face-to-face training, a new format called "Mobile Wednesday" had to be established which included online presentations and discussions and nearly half of the farmers attended the meetings. After a few months, a group of companies belonging to the agricultural value chain was established and also attended the online meetings. The content of the presentations were related to the topics the farmers had asked for in the online survey and additional topics that showed up as part of the agro consulting and the data acquisition on the farm land.

The contents of the training material was provided by the open source e-learning software ILIAS [4,5]. For additional information related to digital teaching and learning, see [6,7] It was structured in order to provide three distinct perspectives for the project team, the participating partner farms and companies and the public. The project partners were trained with respect to the usage of the ILIAS e-learning platform and the creation of different types of content – usually short videos, static media like images or texts and pdf files. Furthermore online self-assessments were created and linked to the respective courses and contents. Finally, the partner farms and companies were trained to use the e-learning platform.

The data acquisition for the farms were meant to provide some kind of starter package of data. In order to provide sustainable data sets, the spatial resolution was much higher than usually applied by the farmers. The farmers could choose from satellite data, drone images (RGB, multispectral, hyperspectral, thermal) and LiDAR point clouds taken by a drone as well as soil data using state of the art chemical sampling and physical soil sampling technology [8]. The drone images were taken by a DJI P1 [9] RGB camera or – preferred – by a Sentera 6X [10] multispectral camera. The results and drone images were processed and analysed by Pix4Dfields [11] and the results exported into a cloud storage with specific access for each of the farms.

Implementation and Results

Online Survey: Charaterisation of the Farms and Farmers' intentions

The farms (n=65) were cultivating between 3 ha and 1050 ha, 54 as professional farming and 11 as part-time farming. 55 out of 65 farms have grassland and farmland, 10 focus on farmland cultivation. 2 farms do organic farming and 63 conventional farming.

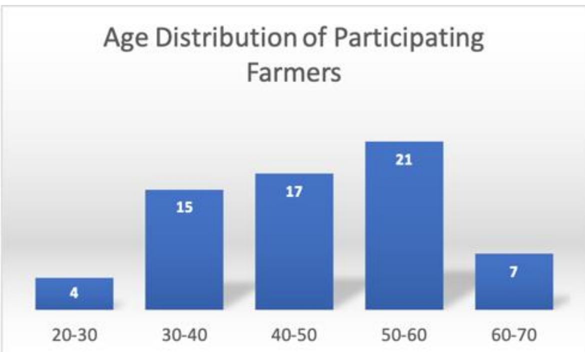

Figure 3: Age distribution of the participating farmers (n=65).

Apart from one woman, all the heads of the participating farms are men. The age distribution (cf. Figure 3) reveals the age interval of 50 to 60 was the most prominent one (21) followed by the intervals 40 to 50 (17) and 30 to 40 years (15). The intervals 20 to 30 years (4) and 60 to 70 years are less common which might be attributed to the required professional experience (interval 20 to 30 years) and to the decreasing interest for innovations in the last years prior to retirement (n=65).

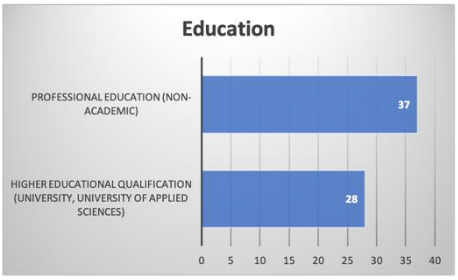

Figure 4: Highest educa.onal degree of the heads of the par.cipa.ng farms.

The highest educational degree (cf. Figure 4) was either an academic degree (university or university of applied sciences, 28 farmers) or a non-academic professional education (39 farmers) with n=65. The average part of academic degrees among farmers in the federal state of NRW is much smaller (13.3 % in 2020 [2]).

The question about the experience related to digitalization in agriculture revealed that most of the farmers had little or some experience with specific topics. Figure 5 also shows that for each topic there were at least some farmers that already had some experience with the respective topic which was a good basis for the experience exchange groups. On the other hand (not shown here), most of the farmers already had at least one farm machine which was ready for digital workflows.
In order to support the farmers in their digitalization training and progress, they were also asked about their preferred training.

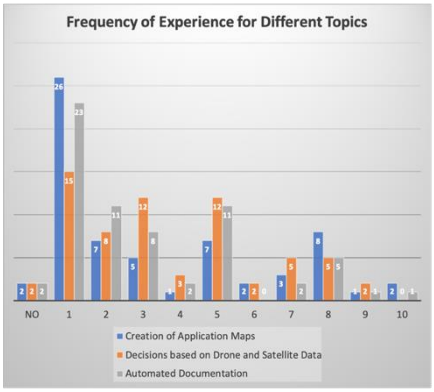

Figure 5: Experience of the farmers with selected topics related to digitalisation in agriculture. The level of experience could be expressed from no experience to 10 (all-encompassing experience).

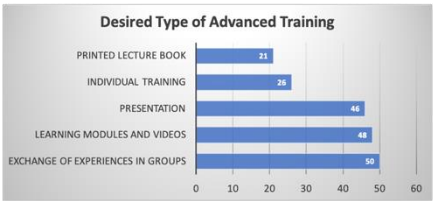

Figure 6: Desired type of the advanced training offered by the project (n=65).

The most desired type of advanced training (cf. Figure 6) was the exchange of experience in groups (50 out of n=65) followed by online training (48) and presentations (46). Individual training (26) and print media (21) was asked for rarely, so both types were dropped and the didactical design focused on presentations, online training and face-to-face exchange of experiences in groups.

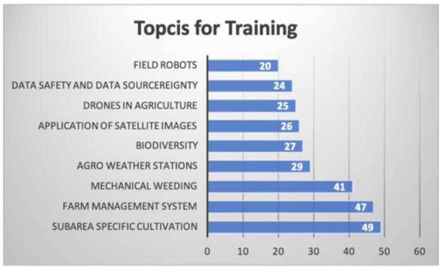

Figure 7: Desired topics for the digitalization training. Most of the farmers (n=65) asked for subarea specific cultivation, farm management systems and mechanical weeding.

The desired topics are shown in Figure 7. They reflect the most common topics from exhibitions and field days. In order to reach a high learning success, these topics have been transformed into learning modules, face-to-face or online presentations, hands on-training and agricultural extensions.

Online Courses and e-Learning Platform

Most of the online courses and training modules became available half a year after the online survey was analysed. Video training material was limited to runtimes of a few minutes. The “Drone Applications in Agriculture” module, e.g., consists of the following sub-modules:

- Types of drones
- Method of operation
- Application scenarios
- Suitable cameras
- Legal regulations
- Flight planning and preparation
- Flight operations
- Postprocessing and analysis of aerial images

accomplished by a self-assessment containing 12 tasks. The ILIAS learning management system provides several types of tasks, including, e.g., multipe choice, assignment and mapping, numeric answers, image based tasks or free text input. The farmers’ preferred period of learning was the winter time with the frequency of using the learning management system decreasing drastically at the end of the winter period.

Data Acquisition and Data Starter Package

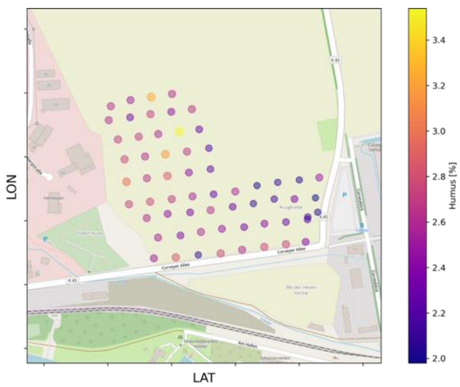

Figure 8: Humus content of the soil as seen by a FarmLab device on one of the arable areas of the project. The same area was also analysed based on satellite images and images taken during a drone flight.

For the data acquisition on the farm land, the farmers were asked about actual challenges and their preferences in order to closely relate the training, the data acquisition and their daily business. They usually named 3 to 5 areas of arable land. Depending on the season of the year, different methods and procedures were applied by the data acquisition team and either basic nutrients or nitrogen concentrations were analysed and drone images taken. The FarmLab device provided complementing as well as comparison data, c.f. Figure 8.

Figure 9: Image locations (left) from a drone flight and zone maß (right) as derived from the multispectral images. The zonation file can be used as an input for the agricultural machines.

The workflow for the multispectral aerial images take by the drone starts by selecting and stitching the images resulting in an orthomosaic image. From the 5 channels (red, green, blue, NIR, red edge and the RGB image, a digital elevation model (DEM) and several vegetation index images were created. The vegetation index image was used to create zonation files which were transformed into a shapefile suitable to be used by most of the agricultural machines, cf. Figure 9.
Some of the farmers had specific tasks during the project. One of the farmers, e.g., had applied different types and quantities of fertilizer in a field of corn and asked for an estimation of the crop height as a measure for the biomass. For this task, the project team performed drone flights with a scanning LiDAR and RGB images in order to provide suitable data for the answers.

Consultations by the Chamber of Agriculture

Farm specific aerial images and satellite images were used by the consultants of the chamber of agriculture to introduce and train the process of subarea cultivation. In order to display and discuss the aerial images and derived products, the open source geographic information system QGIS [11] was introduced as it is widely used among German farmers and related communities.
In the second winter season of the project, several training meetings were organized in different parts of the project region. Each time, one of the farmers was host of the event. The training meetings were meant to build up hands-on-experience. Therefore, the groups were small with up to 6 farmers, see Figure 10. The farmers were trained to use, e.g., a drone to take aerial images, the FarmLab device to analyse the soil or a RTK system to find border stones. The hands-on-traing was complemented by experience exchange discussions.

Figure 10: Photo taken during a meeting for training and exchange of experiences. Topics included, e.g., physical soil sampling or drone operation.

Aspects of Project Sustainability

The project partners have agreed to continue their work towards more digitalization in agriculture. The federal chamber of agriculture continues to use their online training material for their training activities. The University of Applied Sciences Ostwestfalen-Lippe offers their training modules as part of the study programme Precision Farming and continues their airborne and ground based measurements in cooperation with the farmers.

DISCUSSION AND OUTLOOK

The project aimed to introduce more digitalization for approx. 60 farms in the region Ostwestfalen-Lippe located in the center of Germany. This was accomplished by providing online training courses, professional networking, consultation and hands-on-experierence. Due to the Corona pandemic, the initial phase of the project was characterized by more online meetings than face-to-face meetings, but the newly developed formats of training and exchange turned out to be successful. As a consequence, the farmers expressed their interest to continue the work and training. The project partners will continue to provide their training materials and – at least on a smaller level – the measurements as part of education and on-farm-research and the consultations.
Accompanying research was performed by the University of Göttingen. Its main scope was the change in the life of farmers due to digitalization. Results will be published elsewhere.

Acknowledgement

This work was funded by the Federal State of North Rhine Westphalia and the European Union (European Fonds for Regional Development, grant 34.EFRE-0300241).

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RISKS IN TROUT AQUACULTURE IN SERBIA, BOSNIA AND HERZEGOVINA AND NORTH MACEDONIA

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Abstract. *Trout farming is conducted in various aquaculture systems all over the world. Significant risks and uncertainties are connected with trout aquaculture, and they can play a decisive role in the production and financial results of trout farming. This article deals with risks in trout aquaculture in Serbia, Bosnia and Herzegovina and North Macedonia. The analysis has shown that there are numerous risks and that they are specific to the culture system and the farm's location. There are also some differences in risks between analyzed countries. It is advisable to include risk analysis in any future trout farming investment in all countries.*

Key words (bold): *trout farming, risks and uncertainties*

1. INTRODUCTION

Trout farming is organized in different culture systems under various natural, social, business, etc., conditions all over the world. Trout and other salmonid fishes are raised in different intensity systems, from very extensive to super intensive. Various risks and uncertainties are connected with trout farming, which can have a decisive role in the success or failure of investments in trout farms. Those risks and uncertainties depend on many factors, such as intensity level, natural conditions for production, subsidies policy in the country, export and import rules, etc.

All factors influencing the production and economic parameters of trout farming could be seen as certain, risky and uncertain. Apart from the certain factors which are constant, it is very important to be aware of the potential impact of risky and uncertain factors, especially when the decision about investing is about to be made.

In the Republic of Serbia, the Republic of North Macedonia and Bosnia and Herzegovina, rainbow trout are raised in different farming systems, which include cages, concrete raceways and plastic tanks. Rainbow trout fry and fingerlings are bred in plastic and concrete tanks, and bigger fingerlings, pre-consume-size fish and consume-size fish are usually farmed in concrete raceways and cages. This production is sometimes conducted under very different conditions, which differ between countries, farming systems and individual farms (Canak et al, 2022, Savić et al, 2017).

It is important to understand the terms of risk and uncertainty and the difference between them. There are various definitions of risks. Risk is defined as the case where the distribution of outcomes is known either a priori or statistically through experience. Uncertainty is the case where probabilities of outcomes of some event cannot be quantified (Knight, 1921). It should be underlined that the mentioned risk probabilities are often subjective and depend on the person who evaluates them (Hardaker, 2016). According to another source, "risk is the effect of uncertainty on objectives" and can be positive and negative (ISO 31000).

When discussing risks in agriculture, there are five primary types to differentiate between: production, market, institutional, personal, and financial risks (Komarek et al., 2020). In the literature, the aquaculture risks are divided into the following seven categories: pathogen risks, food safety and public health risks, ecological (pests and invasives) risks, genetic risks, environmental risks, financial risks and social risks (FAO, 2009). In the same publication, risk is defined as "the potential occurrence of unwanted, adverse consequences associated with some action over a specified time period". The difference in definition and perspective for analysis also dictate the differences in the above-mentioned risk categories. In this paper, the authors use the definition and risk categories analyzed by Komarek et al.

From the past research and experiences, a need occurred to investigate the nature of risks and uncertainties in trout farming in more detail. This paper is part of the authors' research that should bring new insights into factors affecting production results and profitability of trout farming in a few Balkan countries and in general. This research mainly aims to identify risks in trout farming in the three analyzed countries, detect their origin and analyze differences between countries. Few research methods were used during the preparation of this paper, such as semi-structured interviews, telephone interviews, results from previous research and authors' personal experiences.

2. Risks in trout farming

2.1. **Production risks** include factors that could affect the growth and production results of trout farming in quantitative and qualitative terms. Production risks could be roughly subdivided into natural and technological-technical risks. In this category fall the following risks: trout genetic strain, natural conditions for trout farming, such as water quality and quantity, production system, occurrence of diseases in the country, water recipient or fish, risks of technical and constructional failure, extreme weather events, etc.

The genetic strain of rainbow trout is a variable that affects the speed of growth (specific growth rate) and feed conversion ratio. Farmers should know that eggs, fry or fingerlings of different genetic origins have various production and economic results. If the source and performance of trout are known, then this variable should not be considered a risk.

Water quality and quantity can be considered a risk if one or more parameters change over time. The most influencing water parameters for trout production are quantity, temperature, dissolved oxygen, turbidity, and content of CO_2 and NH_3. There are more critical water parameters in recirculating aquaculture systems (RAS), but RAS are not present in trout farming in Balkan countries.

Water quantity Q (l/s) available for flow through farms changes over the years and during one year. This fluctuation could be very high, and the quotient between maximal and minimal values could be as high as 10 or even higher. The importance of water quantity expresses itself through the amount of O_2 (g/min; kg/day) available for fish breathing and other metabolic processes, at first place. Together with water temperature the amount of available O_2 (g/min; kg/day) for fish is determined by water quantity and that amount can be 10 and more times lower during summer periods than in winter. It is essential to predict the possible range of water quantity, water temperatures and fish biomass in summer and to find solutions for oxygen depletion problems if needed. Water quantity fluctuations are more expressed for springs, streams and rivers than wells.

Water temperature T (°C) directly influences the growth of rainbow trout within the species-specific temperature range. Too cold water slows growth, and too warm water endangers fish health and survival. Water temperatures above 20°C represent a production risk for trout farming, and some measures should be planned when such situation occurs. Cold rains during summer can cause stratified lake water to turnover and cause fish mortalities on cage farms.

Water turbidity occurs after rainfalls. This is common for streams and rivers, but some springs become turbid after rains. Water turbidity represents a risk for egg incubation, alevins and fry health and can lead to mass mortalities. For bigger fish, this phenomenon usually does not mean higher risk.

A particular situation occurs after heavier rainfalls when water carries debris in the form of rotten and whole leaves and other organic material. This represents a risk for trout farming because leaves can clog the water supply system, leaving the tanks without sufficient water flow, which leads to mass mortalities. These situations usually occur during autumn on trout farms with water supply from streams and rivers.

Carbon dioxide (CO_2) in water can represent a risk for trout eggs, alevins and fry in spring water hatcheries. It has been shown many times that some springs periodically can have very high CO_2 content in water. This can lead to health problems and mortalities. Some safe measures should be planned to avoid elevated CO_2 (mg/l) concentrations, such as water aeration. Another case when CO_2 can occur is in high-intensity trout farming systems, such as partial (water) reuse aquaculture systems (PRAS) and RAS.

Ammonia (NH_3) is usually not a significant risk in typical farming densities. In serial water reuse systems such as raceways in summer (big biomass, high temperature, small water flow), in the lower farming tanks, NH_3 can reach higher concentrations and cause some gill problems. In PRAS and RAS farming systems, NH_3 concentrations represent production risk, which can occur from various reasons. In some springs and water from bored wells, NH_3 can have harmful concentrations.

It is very difficult to have a proper risk evaluation of extreme weather events that can influence trout production, such as floods, tropical temperatures, draughts, etc., especially when experiencing many more such events in the last decade. Some such events are still to be seen as uncertainties and some as risks. The perspective wholly depends on specific farm locations and climate history.

In Serbia, North Macedonia and B&H, trout are farmed in serial water reuse systems in concrete raceways and cages on lakes or rivers. There is one partial reuse aquaculture system (PRAS) in Serbia for rainbow trout fingerling production. The general rule is that production intensity also causes higher production risks. Higher rearing densities cause a higher risk of disease outbreaks. On cage farms, algae blooms cause the risk of fish poisoning and illness. Wherever aquaculture equipment is used for water pumping, water aeration and water oxygenation, the risk of electricity shortage or another technical failure should be carefully analyzed.

Disease presence in some water recipient (water source), country or region leads to a greater risk of disease occurrence for a specific farm. Various trout diseases cause different mortalities and treatment costs. Some diseases represent a significant risk for alevins and fry but not for bigger fish and conversely.

Considerable differences exist in natural conditions for trout farming in R. of Serbia, R. of N. Macedonia and Bosnia and Herzegovina. Trout farms in B&H are mainly located on streams and rivers with significant amounts of fresh and clean water. Many of them are supplied with water directly from springs. Water quality parameters for trout farming in B&H are mostly in optimal ranges. Many cage farms (>15) on lakes with good water quality also exist. Generally, trout farming in B&H is based on considerable amounts of high-quality water. The trout production in B&H is a few times bigger than in Serbia and N. Macedonia.

In Serbia, trout production is conducted in much smaller farms than in B&H, with only a few producing 100-300 t. Fluctuations of water quantity and quality are much more noticeable, with expressed problems of low water flow and high temperatures in summer months. Only one trout cage farm operates at the moment. A lot of equipment is used for water aeration and oxygenation compared to the other two countries. Most of the trout farms are located on streams far away from the spring and therefore faced with risks connected with floods, muddy and polluted water, etc.

In all three countries, production is mainly based on stocking material of domestic, Polish and American origin. Many fry and fingerlings are imported into Serbia from B&H each year. There are differences in the presence of significant trout diseases between countries. North Macedonia reported Infectious hematopoietic necrosis in rainbow trout to the World Organization for Animal Health (WOAH). This disease is listed as a nonexotic disease of the EU and is therefore monitored closely by the European Community and the Reference Laboratory for Fish Diseases (Cvetkovikj et al., 2020).

2.2. Market risks include price and cost changes and market access. In the last few years, there have been considerable changes in the aquaculture industry in general and in the three analyzed countries. Those changes were caused mainly by the Coronavirus pandemic and the war in Ukraine, which can be seen as uncertain and unpredictable events. The usual market risks in the trout industry in the Balkan market are market reduction based on an offer of cheap trout from other countries' big trout producers, higher feed costs for imported feed, eyed eggs, higher energy costs, etc.

When discussing the offer of cheap trout, Serbia and N. Macedonia are threatened with import from Albania and Turkiye, and Bosnia is not. With large quantities of high-quality trout, Bosnia represents a threat and risk for variations in wholesale prices in Serbia and N. Macedonia. Serbia and N. Macedonia are countries that import a lot of trout.

The risk of higher electricity costs is much higher on farms that use a lot of equipment than on cage farms or simple flow-through farms.

The risk of higher transportation costs could be much higher for Bosnia because their big trout producers are forced to export significant quantities abroad.

Generally speaking about farm size, big producers have to transport and sell to distant markets, and small trout producers usually can sell on the farm.

2.3. Institutional risks come from changes in the policies and regulations that affect agricultural production, e.g., trout farming. Institutional risks are mostly not under farmers' control, and farmers have minimal influence. This risk category includes changes in subsidy policies, export and import regulations, and veterinary, agricultural and ecological regulations that affect trout farming.

Huge differences do exist between the three countries regarding subsidies for table-size trout. In Serbia, there are subsidies for table-size fish in an amount of 0.085€/kg (Official Gazette RS", no. 139/22), but it is not sure that all applied amounts will be paid.

In Bosnia and Herzegovina (Republic of Srpska and Federation of Bosnia and Herzegovina) different subsidies do exist, in the Republic of Srpska for table size trout the subsidy is up to 0.256 €/kg, and for the production and sale of trout fingerlings it is up to 0.818 €/kg ("Official Gazette" of the Republic of Srpska, no. 11/23), while in the Federation of Bosnia and Herzegovina for freshwater fish subsidy amounts to 0.92 €/kg (Official Gazette of the Federation of Bosnia and Herzegovina, no. 30/23).

In North Macedonia, a financial support of 35 million denars is allocated for aquaculture, covering 50 percent of the investments, providing assistance for fish breeding material equivalent to 50 percent of the value of the acquired or self-produced fry. ("Official Gazette of North Macedonia, No. 37 dated February 20, 2023."). There are no table-size trout related subsidies at the moment.

All three countries on their way to the EU will face similar difficulties that are institutional in their origin. Big farms will have to adapt more quickly, and they often do have the means to implement new standards. For these reasons, a country with more big trout farms should generally be in a better position.

2.4. Personal (human) risks are specific to an individual and include factors like health, relations, motivation, qualification level, working ethics, etc., which could influence farm results.

Trout farming is mainly connected with work under the open sky; therefore, younger workers with stronger health should produce less risk. Some recorded cases that fall into this category are bad working habits when working in the hatchery, sleeping during 3rd (night) shift, bad personal and professional relations, careless and unprofessional use of chemicals and drugs in fish treatments, etc.

No significant differences exist between Serbia, B&H and N. Macedonia regarding human risks, as the authors see this question.

2.5. Financial risks refer to all aspects of financing the investment and operation of trout farms. There is the risk that the financial means for financing the operation wouldn't be sufficient. Changes in bank interest rates for long-term and short-term credits also fall in this category.

Different levels of financial risks are connected with various trout farms and are farm-specific. There have been big changes in bank interest rates since the beginning of Coronavirus pandemics which affected Serbia, B&H and North Macedonia. There is no evidence that financial risks are more country-specific than farm-specific for the three analyzed countries.

3. Discussion and Conclusion

Trout farming in Serbia, B&H and N. Macedonia and face numerous risks identified during this research. Differences in the risk elements and the risk severity between countries originate from differences in natural conditions, farming systems, farm size, market size in the country, country's policies that affect trout farming, etc. Risks are location and farm-specific, but some general conclusions could be made.

Generally speaking, natural risks could be more significant in Serbia compared to N. Macedonia and B&H. Trout farms in Serbia are mainly located on streams and rivers far away from springs with lower water quality. Technical-technological risks could also be more pronounced in Serbia due to a higher number of farms which use equipment in trout farming.

On the other hand, market risks could have more significance in N. Macedonia and B&H. Prices for trout are the highest in N. Macedonia, and B&H exports substantial amounts of its trout. Institutional risks could be the highest in B&H due to a high subsidies for consume-size trout.

Human risks could be the same for all three countries. Financial risks could be more farm-specific than country-specific for the three analyzed countries.

Many risks and their origin were identified in this research in all three analyzed countries. Some of them are farm-specific, and some are country-specific. The authors conclude that future research should include more risk analysis case studies in B&H, N. Macedonia and Serbia and risk evaluation for each risk type. The final goal should be to define measures for risk mitigation for each risk.

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THE SIGNIFICANCE OF THE FIRST 100 DAYS OF LACTATION ON THE KEY PRODUCTION AND REPRODUCTIVE INDICATORS IN HOLSTEIN-FRIESIAN AND SIMMENTAL COWS

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Abstract. *Contemporary dairy production, due to the increasing demands of the market, implies continuous improvement. Milk production during the first 100 days of lactation of Holstein-Friesian and Simmental cows can be a valid indicator of production success for the entire lactation period, especially given that maximum milk production is achieved 40 to 60 days after calving. The examination of milk yield and quality in the first 100 days of lactation was carried out on 28 farms in the districts of Belgrade, Mačva, Kolubara and Moravica. Important production and reproductive indicators were monitored in 150 Holstein-Friesian and 115 Simmental cows. The average milk yield in the first 100 days of lactation in the population of the Holstein-Friesian cows was 3,159 kg of milk with 3.89% milk fat and 3.28% protein, while the population of tSimmental cows in the first 100 days produced an average of 2,229 kg of milk with 4.04 % milk fat and 3.24 % protein. The longer average duration of the service period also led to a longer average calving interval in both breeds.*

Key words (bold): *100 days of lactation, production traits, reproductive traits, Holstein-Friesian breed, Simmental breed*

INTRODUCTION

Market conditions also affect milk production on family farms. Milk production on farms is accompanied by numerous problems, primarily related to a constant increase in input prices and maintaining the satisfactory quality of the milk produced. (Beskorovajni, 2014). For successful milk production on family farms, in addition to raising high-quality, highly productive cows, it is necessary to ensure adequate conditions, primarily in terms of quality nutrition, accommodation, care and health care (Beskorovajni et al., 2015).

In terms of breeds, there are two breeds predominant in Serbia: Holstein-Friesian and Simmental breed. Milk production in the first 100 days of lactation of Holstein-Friesian and Simmental cows can be a good indicator of production success for the entire lactation period, especially given that maximum milk production (peak milk production) is achieved 40 to 60 days after calving. Therefore, it is particularly important to monitor and keep records of production data in the first 100 days of lactation, since it can help better planning and more efficient use of available resources during the entire production (Janković, 2001).

Reproductive traits are complex and mostly affected by a number of factors. In addition to genetic factors, they are significantly affected by other factors, such as: the age of cows, milk yield, calving season, management, nutrition and many others (Vuković et al., 2013).

MATERIAL AND METHOD

The examination of milk yield and quality was carried out on 28 farms, with Simmental and Holstein- Friesian breeds in the districts of Belgrade, Mačva, Kolubara and Moravica. The production indicators were established for 115 Simmental and 150 Holstein-Friesian cows, raised on 14 farms in the aforementioned districts. Milk yield control was done once a month, alternately in the morning and in the evening, for cows that calved in the period from June 1, 2022. until January 31, 2023. The data on milk production and quality in the first 100 days of lactation were obtained based on the amount of milk measured on the day of control, as well as the detected content of milk fat and protein, in accordance with the reference method AT_4. The calculated reproductive indicators were, as follows: the average age at first calving, the average length of the calving interval and the average duration of the service period.

RESULTS AND DISCUSSION

Milk yield traits are subject to continuous variability. The resulting changes come from a constant interaction of genotype and environmental factors, with a smaller or larger effect on the manifestation of these traits. Yields of milk, milk fat and protein are the most significant traits from the economic aspects and, as such, they have a special place in breeding and selection programs. The average values of production indicators of Holstein- Friesian cows (HF) are shown in Table 1. The detected values of milk yield traits are listed according to the order of lactation.

The examination included 150 cows of the Holstein-Friesian breed, 33 of which were heifers and 117 cows in later lactations, from the second to the eighth. As expected, the highest milk yield of 3,363 kg with 3.91% milk fat was achieved by cows that started the third lactation.

The average milk yield, for the observed populations of the HF breed, was 3,159 kg of milk with 3.89% milk fat and 3.28% protein. These yields are higher than the average yields of HF cows recorded in 2022 in Central Serbia and stated in the Expert Report by the Main Breeding Organization. The content of fat and protein in milk are also higher when the obtained values for the period of 100 days are converted to the standard duration of lactation.

Table 1 Average values of production indicators for the first 100 days of lactation, HF breed

No.	Number of lact..	Average milk yield, 100 days	Average milk fat content, 100 days	Average protein content, 100 days	P2/P1
1	33	3,014	3.88	3.27	0.87
2	53	3,297	3.9	3.29	0.85
3	29	3,363	3.91	3.28	0.89
4	13	3,241	3.89	3.27	0.89
5	10	2,830	3.9	3.3	0.87
6	7	2,628	3.9	3.28	0.81
7	3	2,777	3.86	3.23	0.91
8	2	2,535	3.88	3.32	0.83
Total	**150**	**3,159**	**3.89**	**3.28**	**0.86**

For cows that calved in the period from the beginning of June to the end of December 2022, the production and quality of milk was monitored in the second 100 days of lactation, in order to establish the evenness (persistence) of milk production. The relation between milk production in the second and first 100 days is expressed in relative terms. The obtained values are in accordance with research on the persistence of lactation for the Holstein-Friesian breed.

The average values of production indicators of Simmental cows (S IM), for a period of 100 days, are shown in Table 2.

It was noted that the cows of the Simmental breed had a longer production life than the cows of the HF breed, as several cows had calved 9 and 10 times. As with the HF breed, the highest average milk yield of 2,399 kg was achieved in the third lactation, while the highest average milk fat content of 4.10% was recorded in the cows in the sixth lactation. The protein content was the highest in the first 100 days of the seventh lactation. The observed Simmental cows produced an average of 2,229 kg of milk with 4.04% milk fat and 3.24% protein in the first 100 days. Compared to the results achieved by Simmental cows in a standard lactation in Central Serbia, a higher average milk yield was achieved, as well as higher contents of milk fat and protein, when the values obtained in the research are converted to a standard duration of lactation. The obtained values for the persistence of lactation are in accordance with the results reported for the Simmental breed.

Table 2 Average values of production indicators for the first 100 days of lactation, SIM breed

No.	Number of lact.	Average milk yield, 100 days	Average milk fat content, 100 days	Average protein content, 100 days	P2/P1
1	28	2,170	4.03	3.21	0.82
2	22	2,357	4.01	3.16	0.83
3	16	2,399	3.99	3.25	0.82
4	17	2,188	4.07	3.27	0.81
5	8	2,095	4.08	3.24	0.83
6	6	2,189	4.1	3.28	0.78
7	8	2,129	4.05	3.29	0.79
8	3	2,163	4.05	3.27	0.94
9	4	2,146	4.06	3.25	0.83
10	3	2,033	4.08	3.14	0.81
Total	**115**	**2,229**	**4.04**	**3.24**	**0.82**

Reproductive traits are complex and their manifestation affected by a number of factors. In addition to genetic factors, numerous other factors can significantly affect reproductive traits, such as: the age of cows, milk yield, calving season, management, nutrition, health status and others. Table 3 shows the more important reproductive indicators, based on the data from the registry of the Primary Breeding Organization, the Institute for Science Application in Agriculture.

Table 3 Average values of reproductive indicators of the HF cows

Average age at first calving, days	Average calving interval, days	Average service period, days
787	456	120

The obtained values for all observed fertility traits deviate from the values stated as desirable in the Main Breeding Program for Holstein-Friesian cattle. The cows calved for the first time at the age of 787 days or 26 months, which is two months later than optimal. The long service period affected the duration of the calving interval, making it about 50 days longer than it is technologically and economically acceptable for this breed. Significantly better values were obtained for the duration of the service period related to the ongoing lactation. However, its average length of 120 days may also be a result of unrecorded repeated inseminations. Table 4 shows the average values of the key reproductive indicators monitored in the examined population of Simmental cows.

Table 4 Average values of reproductive indicators of the Simmental cows

Average age at first calving, days	Average calving interval, days	Average service period, days
817	416	101

The observed Simmental cows calved for the first time at the age of 27 months, which is considered to be the upper limit for this breed. The significantly longer average service period also affected the average duration of the calving interval, being 416 days, which is longer than optimal. The service period after the last calving is within the limits considered to be optimal for the Simmental breed.

The obtained average values for fertility traits, both of the Holstein-Friesian and Simmental breed, point to the conclusion that they must be continuously improved, especially keeping in mind these are low heritable traits and that their manifestation is affected by a large number of non-genetic factors. Fertility traits must be payed special attention, since they significantly affect the economic efficiency of milk production.

CONCLUSION

Based on the obtained values for milk yield and quality, it can be concluded that the production in the examined populations of Holstein-Friesian and Simmental cows was satisfactory when the achieved results are compared with the average production of these breeds in Central Serbia. However, the genetic potential of cows for high production has not been fully achieved, both in terms of yield and milk quality. The reason for this lies is numerous deficiencies detected on the analyzed farms, mostly in terrms of inadequate breeding conditions. accommodation and feeding of milking cows. In addition, a large number of farmers do not keep records of the costs of milk production on their farms. In order to overcome the current situation and improve milk production on farms, it is necessary that farmers constantly educate themselves and accept the advice of experts from advisory services, primarily advice on breeding technology, nutrition and reproduction. Genetic improvement in herd is mainly achieved through the selection of quality bull semen for insemination, but farmers must also be open to use new biotechnologies. The insemination of cows with sexed semen and the use of genomic selection to select the best quality cows in a herd is the fastest way to genetic prosperity and economically profitable milk production. Equally important is the improvement of work productivity through the modernization of farm machinery, keeping records and reducing total production costs, all to increase the efficiency and profitability of milk production on farms.

Acknowledgement: *The paper is part of the research project funded by the Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia.*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

TECHNICAL EQUIPMENT WITH MECHANIZATION ON MEDIUM-SIZED FAMILY FARMS

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Abstract. *The work investigated the equipment of tractors, attachments and combines in a medium-sized family farm. The research was conducted on the registered family farm "Đurković" in the village of Čestin in the municipality of Knić. The farm cultivates arable and forage crops for feeding dairy cows and fattening oxen on an area of 44 ha. In the sowing structure, meadows are the most represented with 20 ha (45.45%), alfalfa 5 ha (11.36%), silage maize 3 ha (6.83%) and perko 0.4 ha (0.91%). The farm also grows barley on 2 ha, wheat on 1.5 ha, soybeans on 0.7 ha, oats on 0.4 ha, and peppers for processing on 40 ares. The production process is carried out with three tractors, 22 implements, a self-propelled combine for small grains and a combine for silage. One tractor with an average engine power of 41.4 kV works 14.67 ha of available land with 7.33 attachments. The total available power of the tractor engine is 129.43 kW, and the energy equipment of the farm is 2.94 kW/ha, which is the average of family farms in Serbia. If the combine engine power for small grain and silage were added, the energy equipment would increase to 7.85 kV/ha. Combines are underutilized because they are used only for subsistence. The average age of mechanization is over 40 years, so replacement and purchase of new agricultural machinery is not possible.*

Key words: *Family farming, sowing structure, equipment and mechanization level.*

1. INTRODUCTION

The development of agriculture in Serbia, the economically successful production of arable crops, especially in the hilly areas, depends largely on the equipment of productive farms with modern means of mechanization. According to data from the Register of Agricultural Holdings, maintained by the Agricultural Payments Directorate of the Ministry of Agriculture, there are 466,000 agricultural holdings in Serbia, of which 462,000 are family farms. Agricultural production takes place on an area of 2,816,424 ha of usable land. According to research [1, 2], most of the production of basic agricultural products is realized in family farms. The high percentage of small family farms, low use of agricultural technology, outdated mechanization and low percentage of irrigated land have a strong impact on the economic results of these farms. From the point of view of rational use of agricultural mechanization and successful organization of agricultural production, land holdings are considered small if they are less than 30 ha, and medium if they are 30 to 200 ha [2, 3].

The registered farm "Đurković" is engaged in agricultural production for livestock needs and cultivates 44 ha. According to the cultivated area, it is one of the medium-sized farms in Serbia. The 20 ha of land they own is not enough to provide enough fodder for domestic animals, so they are forced to lease another 24 ha of land. Out of a total of 1,513 selected farms in Vojvodina, 31% produce on an area of more than 40.01 ha [4]. The aim of the study is to show the sowing structure, technical equipment with mechanization and to analyze the energy equipment and labor input in a medium-sized farm.

2. Materials and methods

The research was conducted using the case study method on the example of a medium-sized registered family farm from the village of Čestin, 12 km from Knić and 20 km from Kragujevac, which belongs to the Šumadija region. Four generations with a total of eight household members aged 2-72 years live on the farm in the family house. All work related to fodder production and livestock breeding on the farm is performed by five family members. The basic income of the farm is generated not only by farming, but also by the additional work of three family members.

Basic data about the farm were collected on site, based on which the following were determined: the existing level of mechanization, the available land and the sowing structure. Other data mentioned in the paper were obtained from the official data of the Institute of Statistics of the Republic of Serbia and from the book of the Agricultural Census 2012 of the Republic of Serbia. Based on the above statistical data, the average area of agricultural land available to a family farm in Serbia was calculated, as well as the number of tractors and implements. In addition, data from literary sources published by domestic and foreign authors were used.

3. Results

The family farm "Đurković" owns a dairy farm with 18 cows of Simmental breed, 5 calves and 8 fattening steers. All the fodder needed for feeding the cattle is produced on the farm on an area of 44 ha. Annually, about 360 bales of meadow and alfalfa hay, 135 tons of corn silage, 42 tons of grain corn, 14 tons of small grain, and about 2 tons of soybeans are processed (Table 1). There are facilities for bulk storage on the farm: two silos for preservation and storage of silage from the whole corn crop, and storage rooms for storage of hay and grain crops. From 2022, the farm started organized production of peppers on an area of 40 hectares. An average farm in Serbia has 4.48 ha of agricultural land divided into 5 plots of 90 ares each. For the production of coarse and grain fodder for livestock feeding, the farm cultivates 44 ha of land. The available arable land is divided into 37 plots, so the average area of a plot is 1.19 ha. The two largest plots of 2.5 ha are planted with corn and meadows. By landholding size, the farm belongs to the medium size farms in Serbia and is larger than the farms in Montenegro, where the farm size is 4.60 ha, Greece (6.4 ha), Portugal (8 ha), Italy (9.3 ha), Western Turkey (10 ha), Spain (22 ha) and Germany (28.9 ha), and smaller than the farms in Great Britain, where the farm size is 109.7 ha. A similar farm structure of land ownership is found only in France (44.8 ha) [5, 6, 7, 8, 9, 10].

Table 1. Sowing structure and average yields

Crop	Area (ha)	Number of plots	Total production (t)	Participation in crop rotation %
Sown meadows	20	15	100	45.45
Corn for grain	9	5	42	20.45
Alfalfa	5	6	70	11.36
Maize for silage	3	3	135	6.83
Barley	2	2	6	4.54
Wheat	1.5	2	6	3.41
Soy	1.5	1	3	3.41
Oats	0.7	1	2	1.59
Perko	0.4	1	12.5	0.91
Vegetables and economic yard	0.9	1	10	2.04
Total / Average	44	37		100

In the sowing structure, forage crops are the most represented with 65.67% or 28.4 ha, followed by arable crops with 33.41% or 14.7 ha, and vegetable crops the least with 0.4 ha or 0.91% of the total area. For bulk forage production, 20 ha (45.45%) of meadows were sown on 15 plots, followed by 5 ha (11.36%) of alfalfa on 6 plots, 3 ha (6.83%) of silage maize on 3 plots and 0.4 ha or 0.91% of sorghum (Table 1). To ensure a sufficient amount of green bulk, forage peas and sorghum were also sown on the farm during the last production year, in addition to the crops mentioned above. In addition, perko is sown on an area of up to 1 ha each year, which is used as green fodder for the cows. Field crops are grown on an area of 14.7 ha. Grain maize is grown the most on 9 ha, barley on 2 ha, soybeans and wheat on 1.5 ha each, and oats the least on only 0.7 ha. Crop production is a function of animal production, ensuring high quality and cheap food for feeding domestic animals on the farm. In this way, the products of crop production are marketed in the form of milk and meat.

The equipment of the farm with tractors and suitable implements depending on the assortment is determined by many factors: the size of the land, the nature of the terrain, the structure and volume of production, the economic strength of the farm and the machinery available on the market. In order to better compare and assess the level of agricultural machinery equipment, the tables provide an overview of the number of tractors and implements in the studied area and on the farm.

According to the 2012 agricultural census in the Republic of Serbia [11], the total number of two-axle tractors used on family farms is 410,894 tractors, of which 94.87% are older than 10 years. In addition to tractors, farms own 2,421,065 implements, 93% of which are older than 10 years (Table 2).

In the region of Šumadija and Western Serbia, 262,940 family farms are registered, which have 1,865,957 ha and own 149,401 two-axle tractors (0.56 tractors/farm), of which 95.84% are older than 10 years. In the Šumadija region, there are 26,941 registered farms with an available area of 151,922 ha and 19,198 two-axle tractors (Table 2). In the territory of Knić municipality, there are 3,941 registered farms cultivating 24,211 ha of available land with 3,218 two-axle tractors, of which 3,135 are older than 10 years. In the village of Čestin, there are a total of 174 registered farms and 140 two-axle tractors cultivating a total of 1,276 ha of available land (Table 2).

Table 2. Condition of tractors and harvesters in the researched area

Area	Total number of farms	Available area	Number of two-axle tractors	Number of grain harvesters	Number of silage harvesters
Republic of Serbia	631,552.00	5,346,596.52	410,894.00	19,474.00	10,788.00
The Šumadija region and Western Serbia	262,940.00	1,865,957.69	149,401.00	4,943.00	5,573.00
Šumadija region	26,941.00	151,922.74	19,198.00	967.00	955.00
Municipality Knic	3,941.00	24,211.40	3,218.00	168.00	200.00
The village Chestin	174.00	1,276.01	140.00	5.00	4.00

From the above statistical data, it can be concluded that in the Šumadija region family farms own 0.71 two-axle tractors/farm and that one tractor cultivates 7.92 ha of available land. The situation is similar in the area of Knić municipality: 0.83 tractors/household and 7.52 ha per tractor. In Čestin municipality, the average household owns 0.80 tractors and thus cultivates 9.11 ha of available land.

In terms of the number of tractors per farm, this is more than in Hungary (0.25), Kosovo (0.43), Portugal (0.51), Italy (0.59), Serbia (0.64), Poland (0.77) and less than in Montenegro (0.84), Turkey (0.99), Austria (1.32), Slovenia (1.47), France (1.58), United Kingdom (2.05), and Croatia-Osijek Baranja County (3.3) [5].

The farm has full mechanization for the production of forage and field crops, so the processes of forage production are fully mechanized. The farm has 3 two-axle tractors: IMT 539, IMT 558 and FIAT 78. It can be seen that domestically produced tractors of Belgrade IMT factory dominate (66.66%), which produced these tractors in the eighties of the last century. The factory has very old tractors and machines that are over 40 years old. The tractors IMT 539 and IMT 558 were purchased in 1979 and have been in use on the farm for more than 43 years, while the tractor FIAT 78 from 1989 was purchased used in 2015 (Table 3).

Table 3. Numerical condition and age of tractors on the Farm

Serial number	Manufacturer	Number of pieces	Engine power kW	Year of production	Age of the tractor (years)
1.	IMT-539	1	29.5	1979	43
2.	IMT-558	1	42.6	1979	43
3.	FIAT-780	1	57.33	1989	33
Total/average	-	3	129.43/41.14	-	119/39.67

In Serbia, more than 95% of tractors are older than 10 years [8]. In comparison, 91.8% of registered tractors in Croatia are older than 10 years, and the average age of tractors in Slovenia is 21 years. In Hungary, the average age of tractors was 18.3 years by 2013 and 12 years in 2016. In Turkey, 54% of tractors are older than 24 years, and in Western Turkey, only 12% of tractors are older than 20 years. In Montenegro, 52% of tractors are older than 20 years, and 8.4% are younger than 10 years [5, 12].

Table 4. Numerous condition and age of self-propelled harvesters

Serial number	A type of harvester	Combine harvester manufacturer	Engine power kW/HP	Year of production	Age of the machine (year)
1.	Combine harvester	DRAGON-133	55	1978	44
2.	Silo combine	CLASS JAGUAR 70 SF	161	1981	41

In addition to the tractors, the farm also has a Zmaj-133 self-propelled universal forage harvester for harvesting small grains with its own 55-kW engine and a Klass Jaguar 70 self-propelled silage forage harvester SF with a 161 kW engine. As for the tractors, the age of the Zmaj-133 harvester is over 44 years and the age of the silage harvester is 41 years (Table 4). The Class Jaguar 70 SF self-propelled silage harvester, manufactured in 1981 and acquired in 2021, worked only on 3 ha on its own property when preparing silage from the entire corn crop. Until last year, a single-row Lipham 30 silage chopper was used for processing silage from the entire corn plant on the farm, but due to the low output, a self-propelled chopper with a larger capacity was purchased.

In the Republic of Serbia, family farms are not sufficiently equipped with two-axle tractors, only 0.64 tractors per farm. With a two-axle tractor with an average engine power of 32.27 kW (43.52 HP), 6.99 ha of land are cultivated with 5.89 implements. The power equipment of family farms in Serbia is 2.89 kW/ha, and the average age of tractors is 17.5 years. The average annual use of tractors on family farms is 421 hours [8, 13].

Table 5. Energy equipment of the farm with machinery

Equipment (unit of measurement)	Tractor (pc)	Total engine power (kW)	Cultivated area (ha)	Power equipment (kW/ha)	Number of connected machines per tractor (pc)	Cultivated area per machine (ha)
Tractors	3	129.43	44	2.94	7.33	14.67
Small grain harvester Soybean and corn harvester	1	55.00	14.7	1.68	-	14.70
Harvester for corn silage	1	161.00	3.0	53.67	-	3.00
Total/Average	3+2	345.43	44	7.85	22/7.33	

On the studied medium-sized family farm "Đurković", one tractor with an average engine power of 41.4 kW with 7.33 implements cultivates 14.67 ha of available land. It can be seen from Table 5 that the total power of the tractor engine is 129.43 kW and the energy equipment of the farm is 2.94 kW/ha, which is the average for family farms in Serbia. However, if we take into account the combine engine power for small grain and silage, the energy endowment of the farm increases to 7.85 kW/ha. Analyzing the seasonal power and harvested area in the production year 2021/2022, we conclude that the combine harvesters were underutilized, as they were used only on the farm's own land (Table 5).

According to research [14], a medium-sized farm in Vojvodina owns 3.25 tractors with an average engine power of 62.50 kW and energy equipment of 2.2 kW/ha. One tractor manages on average 28.38 ha with 4.46 machines. The data provided by the authors do not match the results presented in this paper.

An overview of the number of attached machines in Serbia as well as in the Šumadija region and western Serbia, the municipality of Knić and the village of Čestin, is provided in Table 6.

Table 6. Number of attached machines in Serbia in relation to the village of Čestin

Area	Republic of Serbia	The region of Šumadija and Western Serbia	Šumadija region	Municipality of Knic	The village of Chestin
Plows	336,928	118,046	16,379	2,653	125
Subsoilers	14,440	2,697	688	17	0
Crushers	3,364	562	130	8	0
Plows	146,647	51,968	9,273	1,702	76
Harrows	218,161	86,796	12,596	2,021	71
Sowing preparation	60,453	9,042	1,070	241	7
Tillers	36,685	21,797	1,789	149	2
Mineral fertilizer spreaders	95,378	24,206	5,143	906	28
Manure spreaders	13,371	4,334	438	73	2
Liquid manure spreaders	13,629	6,344	519	71	8
Planters	114,710	35,250	4,970	823	25
Sprinklers	138,084	45,890	5,502	944	29
Trailers	298,667	98,560	12,116	1,822	70
Mowers	148,191	74,151	9,119	1,792	76
Hay collectors	92,686	42,758	6,889	1,342	49
Balers	46,706	21,324	3,340	657	26
Total	1,778,100	643,725	89,961	15,221	594

For comparison, in Vojvodina, the energy endowment of the private sector is 3.54 kW/ha, and a tractor with an average power of 40 kW covers 15.83 ha of agricultural land. In America, the use of mechanical tractor power is 0.783 kW/ha, in Europe 0.694 kW/ha, in Turkey 2.42 kW/ha, in Kosovo 2.55 kW/ha, in Poland 4.9 kW/ha [5, 8, 9, 15]. In Serbia, a two-axle tractor with an average engine power of 32.00 kW (43.52 HP) cultivates 6.99 ha of land with 5.89 implements per tractor. In Turkey, one tractor covers 7.26 and in Montenegro 1.85 implements [6,8,10].

The numerical status of all connected machines owned by the farm is shown in Table 7.

Table 7. Numerous state of attached machines on the Farm

Type of machine	Manufacturer	Required tractor power kW/HP	The year of production	Age of the machine (year)
Plow turners (three furrow)	HUARD 265	57/78	1995	27
Plow turner (double furrow)	IMT 565	29.5/39	1990	32
The saucer	Lemind Leskovac 24	29.5/39	1980	42
A harrow	IMT	29.5/39	1980	42
Rotary harrow	LEMKEN	57/78	1990	32
Artificial fertilizer spreader	Aggrex	29.5/39	2017	5
Manure spreader	WELGER LS300	42.6/58	1993	29
Seeder for small grains	IMT 632	29.5/39	1985	37
Pneumatic seed drill for hoes	NODET	29.5/39	1994	28
Rotary mower	KUHN	29.5/39	1998	24
Roller press	WELGER RP12	42.6/58	1999	23
Tedder - hay collector	IMT	29.5/39	1998	25
Tedder - hay collector	Pottinger	29.5/39	2001	12
Singlerow silage harvester	Lipham-30	29.5/39	1986	37
Tank for liquid manure	KAISER	42.6/58	2000	22
Sprinkler system	CROCUS	29.5/39	2019	3
Mixer trailer	Trioliet Gigant 500	IMT 558	2002	20
Tractor front loader for large bales	Calvet	FIAT	1996	27
Trailer for roll bales	Own production	IMT 558	2019	4
Trailer	IMT	IMT 539	1979	44
Hydraulic craneloader	Donder	IMT 539	2008	15
Tractor rear loader for manure	Ferocoop	IMT 539	2012	11

In Latvia, the average tractor power is 63 kW, and the energy equipment of farms up to 50 ha is 3.1 kW/ha, i.e. 4.3 tractors per 100 ha. The average age of tractors is 23.7 years, with 48% of tractors being 21-30 years old [16].

Based on the number of implements and available power per unit area, the farm is well supplied with tractors. However, considering the age structure of the tractors and the area cultivated by the farm, there is a need to purchase a newer tractor with power greater than 90 kW, a chisel plow with rollers (Germinator), medium-heavy disk harrows, a seeder, and a seedbed.

From the previous analysis, it is clear that the gradual replacement of agricultural machinery and the purchase of new means of mechanization in the farm is necessary, for which significant financial resources are required.

4. CONCLUSION

The "family farm "Đurković" belongs to the medium-sized farms in Serbia, measured by the size of the cultivated area. The main activity of the farm is the production of coarse and granular fodder for feeding cattle on an area of 44 ha, of which 20 ha are owned. On the available land in the production year 2021/22. In 2008 were sown: meadows (20 ha), grain corn (9 ha), alfalfa (5 ha), silage corn (3 ha), barley (2 ha), wheat and soybeans (1.5 ha each), oats (0.7 ha), perko (0.4 ha) and peppers (0.4 ha). Three tractors (IMT 539, IMT 558 and FIAT 78), 22 implements, a self-propelled grain harvester and a silage harvester are used for forage production.

One tractor with an average engine power of 41.4 kW works 14.67 ha of available land with 7.33 implements. The power equipment of tractors on the farm is 2.94 kW/ha, which corresponds to the average equipment of family farms in Serbia. The average age of the machinery is over 40 years.

Considering the age structure of tractors and the area cultivated by the "Đurković" farm, gradual replacement is required Farm cultivated area it is necessary to gradually replace and acquire new agricultural machinery, especially tractors with higher power, chisel plows, medium-heavy disk harrows, seeders for planting seedlings and seedbeds.

Acknowledgement: *This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, Contract No. 451-03-47/2023-01/200088 and 451-03-47/2023-01/ 200383.*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

ADVANCING AGRICULTURAL PRODUCTIVITY: NONDESTRUCTIVE OPTICAL SENSING FOR EARLY DETECTION AND MANAGEMENT OF PLANT STRESS

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Abstract. *Plant stress poses a significant threat to global food security, driven by various environmental factors like drought, salinity, diseases, and nutritional imbalances. Traditional methods of assessing plant stress are often invasive, time-consuming, and lack temporal resolution. In contrast, nondestructive optical sensing emerges as a promising solution, allowing real-time data collection without disrupting the plant growth. We conducted experiments in a controlled indoor environment, employing red LED light sources and optical fibers to measure transmission of plants leaves. We explored plant stress induced by nutritional deficiency, water scarcity, intensity of white light and pathogen infection. The proposed nondestructive optical method detects early stress, demonstrating its potential for effective plant stress assessment and timely intervention ultimately enhancing agricultural productivity.*

Key words: *Nondestructive optical method, leaf transmittance, plant health assessment.*

1. INTRODUCTION

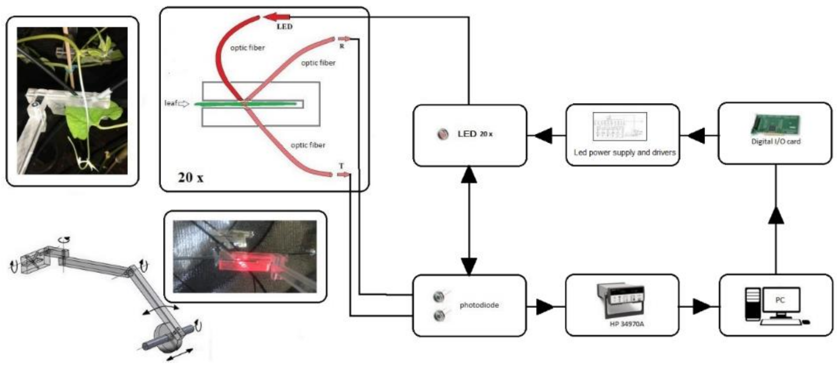
Plant stress poses a significant threat to global food security, necessitating advancements in technologies and methodologies to enhance crop growth and yields while ensuring sustainability in agriculture [1-4]. Various environmental stressors like drought, salinity, diseases, and nutrient imbalances significantly impact crop productivity. Traditional methods [5-10] for identifying plant stress often involve invasive procedures and provide limited, sporadic insights into the plant's stress status, leading to a sacrifice of plant material and potential alterations in plant physiology during sampling. To address these limitations and achieve a more dynamic, continuous assessment of plant stress, the paradigm is shifting towards nondestructive optical sensing—a promising solution that allows real-time data collection without disrupting plant growth [9-14]. Leveraging advanced optical technologies to measure the interaction of light with leaf tissue, nondestructive optical sensing enables the collection of spatial and spectral data, significantly advancing our understanding of plant stress dynamics. Notably, an essential aspect of plant growth is the circadian rhythm, orchestrating a wide range of physiological, biochemical, and behavioral functions in an approximately 24-hour cycle. This internal biological clock, akin to the circadian rhythms in animals, plays a critical role in synchronizing vital plant functions such as photosynthesis, nutrient intake, hormone production, growth, and stress responses. The circadian rhythms [15-16] intricate interplay with plant stress responses, influenced by external cues like light and temperature, underscores the necessity of integrating circadian considerations when studying plant stress physiology and developing effective stress management strategies. The plant's circadian clock is a complex network of genes and proteins exhibiting cyclical patterns of expression and regulation. In plants, the circadian rhythm plays a crucial role in synchronizing vital functions such as photosynthesis, nutrient intake, hormone production, growth, and stress responses. By continuously monitoring a plant's optical characteristics and considering the circadian element in obtained spectra, nondestructive optical sensing offers a comprehensive understanding of the plant's stress responses, paving the way for precision stress management in agriculture and ultimately bolstering global food security.

2. Materials and methods

Experimental setup

The experimental setup was conducted within a controlled indoor environment. The primary apparatus, as illustrated in Figure 1 [17], consisted of 20 distinct "channels," each corresponding to an individual leaf of the plant. Figure 1.

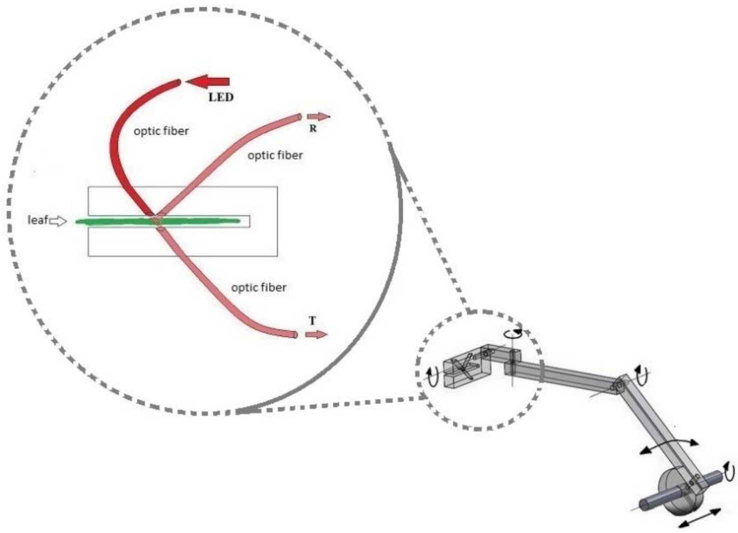
Figure 1. Block diagram [17]



This configuration provided sufficient measurements for both the control group and the group exposed to the specific stress factor.

In each channel, a red LED light source with a spectral emission peak at 656 nm, referred to as "Signal LEDs," was meticulously housed within temperature-controlled enclosures and connected to optical fibers, following established methodologies (Bornman and Vogelmann, 1991; Vogelmann, 1993; Vogelmann et al., 1988). The opposing end of the optical fiber was affixed to a transparent plastic leaf holder made of methyl methacrylate, as depicted in Figure 2. A stable power supply was meticulously regulated and provided to the Signal LEDs under the control of the data acquisition computer. Furthermore, the arrangement incorporated two optical fibers—one for collecting transmitted light and the other for collecting reflected light. These fibers transmitted the gathered light to photodiodes housed within a thermostated shielded box, effectively mitigating stray light, electrical interference, and temperature fluctuations. Additionally, a sharp band-pass interference filter, centered at 665 nm, was introduced in front of each photodiode to further diminish ambient light interference.

Figure 2. Single measurement channel [17]



The leaf holder was ingeniously designed to enable mechanical movement in five degrees of freedom, facilitating precise monitoring of the leaf's position and orientation. The entire system underwent calibration using a set of calibrated neutral density filters (NDFs).

Plant Stress Due to Nutritional Deficiency

Plant stress caused by a lack of nutrients is a major concern in agricultural settings. Plant physiology and metabolism are profoundly impacted by insufficient availability or uneven absorption of key nutrients [18-25]. This stress caused by a deficiency can appear in a variety of ways, altering plant morphology, leaf colour, biomass output, and overall crop yield. Specific nutrient deficiencies can disturb critical biological activities such as photosynthesis, nutrient transport, and enzyme activation. As a result, plants that are nutritionally stressed are more vulnerable to environmental adversities such as diseases, drought, and severe temperatures. Understanding the optical reactions of plants under nutritional stress can provide important insights into the early detection and monitoring of nutrient deficits, allowing for prompt interventions and effective crop management.

In this study, we selected *Ocimum basilicum*, a species of basil, as the focal point of investigation owing to its suitability for hydroponic cultivation—an innovative method devoid of soil, utilizing a nutrient-enriched aqueous medium [26-28]. Hydroponic systems afford basil roots immediate access to essential nutrients and oxygen, fostering accelerated growth and proficient nutrient assimilation. This controlled cultivation environment enables precise nutrient regulation and mitigates water consumption. When juxtaposed with conventional soil-based cultivation, hydroponically grown basil typically manifests heightened growth rates, elevated nutrient composition, and augmented yields, rendering it an optimal choice for both commercial and domestic hydroponic cultivation.

The ensuing figure (Figure 3) delineates the percentage alterations in transmission coefficients over a temporal trajectory, contrasting the control cohort with the group subjected to induced nitrogen deficiency-induced stress.

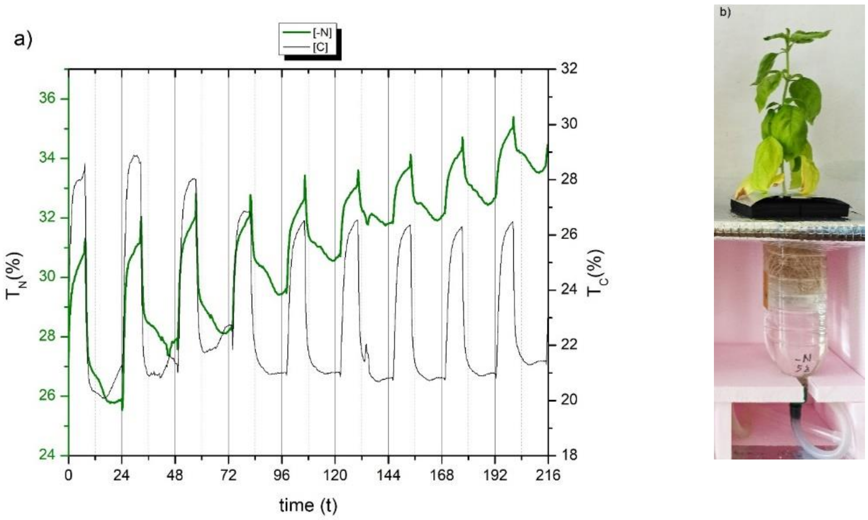


Figure 3. a) Variation of transmittance T (%) as a function of time in days [C] – control group – black, and group [–N] nitrogen deficiency – green, left. b) *Ocimum basilicum* plant after treatment.

In our experimental setup, six plants were meticulously nurtured employing the Hoagland nutrient solution, a widely acknowledged standard nutrient amalgam employed in hydroponic and soilless culture methodologies for plant growth. After a growth period of four weeks, one group comprising three plants was subjected to a nitrogen-deficient solution for the ensuing nine days, while the control cohort remained within the nutrient solution containing the full spectrum of essential nutrients. Nitrogen, a pivotal plant nutrient, assumes a pivotal role in chlorophyll biosynthesis—an indispensable process for photosynthesis and energy generation. It constitutes a foundational element in proteins, enzymes, amino acids, and nucleic acids, profoundly influencing plant growth, genetic processes, and metabolic pathways. Sufficient nitrogen availability facilitates robust vegetative growth, expedites nutrient conveyance, enhances stress resilience, and bolsters the maturation of seeds and fruits when maintained at appropriate levels.

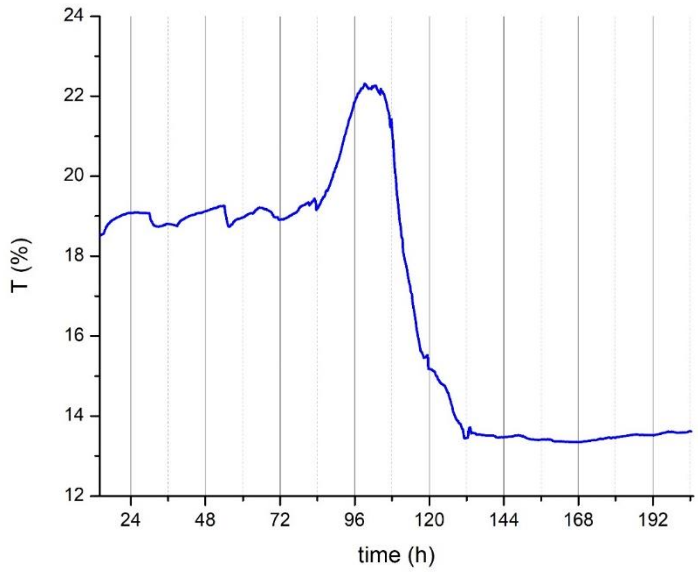
The control cohort evinced a consistent, gradual function with stable values for the daily local minimum, denoted as the 'baseline.' Conversely, the second group exhibited a discernible, gradual linear escalation in the daily local minimum commencing from the second day post-treatment. By the fourth day post-treatment, a conspicuous, rapid, nonlinear augmentation in the daily local minimum became evident, markedly affecting the amplitude of the daily local maximum. Post nine days from the commencement of the treatment, a significant reduction of approximately fourfold was discernible in the range of values for the daily local maximum amplitude. Concurrently, the local minimum displayed a notable surge of approximately 8.2 % in comparison to the initial day. It is imperative to underscore that these documented alterations in optical transmission transpired significantly earlier than observable manifestations of plant stress using conventional methodologies, such as the evaluation of chlorophyll fluorescence parameters and chlorophyll content.

Plant Stress Due to Water Deficiency

Plant stress caused by a lack of water (Figure 4), also known as drought stress, is a serious obstacle that affects plant development and productivity [29-35]. Plants' ability to carry out important physiological activities such as photosynthesis and nitrogen uptake is significantly hampered when they do not obtain adequate water. This causes slowed growth, wilting, and leaf curling, and can cause irreversible damage or even plant death. Water scarcity upsets the water balance within plant cells, altering turgor pressure and overall structural integrity. It is a major challenge in agriculture, needing effective water management measures to offset its negative impacts and assure long-term crop production.

Figure 4 illustrates the temporal variation in transmittance time for *Ocimum basilicum* plants subjected to water deficiency conditions. Notably, during the initial four days of the experiment, a discernible circadian rhythm is observed. However, this rhythm exhibits distinct characteristics compared to the state when the plant is adequately supplied with essential nutrients and water (Figure 3). This rhythmic pattern persists for an additional five days but becomes entirely disrupted after the fifth day. This disruption is indicative of leaf necrosis, commonly associated with plant tissue death.

Figure 4: Transmittance variation (%) over time (days) for a water-deficient plant



Plant Stress Due to Patogen Infection

Pathogens infiltrate plants, disrupting their physiological functions and impeding normal growth [36-38]. These incursions often manifest in visible symptoms such as lesions, discoloration, stunted growth, and tissue decay. Beyond the observable signs, pathogen-induced stress weakens the plant's immune system, heightening susceptibility to subsequent infections and compromising crop yield and quality. Effective disease management strategies are imperative to mitigate this form of plant stress and ensure the health and productivity of agricultural crops.

Phytophthora plurivora, an oomycete and plant pathogen, is closely related to algae and diatoms. It represents a destructive pathogen causing ailments like *Phytophthora root* rot and collar rot in various plant species, including trees, shrubs, and woody plants. The infection primarily targets the roots and collar (base of the stem), inducing root degradation, slowed development, wilting, and ultimately, plant demise. The pathogen propagates through infected plant remnants, soil, and water.

In this *experiment*, we employed a nondestructive method to detect infections by this invasive pathogen in sweet chestnut (*Castanea sativa*) leaves. Experimental plants were divided into two groups, each comprising ten plants, and were cultivated in separate independent containers, both under identical environmental conditions. To initiate the infection process, plants in the second group underwent a flooding treatment, followed by inoculation with *Phytophthora plurivora*. The flooding procedure involved immersing each plant's root system in water for 48 hours. The accompanying Figure 5 illustrates the percentage fluctuations in transmission coefficients over time, drawing a comparison between the control group and the group subjected to the invasive pathogen.

The *control* group of plants displayed a well-defined circadian rhythm characterized by a gradual increment in a trigonometric function, maintaining consistent daily and nocturnal amplitudes. Conversely, the infected group exhibited an initial surge in activity 96 hours after infection when exposed to light, deviating from previously established patterns, signifying the onset of stress. After 9 days of treatment, this surge became markedly pronounced, attaining an amplitude equivalent to the entire magnitude at that juncture. On the 10th day, a reduction in the circadian rhythm amplitude was observed, while the surge became increasingly conspicuous.

By the 15th day, the surge value encompassed half of the diminished amplitude, which had declined to half of its initial value. These observations signify noteworthy alterations in the circadian rhythm and a decline in its transmission amplitude in infected plants, acting as unequivocal indicators of stress.

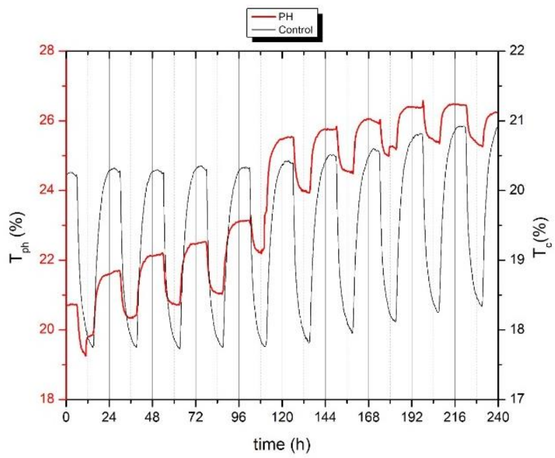


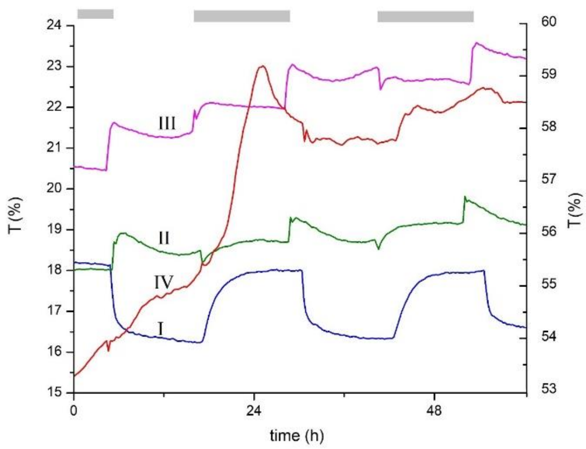
Figure 5. Graph depicting the time-dependent optical transmission dependence of inoculated (red line) and non-inoculated (black line) Sweet chestnut, starting from midnight

Plant Stress Due to Variation in White Light Intensity

In their natural habitat, plants often encounter abrupt and unpredictable fluctuations in light intensity, stemming from varying weather patterns, diurnal cycles, and cloud cover. These dynamic alterations in sunlight exposure significantly influence plant responses, intricately impacting growth, developmental processes, and physiological functions. Investigating how plants adeptly adapt and react to these varying light intensities is fundamental for optimizing growth outcomes in both uncontrolled natural environments and carefully regulated conditions [40-44]. This study delves into comprehending the plant's adeptness in acclimating to the ever-changing light dynamics, elucidating their resilience and adaptive mechanisms. Excessive light represents a potential threat to plants, a phenomenon recognized as photoinhibition. Photoinhibition involves the impairment of the photosynthetic apparatus, inducing degradation of vital photosynthetic pigments like chlorophyll. Additionally, plants respond to excess light by strategically closing their stomata, effectively mitigating water loss through transpiration and aiding in preservation efforts. These mechanisms signify critical plant adaptations in response to light stress, highlighting their intricate coping strategies under such environmental challenges. Our investigation unraveled the reversible and intricate kinetics of red-light transmittance in both green and white leaf sectors of *Variegated Pelargonium zonale*.

Our study, showcased through Figure 6, provides a visual representation of diurnal variations in red-light (665 nm) transmittance (T), expressed as a percentage of total transmittance through green sectors of leaves.

Figure 6. Graph depicting the time-dependent optical transmission dependence of four distinct light intensities, respectively



These measurements were taken at four distinct light intensities: I: 25 µmol photons m^{-2} s^{-1}; II: 290 µmol photons m^{-2} s^{-1}; III: 350 µmol photons m^{-2} s^{-1}; IV: 1200 µmol photons m^{-2} s^{-1}, as depicted on the secondary axis. Dark and light periods are visually distinguished.

These findings underscore the dynamic interplay between chloroplast accumulation and avoidance responses, a dynamic that hinges heavily on white light intensity. Similar kinetics was observed with blue-light-induced transmittance, suggesting the involvement of phototropins in these processes. These insights enhance our comprehension of the intricate relationship between light intensity and chloroplast responses, offering valuable contributions to our understanding of plant adaptation mechanisms under dynamic light conditions.

4. Conclusion

This study highlights how nondestructive optical sensing technologies have the potential to revolutionize plant stress monitoring and management, facilitating early detection and intervention for enhanced agricultural productivity and global food security. We employed a nondestructive optical method to investigate four significant sources of plant stress: deficiencies in nutrients, water scarcity, pathogen infections, and exposure to varying levels of white light intensity. In each of these scenarios, the spectral patterns of the circadian rhythm exhibited modifications well before any discernible visual cues of plant distress emerged.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

PERFORMANCE OF MACRODIVERSITY RF COMMUNICATION SYSTEM IN SMART AGRICULTURE

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Abstract: *RF communication systems are often applied in agricultural communication systems and other applications in smart agriculture. Performance of RF communication system consisting of a macrodiversity system with 2 SC (Selection Combiner) microdiversity receivers is analyzed in this paper. Processing done on one diversity branch made SC diversity receiver suitable for practical realization. The SC receiver extracts the branch with the highest signal-to-noise ratio. When the noise power in all branches is the same, branch with the strongest signal in the SC receiver is selected. Two input SC receiver with k-μ fast fading and slow gamma fading is considered. Analytical expression of LCR (Level Crossing Rate) for the given system is calculated. Numerical and graphical results based on the given analytical expression were obtained. Results show LCR behavior and received signal performance of the macrodiversity system depending on several system parameters: Ricean k factor, the depth of channel shading c and the number of clusters μ.*

Key words: *fading, level crossing rate (LCR), macrodiversity system, smart agriculture, selection combiner (SC)*

1. INTRODUCTION

In recent years, opportunities for the implementation of intelligent agricultural production have increased by the rapid development of Internet of Things (IoT) technology [1]. Agricultural IoT refers to a network in which physical components, environmental elements, production tools and various elements in the agricultural system are connected to perform agricultural information exchange and communication [2, 3]. Interconnection of agricultural IoT enhanced farmers ability to control complex agricultural systems, assist in handling agricultural emergencies and manage essential parts of the agricultural processes. The main challenges that arise in agricultural areas is a lack of connectivity or poor connection quality. In this paper, performance evaluation of RF communication system that can be used in IoT for agriculture is analyzed. Fig. 1 shows example of a WAN network architecture implemented in smart agriculture, realized with wireless RF communication system [3]. Illustration of implemented wireless RF communication system in agricultural environment is presented in Fig. 2 [3].

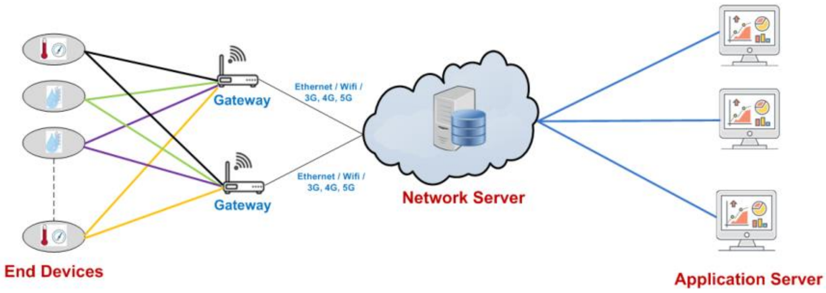

Fig. 1 Example of a WAN network architecture implemented in smart agriculture [3]

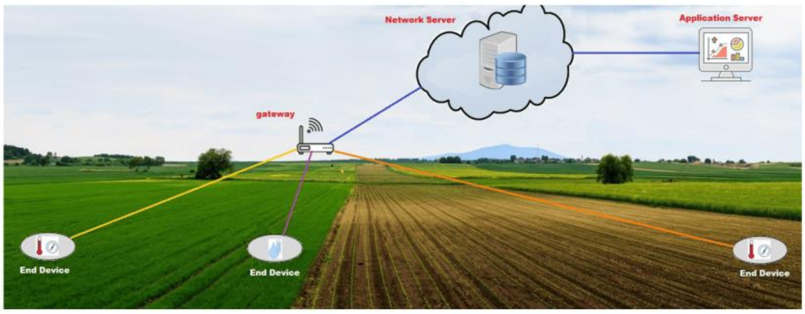

Fig. 2 Illustration of implemented wireless RF communication system in agricultural environment [3]

A variety of diversity techniques are used to reduce the impact of fast fading, slow fading and inter-channel interference on RF communication system performance. The diversity techniques can be spatial, temporal and frequency techniques. Multiple replicas of the same information signal are combined within diversity techniques. Spatial diversity techniques are most often used and they are realized with multiple antennas placed on the receiver. The application of spatial diversity techniques increases system reliability and channel capacity without increasing transmitter power and expanding the frequency range. There are several spatial diversity combining techniques that can be used to reduce the impact of fading and inter-channel interference on system performance depending on the complexity of the implementation and diversity gain. The most commonly used diversity techniques are MRC (maximum ratio combining) [4], EGC (equal gain combining) [5], SC (selection combining) [6], GSC (general selection combining) [7] and SSC (switch and stay combining) [8, 9].

Macrodiversity systems are used to reduce the simultaneous impact of fast and slow fading on system performance, and they are consisted of one, two or more microdiversity receivers (combiners). These systems are formed on base stations, and one macrodiversity combiner uses a signal from two or more base stations. Microdiversity receiver reduces the impact of fast fading on system performance, and macrodiversity reduces the impact of slow fading on system performance. Fading caused by multipath signal propagation can be correlated or uncorrelated. Slow fading caused by the shadow effect is mostly correlated. Cellular systems function in an interference-limited environment, so the power level of inter-channel interference is known to be higher than the power level of Gaussian noise. Therefore, the noise effects on system performance can be ignored [8]. Very often, the useful signal is exposed to fading with a dominant component, and inter-channel interference arising from another channel does not have a dominant component. It is important to determine how the error probability and failure probability of the telecommunication system changes under the influence of fading and inter-channel interference.

SC diversity receiver is simple, for practical realization, because the processing is done on one diversity branch only. The SC receiver selects the branch with the highest signal-to-noise ratio. If the noise power is the same in all branches, then the SC receiver selects the branch with the strongest signal.

The k-μ distribution can be used to describe the variation of the signal envelope in linear environments when: there is a dominant component, there are multiple clusters in the propagation environment, and the in-phase and quadrature component strengths are equal. k-μ distribution has two parameters. The parameter k is the Ricean factor and it is equal to the quotient of the power of the dominant component and the linear components. A sharper effect of fading occurs when Ricean k factor is smaller. The k-μ distribution is a general distribution. The Ricean, Nakagami and Rayleigh distributions can be obtained from the k-μ distribution, as special cases [10, 11]. When the parameter k=0, then the k-μ distribution changes to the Nakagami-m distribution. When μ=1, the Ricean distribution can be obtained from the k-μ distribution. Also, when k=0 and μ=1, the k-μ distribution approximates the Rayleigh distribution [4].

For all these receivers, it is necessary to determine the statistical characteristics of the signals at their outputs as well as the performance of the wireless telecommunication system. In order to calculate the performance of the second order, it is necessary to determine the joint probability distribution of the signal and the first derivative of the signal at the output of the diversity receiver [12]. This joint probability distribution is determined by transformation methods. Using this joint probability distribution, the LCR is determined. The LCR is determined as the mean value of the first derivative of the signal. Using the average number of axle sections (LCR), the average system failure time is determined. The mean duration of the failure is determined using the signals joint probability distribution (at two moments of time). and their first derivatives.

2. STATISTICAL CHARACTERISTICS OF THE SIGNAL AT THE SC COMBINER OUTPUT

A SC combiner with two inputs is considered. k-μ fading is present at the inputs. The model of the system under consideration is shown in Fig. 3.

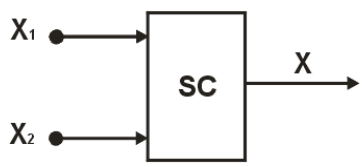

Fig. 3 SC combiner with two inputs

The signals at the inputs are marked with x_1 and x_2, and the signal at the output is marked with x. The probability densities of x_1 and x_2 are [8]:

$$p_{x_1}(x_1)=\frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}}e^{\mu k}\Omega_1}\sum_{i_1=0}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2i_1+\mu-1}\frac{1}{i_1!\Gamma(i_1+\mu)}x_1^{2i_1+2\mu-1}e^{-\frac{\mu(k+1)x_1^2}{\Omega_1}} \quad (1)$$

$$p_{x_2}(x_2)=\frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}}e^{\mu k}\Omega_2}\sum_{i_2=0}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_2}}\right)^{2i_2+\mu-1}\frac{1}{i_2!\Gamma(i_2+\mu)}x_2^{2i_2+2\mu-1}e^{-\frac{\mu(k+1)x_2^2}{\Omega_2}} \quad (2)$$

where Ω_1 and Ω_2 represent the signal strength at inputs 1 and 2 of the SC combiner. The joint probabilities of x_1 and x_2 are:

$$F_{x_1}(x_1)=\frac{\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}}e^{\mu k}\Omega_1^{\mu+1}}\sum_{i_1=0}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2i_1+\mu-1}\frac{1}{i_1!\Gamma(i_1+\mu)}\left(\frac{\Omega_1}{\mu(k+1)}\right)^{i_1+\mu}\gamma\left(i_1+\mu,\frac{\mu(k+1)}{\Omega_1}x^2\right) \quad (3)$$

$$F_{x_2}(x_2)=\frac{\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}}e^{\mu k}\Omega_2^{\mu+1}}\sum_{i_2=0}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_2}}\right)^{2i_2+\mu-1}\frac{1}{i_2!\Gamma(i_2+\mu)}\left(\frac{\Omega_2}{\mu(k+1)}\right)^{i_2+\mu}\gamma\left(i_2+\mu,\frac{\mu(k+1)}{\Omega_2}x^2\right) \quad (4)$$

where where $\gamma(\cdot)$ represents the lower incomplete Gamma function. The joint probability distribution of x and $\dot{x}$ is:

$$p_{x\dot{x}}(x\dot{x})=p_{x_1\dot{x}_1}(x\dot{x})F_{x_2}(x)+p_{x_2\dot{x}_2}(x\dot{x})F_{x_1}(x)=2p_{x_1\dot{x}_1}(x\dot{x})F_{x_2}(x), \quad (5)$$

The LCR for $\dot{x}$ (5) is:

$$N_x=\int_0^{\infty}dx\dot{x}p_{x\dot{x}}(x\dot{x})=2F_{x_2}(x)\int_0^{\infty}dx\dot{x}p_{x_1\dot{x}_1}(x\dot{x})=2F_{x_2}(x)N_{x_1}, \quad (6)$$

where Nx_1 is given by:

$$N_x=\frac{\sqrt{2\pi}f_m\mu^{\frac{1}{2}}(k+1)^{\frac{\mu}{2}}}{k^{\frac{\mu-1}{2}}e^{\mu k}x_0^{\mu+\frac{1}{2}}}\sum_{i_1=0}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{x_0}}\right)^{2i_1+\mu-1}\frac{1}{i_1!\Gamma(i_1+\mu)}x^{2i_1+2\mu-1}e^{-\frac{\mu(k+1)x^2}{x_0}}, \quad (7)$$

and Fx_2 with (4). After substituting (7) and (4) into (6), the LCR for $\dot{x}$ is:

$$\begin{aligned}N_x=&\frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}}e^{\mu k}\Omega_1^{\mu+1}}\sum_{i_2=0}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2i_2+\mu-1}\frac{1}{i_2!\Gamma(i_2+\mu)}\left(\frac{\Omega_1}{\mu(k+1)}\right)^{i_2+\mu}\gamma\left(i_2+\mu,\frac{\mu(k+1)}{\Omega_1}x^2\right)\times\\&\times\frac{\sqrt{2\pi}f_m\mu^{\frac{1}{2}}(k+1)^{\frac{\mu}{2}}}{k^{\frac{\mu-1}{2}}e^{\mu k}\Omega_1^{\mu+\frac{1}{2}}}\sum_{i_1=0}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2i_1+\mu-1}\frac{1}{i_1!\Gamma(i_1+\mu)}x^{2i_1+2\mu-1}e^{-\frac{\mu(k+1)x^2}{\Omega_1}}\end{aligned}. \quad (8)$$

Based on Eq. 8, Fig. 3 shows the change in LCR depending on the signal amplitude *x*, for the values of Ricean *k* factor and the number of clusters μ. The average signal strength is Ω_1=1. The maximum of LCR, in the given sections, is significantly increased for lower values of Ricean *k* factor and parameter μ. Also, the maximum value of LCR is lower for higher values of parameter *k* and parameter μ.

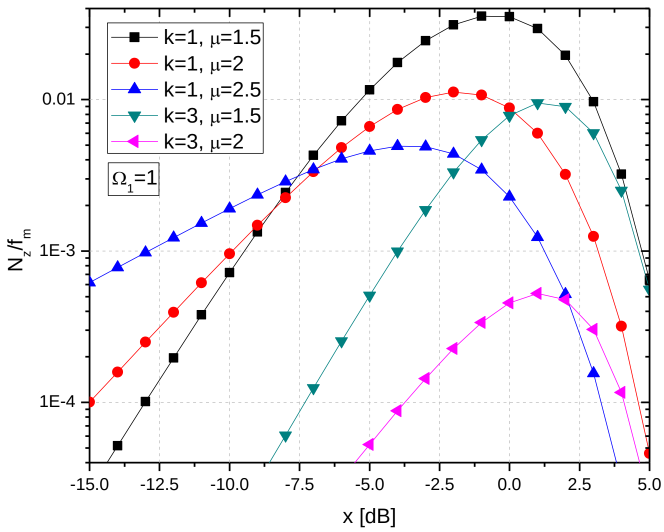

Fig. 4 LCR at the output of the microdiversity SC receiver for different values of the Ricean *k* factor and the number of clusters μ

3. MACRODIVERSITY SYSTEM WITH TWO MICRODIVERSITY SC COMBINERS

A macrodiversity system with one macrodiversity SC receiver and two microdiversity SC combiners is observed. The model under consideration is shown in Fig. 5. There is *k*-μ fading at the inputs. The signals at the inputs of the first microdiversity SC combiner are x_1 and x_2. The inputs of the second microdiversity SC combiner are y_1 and y_2. The output signal of the first microdiversity SC combiner is x and the output of the second microdiversity SC combiner is y. The output signal from the macrodiversity SC receiver is z.

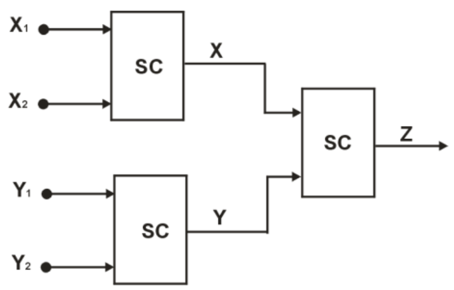

Fig. 5 Macrodiversity system with two microdiversity SC combiners

The LCR for x and y (output signals of the first and second microdiversity SC combiners) are:

$$N_x = \frac{2\sqrt{2\pi} f_m \mu^{\frac{3}{2}} (k+1)^{\mu+\frac{1}{2}}}{k^{\mu-1} e^{2\mu k} \Omega_1^{2\mu+\frac{3}{2}}} \sum_{i_1=0}^{\infty} \left(\mu \sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2i_1+\mu-1} \frac{1}{i_1! \Gamma(i_1+\mu)} x^{2i_1+2\mu-1} e^{-\frac{\mu(k+1)x^2}{\Omega_1}} \times$$
$$\times \sum_{i_2=0}^{\infty} \left(\mu \sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2i_2+\mu-1} \frac{1}{i_2! \Gamma(i_2+\mu)} \left(\frac{\Omega_1}{\mu(k+1)}\right)^{i_2+\mu} \gamma\left(i_2+\mu, \frac{\mu(k+1)}{\Omega_1} x^2\right), \quad (9)$$

and

$$N_y = \frac{2\sqrt{2\pi} f_m \mu^{\frac{3}{2}} (k+1)^{\mu+\frac{1}{2}}}{k^{\mu-1} e^{2\mu k} \Omega_2^{2\mu+\frac{3}{2}}} \sum_{j_1=0}^{\infty} \left(\mu \sqrt{\frac{k(k+1)}{\Omega_2}}\right)^{2j_1+\mu-1} \frac{1}{j_1! \Gamma(j_1+\mu)} y^{2j_1+2\mu-1} e^{-\frac{\mu(k+1)y^2}{\Omega_2}} \times$$
$$\times \sum_{j_2=0}^{\infty} \left(\mu \sqrt{\frac{k(k+1)}{\Omega_2}}\right)^{2j_2+\mu-1} \frac{1}{j_2! \Gamma(j_2+\mu)} \left(\frac{\Omega_2}{\mu(k+1)}\right)^{j_2+\mu} \gamma\left(j_2+\mu, \frac{\mu(k+1)}{\Omega_2} y^2\right). \quad (10)$$

The average signal strengths Ω_1 and Ω_2 have a joint probability distribution:

$$p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) = \frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}} \Omega_0^{c+1}} (\Omega_1\Omega_2)^{\frac{c-1}{2}} e^{-\frac{\Omega_1+\Omega_2}{\Omega_0(1-\rho^2)}} I_{c-1}\left(\frac{2\rho}{\Omega_0(1-\rho^2)} \Omega_1^{\frac{1}{2}} \Omega_2^{\frac{1}{2}}\right) =$$
$$= \frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}} \Omega_0^{c+1}} \sum_{i_3=0}^{\infty} \left(\frac{\sqrt{\rho}}{\Omega_0(1-\rho^2)}\right)^{2i_3+c-1} \frac{1}{i_3! \Gamma(i_3+c)} \Omega_1^{i_3+c-1} \Omega_2^{i_3+c-1} e^{-\frac{\Omega_1+\Omega_2}{\Omega_0(1-\rho^2)}}, \quad (11)$$

where Ω_0 is the root mean square value of power change, ρ is the correlation coefficient at the macro level, and c is the depth of channel shading. The LCR of z (output signal of the macrodiversity SC combiner) is:

$$N_z = \int_0^{\infty} d\Omega_1 \int_0^{\Omega_1} d\Omega_2 N_{x/\Omega_1} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) + \int_0^{\infty} d\Omega_2 \int_0^{\Omega_2} d\Omega_1 N_{y/\Omega_2} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) =$$
$$= 2\int_0^{\infty} d\Omega_1 \int_0^{\Omega_1} d\Omega_2 N_{x/\Omega_1} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2), \quad (12)$$

where $N_{x/\Omega1}$ is given by (9), and $p_{\Omega1\Omega2}$ by (11). After replacing (9) and (11) in (12), we get:

$$N_z = \frac{4\sqrt{2\pi} f_m \mu^{\frac{3}{2}} (k+1)^{\mu+\frac{1}{2}}}{k^{\mu-1} e^{2\mu k}} \sum_{i_1=0}^{\infty} \left(\mu\sqrt{k(k+1)}\right)^{2i_1+\mu-1} \frac{1}{i_1! \Gamma(i_1+\mu)} x^{2i_1+2\mu-1} \sum_{i_2=0}^{\infty} \left(\mu\sqrt{k(k+1)}\right)^{2i_2+\mu-1} \times$$
$$\times \frac{1}{i_2! \Gamma(i_2+\mu)} \left(\frac{1}{\mu(k+1)}\right)^{i_2+\mu} \frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}} \Omega_0^{c+1}} \sum_{i_3=0}^{\infty} \left(\frac{\sqrt{\rho}}{\Omega_0(1-\rho^2)}\right)^{2i_3+c-1} \frac{1}{i_3! \Gamma(i_3+c)} \times$$
$$\times \int_0^{\infty} d\Omega_1 \Omega_1^{-i_1+i_3+c-2\mu-\frac{3}{2}} e^{-\frac{\mu(k+1)x^2}{\Omega_1} - \frac{\Omega_1}{\Omega_0(1-\rho^2)}} \gamma\left(i_2+\mu, \frac{\mu(k+1)}{\Omega_1} x^2\right) \int_0^{\Omega_1} d\Omega_2 \Omega_2^{i_3+c-1} e^{-\frac{\Omega_2}{\Omega_0(1-\rho^2)}}. \quad (13)$$

By applying [9], the integral $\int_0^{\Omega_1} d\Omega_2 \Omega_2^{i_3+c-1} e^{-\frac{\Omega_2}{\Omega_0(1-\rho^2)}}$ is solved, after which it is obtained:

$$N_z = \frac{4\sqrt{2\pi} f_m \mu^{\frac{3}{2}} (k+1)^{\mu+\frac{1}{2}}}{k^{\mu-1} e^{2\mu k}} \sum_{i_1=0}^{\infty} \left(\mu\sqrt{k(k+1)}\right)^{2i_1+\mu-1} \frac{x^{2i_1+2\mu-1}}{i_1!\Gamma(i_1+\mu)} \sum_{i_2=0}^{\infty} \left(\mu\sqrt{k(k+1)}\right)^{2i_2+\mu-1} \times$$
$$\times \frac{1}{i_2!\Gamma(i_2+\mu)} \left(\frac{1}{\mu(k+1)}\right)^{i_2+\mu} \frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}} \Omega_0^{c+1}} \sum_{i_3=0}^{\infty} \left(\frac{\sqrt{\rho}}{\Omega_0(1-\rho^2)}\right)^{2i_3+c-1} \frac{\left(\Omega_0(1-\rho^2)\right)^{i_3+c}}{i_3!\Gamma(i_3+c)} \times , \tag{14}$$
$$\times \int_0^{\infty} d\Omega_1 \Omega_1^{-i_1+i_3+c-2\mu-\frac{3}{2}} e^{-\frac{\mu(k+1)x^2}{\Omega_1} - \frac{\Omega_1}{\Omega_0(1-\rho^2)}} \gamma\left(i_2+\mu, \frac{\mu(k+1)}{\Omega_1} x^2\right) \gamma\left(i_3+c, \frac{\Omega_1}{\Omega_0(1-\rho^2)}\right)$$

The observed integral is:

$$I = \int_0^{\infty} d\Omega_1 \Omega_1^{-i_1+i_3+c-2\mu-\frac{3}{2}} e^{-\frac{\mu(k+1)x^2}{\Omega_1} - \frac{\Omega_1}{\Omega_0(1-\rho^2)}} \gamma\left(i_2+\mu, \frac{\mu(k+1)}{\Omega_1} x^2\right) \gamma\left(i_3+c, \frac{\Omega_1}{\Omega_0(1-\rho^2)}\right). \tag{15}$$

By developing the lower incomplete Gamma function and by applying [9], it is obtained:

$$I = \int_0^{\infty} d\Omega_1 \Omega_1^{-i_1+i_3+c-2\mu-\frac{3}{2}} e^{-\frac{\mu(k+1)x^2}{\Omega_1} - \frac{\Omega_1}{\Omega_0(1-\rho^2)}} \times$$
$$\times \frac{1}{i_2+\mu} \left(\frac{\mu(k+1)x^2}{\Omega_1}\right)^{i_2+\mu} e^{\frac{\mu(k+1)x^2}{\Omega_1}} \sum_{j_1=0}^{\infty} \frac{(i_2+\mu)!}{(i_2+\mu+j_1)!} \frac{\left(\mu(k+1)x^2\right)^{j_1}}{\Omega_1^{j_1}} \times$$
$$\times \frac{1}{i_3+c} \left(\frac{\Omega_1}{\Omega_0(1-\rho^2)}\right)^{i_3+c} e^{-\frac{\Omega_1}{\Omega_0(1-\rho^2)}} \sum_{j_2=0}^{\infty} \frac{(i_3+c)!}{(i_3+c+j_2)!} \frac{\Omega_1^{j_2}}{\left(\Omega_0(1-\rho^2)\right)^{j_2}} = \quad . \tag{16}$$
$$= \frac{1}{i_2+\mu} \left(\mu(k+1)x^2\right)^{i_2+\mu} \sum_{j_1=0}^{\infty} \frac{(i_2+\mu)!}{(i_2+\mu+j_1)!} \left(\mu(k+1)x^2\right)^{j_1} \times$$
$$\times \frac{1}{i_3+c} \frac{1}{\left(\Omega_0(1-\rho^2)\right)^{i_3+c}} \sum_{j_2=0}^{\infty} \frac{(i_3+c)!}{(i_3+c+j_2)!} \frac{1}{\left(\Omega_0(1-\rho^2)\right)^{j_2}} \times$$
$$\times \left(\mu(k+1)x^2 \Omega_0(1-\rho^2)\right)^{-\frac{i_1}{2}-\frac{i_2}{2}+i_3-\frac{j_1}{2}+\frac{j_2}{2}+c-\frac{3\mu}{2}-\frac{1}{4}} K_{-i_1-i_2+2i_3-j_1+j_2+2c-3\mu-\frac{1}{2}}\left(2\sqrt{\frac{4\mu(k+1)x^2}{\Omega_0(1-\rho^2)}}\right)$$

After replacing (16) in (14), the LCR equation for the output of the macrodiversity SC combiner is obtained:

$$
\begin{aligned}
N_z = {} & \frac{4\sqrt{2\pi} f_m \mu^{\frac{3}{2}} (k+1)^{\mu+\frac{1}{2}}}{k^{\mu-1} e^{2\mu k}} \sum_{i_1=0}^{\infty} \left(\mu\sqrt{k(k+1)}\right)^{2i_1+\mu-1} \frac{x^{2i_1+2\mu-1}}{i_1!\Gamma(i_1+\mu)} \sum_{i_2=0}^{\infty} \left(\mu\sqrt{k(k+1)}\right)^{2i_2+\mu-1} \times \\
& \times \frac{1}{i_2!\Gamma(i_2+\mu)} \left(\frac{1}{\mu(k+1)}\right)^{i_2+\mu} \frac{1}{\Gamma(c)\left(1-\rho^2\right)\rho^{\frac{c-1}{2}}\Omega_0^{c+1}} \sum_{i_3=0}^{\infty} \left(\frac{\sqrt{\rho}}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_3+c-1} \frac{\left(\Omega_0\left(1-\rho^2\right)\right)^{i_3+c}}{i_3!\Gamma(i_3+c)} \times \\
& \times \frac{1}{i_2+\mu}\left(\mu(k+1)x^2\right)^{i_2+\mu} \sum_{j_1=0}^{\infty} \frac{(i_2+\mu)!}{(i_2+\mu+j_1)!}\left(\mu(k+1)x^2\right)^{j_1} \times \frac{1}{i_3+c} \frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{i_3+c}} \sum_{j_2=0}^{\infty} \frac{(i_3+c)!}{(i_3+c+j_2)!} \frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{j_2}} \times \\
& \times \left(\mu(k+1)x^2\Omega_0\left(1-\rho^2\right)\right)^{-\frac{i_1}{2}-\frac{i_2}{2}+i_3-\frac{j_1}{2}+\frac{j_2}{2}+c-\frac{3\mu}{2}-\frac{1}{4}} K_{-i_1-i_2+2i_3-j_1+j_2+2c-3\mu-\frac{1}{2}}\left(2\sqrt{\frac{4\mu(k+1)x^2}{\Omega_0\left(1-\rho^2\right)}}\right)
\end{aligned}
\quad ,(17)
$$

Using (17), the LCR of the signal at the output of the macrodiversity SC combiner is presented graphically in Fig. 6, 7 and 8.

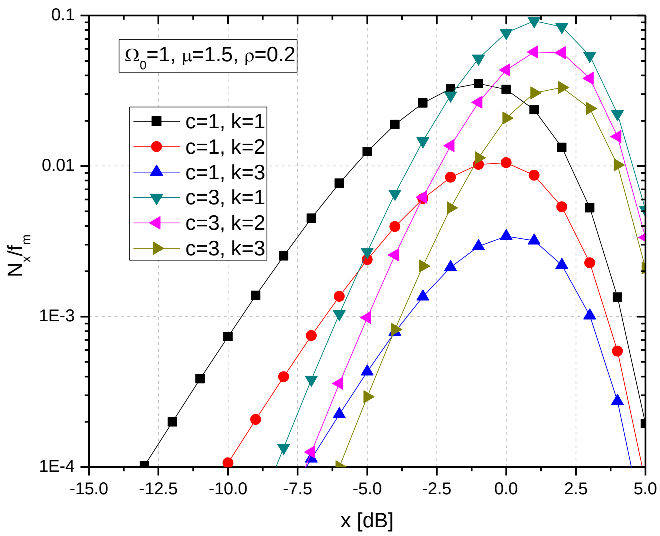

Fig. 6 LCR at the output of the macrodiversity system, for different values of Ricean *k* factor and the depth of channel shading *c*

Fig. 6 shows the normalized LCR at the output of the macrodiversity system depending on the signal amplitude ***x*,** for different values of Ricean *k* factor and depth of channel shading *c*. The mean square value of the power change is Ω_0=1, the number of clusters through which the signal spreads is μ=1.5 and the correlation coefficient is ρ=0.2. The maximum of LCR is reached faster for higher values of depth of channel shading *c* than for lower ones. With an increase of Ricean *k* factor, LCR decreases, while an increase of depth of channel shading *c* leads to LCR increase.

Fig. 7 shows the change in the normalized LCR depending on depth of channel shading *c*, for different values of Ricean *k* factor and the number of clusters μ. The signal amplitude is x=1, and the correlation coefficient is ρ=0.2. *LCR* increases with the increase of the depth of channel shading *c*. At lower values of the channel shading depth *c*, *LCR* increases more slowly. The growth is faster for lower values of the number of clusters μ and Ricean *k* factor. Higher values of *LCR* are obtained for lower values of the number of clusters μ and Rice's *k* factor.

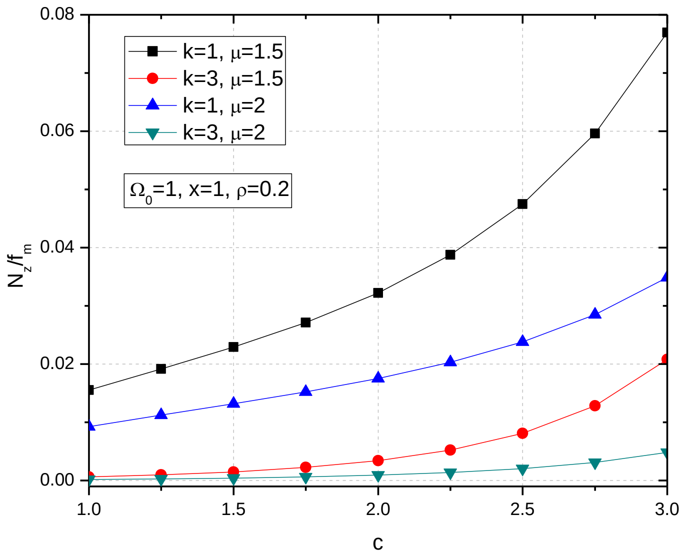

Fig. 7 LCR depending on the depth of channel shading *c*, at the macrodiversity system output

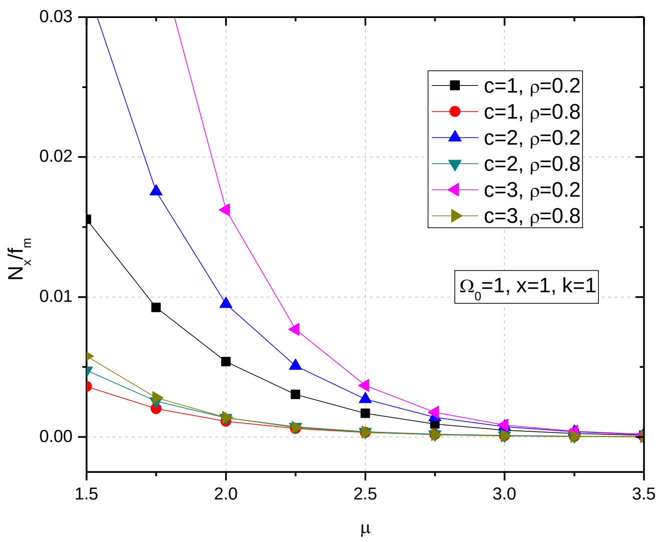

Fig. 8 LCR depending on the number of clusters μ, at the macrodiversity system output

Fig. 8 shows the normalized LCR at the macrodiversity system output, depending on the number of clusters μ, for different values of the channel shading depth c and the correlation coefficient ρ. The mean square value of the power change is Ω_0=1, the signal amplitude is x=1.5, and the Ricean factor is k=1. LCR decreases with the increase in the number of clusters μ**.** The decrease is much more pronounced for lower values of the number of clusters μ, so with its increase, LCR tends to zero. For higher values of the channel shading depth c, the LCR decrease is much more pronounced. For lower values of the correlation coefficient ρ, the decrease in LCR is faster.

3. Conclusion

Smart agriculture has allowed agricultural production to increase while reducing or maintaining system inputs. This can only be sustained by continuous research and investment into novel technologies. Based on the obtained results for the LCR, to determine the amplitude levels and average power of the desired signal, on reception. Furthermore, it is possible to optimize the parameters of wireless transmission and the emission power of the signal, based on the reception characteristics. Using the results presented in this paper, the behavior of different RF wireless communication system implementations for various propagation environments of agricultural IoTs can be predicted. This prediction allows designers to create rational systematic solutions for the desired system performance.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

STATISTICAL MODELS FOR DESCRIBING SIGNAL PROPAGATION IN FSO SYSTEMS IN AGRICULTURE

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Abstract: *FSO (Free Space Optics) is a communication technology that enables wireless gigabit data transmission in both directions (full-duplex). FSO communication refers to Line-of-Sight technology that transmits modulated visible or infrared rays through the atmosphere to establish optical communications. Application of FSO systems in IoT devices, remote sensing and production optimization in agriculture is emerging. Channel description using appropriate model for design of a high-performance communication link for an atmospheric FSO channel is of great importance. There are several models for the joint distribution of amplitudes, although none is universally accepted due to importance of atmospheric conditions. This paper provides an overview of the most popular statistical models for describing signal propagation in FSO systems: Gamma-Gamma, Log-Normal, Negative Exponential, K-distribution, I-K distribution, Rice, Inverse-Gaussian, Double Weibull, Exponential Weibull, Double generalized Gamma distribution. Basic characteristics and mathematical models as a function of signal intensity are given. Also, for general models, reducing one model to another is given.*

Key words: *Free Space Optics (FSO), FSO systems, signal propagation, statistical models, smart agriculture*

1. INTRODUCTION

In smart agriculture, efficient control of irrigation and fertigation is primarily based on automatization and crop monitoring. Choosing the equipment that best suits the needs of the crop is equally important as determination of the ideal communication path between the different actuators and probes to the controller. Measuring the parameters of humidity, temperature, electrical conductivity in soils and substrates, climatic parameters and agronomic variables in smart agriculture is done with the use of wireless technology [1]. Wireless communication systems are used to communicate the various actuators in the field and to read out probes, creating the network (mesh) which allows the control equipment to be connected to remote input and output modules. FSO (Free Space Optics) is a communication technology that enables wireless gigabit data transmission. It finds application in Internet of Things (IoT) devices, remote sensing and production optimization in smart agriculture. Fig. 1 depicts the various areas where FSO can be implemented, such as hospitals, submarines, business buildings, and agriculture farms [2].

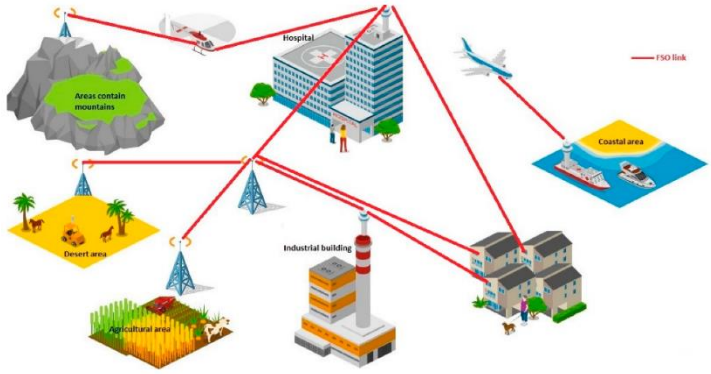

Fig. 1 Various areas of FSO communication system implementations [2]

In recent years, there has been a growing interest in researching and developing new ways of implementing FSO and other wireless communication systems in smart agriculture and precision agriculture (PA) [3, 4, 5].

Continuous development of various services in wireless telecommunication systems leads to more studies and improvements of their performance. The basic requirements in the process of improving the performance of wireless telecommunication systems are: high transmission speeds, high channel capacity and the greatest possible connection range with the least possible error probability. One of the current challenges in wireless communications is the ability to provide a cost-effective high-speed data link in applications where radio frequency (RF)-based technology cannot be used or is not suitable [6, 7]. For example, in closed environments with a large population (railway station, airports, etc.) and the "last mile" network, where end users, using RF wireless technologies, encounter lower data rates and poorer quality services.

A high-speed optical wireless connection is defined as a data connection with a minimum speed of several Gb/s. Nowadays, there is an increasing number of applications that require quality access to data transmission services anywhere, anytime and under all conditions. In a perfect scenario, all end-users should have access to an extremely high-capacity, high-speed, ultra-low-latency fiber-based backbone. Of course, for an environment, like in agriculture, where fiber optic deployment is not economical, a combination of satellite communications and fiber optic communication technologies would be the most suitable option. However, this can be quite expensive and therefore may not be feasible in the long run. Limited bandwidth and the high price of RF technology increased the need to consider alternative technologies [8, 9]. The costs and challenges associated with the installation of optical fibers, as well as the maintenance of such a network, are quite high, especially in agricultural areas. Therefore, optical fibers are not considered for the last kilometer access network (last mile network) [10].

FSO is a new and promising technology for next-generation wireless communications, such as short-range wireless communications, wireless cellular networks, last-mile access, and free-space laser communications. FSO systems enable signal transmission with a throughput of several Gb/s, while microwave connections enable a throughput of several

Mb/s. FSO technology is readily available, secure and capable of offering low error probability as well as high speeds in the range of up to 10 km. Compared with traditional RF communications, the attractive features of FSO technology include license-free operation, simple implementation, high data rate and high transmission security [10, 11, 12].

This paper provides an overview of the most popular statistical models for describing signal propagation in FSO systems: Gamma-Gamma, Log-Normal, Negative Exponential, K-distribution, I-K distribution, Rice, Inverse-Gaussian, Double Weibull, Exponential Weibull, Double generalized Gamma distribution.

2. Statistical models for describing signal propagation in FSO

For the design of a high-performance communication link for an atmospheric FSO channel, it is of great importance to describe the channel using an appropriate model. There are several models for the joint distribution of amplitudes, although none is universally accepted, as atmospheric conditions are clearly important.

2.1. Gamma-Gamma distribution

The Gamma-Gamma distribution is used to model the atmospheric channel in weak, moderate and strong atmospheric turbulence. This model provides good results compared to experimental ones. The Gamma-Gamma turbulence model is based on a modulation process where it is assumed that the fluctuation of light radiation, crossing the turbulent atmosphere, consists of small-scale (scattering) and large-scale (refraction) effects [13, 14, 15]. Scattering is formed by vortex cells smaller than the Fresnel zone or coherence radius, while the refraction effects are formed due to turbulent vortex cells larger than the first Fresnel zone. Accordingly, the intensity of the received signal I is defined as the product of two statistically independent random processes I_x and I_y, i.e.:

$$I = I_x I_y. \tag{1}$$

The random processes I_x and I_y arise from large-scale and small-scale turbulence vortex cells described by the Gamma distribution:

$$f(I_x) = \frac{\alpha(\alpha I_x)^{\alpha-1}}{\Gamma(\alpha)} e^{-\alpha I_x}, \qquad I_x > 0, \qquad \alpha > 0, \tag{2}$$

$$f(I_y) = \frac{\beta(\beta I_y)^{\beta-1}}{\Gamma(\beta)} e^{-\beta I_y}, \qquad I_y > 0, \qquad \beta > 0. \tag{3}$$

The probability density function (PDF) for the Gamma-Gamma model, as a function of intensity, is given by the expression:

$$f(I) = \frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} I^{\frac{\alpha+\beta}{2}-1} K_{\alpha-\beta}\left(2\sqrt{\alpha\beta I}\right), \tag{4}$$

where $\Gamma(\cdot)$ represents the Gamma function, and $K_\upsilon(\cdot)$ is a modified Bessel function of the second kind of the u-th order. The parameters α and β represent the effective number of large-scale and small-scale effects, respectively. These parameters are related to the operating frequency, the aperture of the lens and the distance between the transmitter and the receiver (propagation length of the optical signal). Parameters α and β are parameters of atmospheric turbulence that describe the scintillation of plane waves, in the case when $l_0 = 0$ ("zero inner scale"). If it is assumed that the optical radiation is a plane wave, these parameters, that characterize the radiation fluctuation (scintillation), can be expressed as:

$$\alpha = \left[e^{\frac{0.49\sigma_R^2}{\left(1+1.11\sigma_R^{12/5}\right)^{7/6}}} - 1 \right]^{-1}, \quad (5)$$

$$\beta = \left[e^{\frac{0.51\sigma_R^2}{\left(1+0.69\sigma_R^{12/5}\right)^{5/6}}} - 1 \right]^{-1}, \quad (6)$$

where σ_R^2 represents the Rytov approximation described by Eq. 2.

2.2. Log-Normal distribution

Atmospheric turbulence degrades the performance of the FSO link by causing the received optical signal to vary randomly, leading to signal dropouts. The strength of fading depends on the length of the connection, the wavelength of the optical radiation and the structure parameter of the refractive index of the channel. The Log-Normal distribution is commonly used to model the atmospheric channel in low and moderate atmospheric turbulence. Also, it is suitable for characterizing FSO communications in clear sky conditions over several hundreds of meters. This model is mathematically feasible and it is characterized by Rytov approximation. Fading caused by turbulence is considered weak, when $\sigma_R^2 < 1.2$. This defines the validity limit of the Log-Normal model [13, 16]. In the case of the Log-Normal model, it is assumed that the atmospheric turbulence intensity I (of the laser light crossing) is normally distributed with a mean value of $\sigma_R^2/2$. Thus, the PDF of the Log-Normal distribution, as a function of the intensity at the receiver, is given by:

$$f_I(I) = \frac{1}{\sqrt{2\pi\sigma^2}} \frac{1}{I} exp\left(- \frac{\left(ln(I) + \frac{\sigma^2}{2} \right)^2}{2\sigma^2} \right), \quad (7)$$

where the parameter σ represents the scintillation index defined by Eq. 2 [17].

2.3. Negative exponential distribution

The negative exponential distribution can be used for channel modeling in conditions of strong atmospheric turbulence or when the scintillation index is 1. The negative exponential distribution can be used for communication over longer distances of the order of several kilometers.

The PDF for the Negative Exponential Model is given by the expression:

$$f_I(I) = \frac{1}{I_0} e^{-\frac{I}{I_0}}, \quad (8)$$

where I_0 is the mean value of the received intensity [18, 19, 20].

2.4. Rice distribution

Rice's turbulence model proved to be the most suitable for turbulence scenarios that occur in terrestrial communication, over sparsely populated areas and suburbs [21, 22, 23]. The PDF of the fading amplitude, of the Ricean distribution, is given by the following expression:

$$f_{\alpha_a}(\alpha_a) = \frac{2\alpha_a(1+K)}{\overline{\alpha_a^2}} e^{-K-\frac{(1+K)\alpha_a^2}{\overline{\alpha_a^2}}} I_0\left(2\alpha_a\sqrt{\frac{K(1+K)}{\overline{\alpha_a^2}}}\right), \tag{9}$$

where $I_0(\cdot)$ is a modified zero-order Bessel function of the first kind. The parameter α_a represents the effective FSO fading fluctuation in the channel. This parameter represents the influence of the amplitude and phase fluctuation of the optical field ($\alpha_a^2 = \alpha_r^2 + \alpha_i^2$), with a mean value of $\overline{\alpha_a^2}$. The parameter K is the ratio of the power of the coherent and incoherent components, and it is given by:

$$K = \left[\frac{\overline{\alpha_a^2}}{\sqrt{\overline{\alpha_r}^4 + 2\overline{\alpha_r}^2(\sigma_i^2 - \sigma_r^2) - (\sigma_i^2 - \sigma_r^2)^2}} - 1\right]^{-1}, \tag{10}$$

while:

$$\overline{\alpha_a^2} = \sigma_i^2 + \sigma_r^2 + \overline{\alpha_r}^2, \tag{11}$$

with parameters expressed depending on the wave number $k = 2\pi/\lambda$, refractive index C_n^2 and propagation length. Amplitude and phase fluctuations of the optical field define the statistics of fading intensity. Therefore, α_r and α_i represent the real and imaginary part of the parameter α_a and it is valid that:

$$\overline{\alpha_r} = e^{-\frac{\left(\sigma_\chi^2 + \sigma_\phi^2\right)}{2}},$$

$$\overline{\alpha_i} = 0,$$

$$\sigma_r^2 = \left(\frac{1}{2G}\right)\left(1 + e^{-2\sigma_\phi^2} - 2e^{-\sigma_\chi^2 - \sigma_\phi^2}\right),$$

$$\sigma_i^2 = (1/2G)\left(1 + e^{-2\sigma_\phi^2}\right), \tag{12}$$

where σ_χ^2 is the Log-amplitude variance, which is given as: $\sigma_\chi^2 = 0.307 C_n^2 k^{7/6} L^{11/6}$. σ_ϕ^2 is the residual variance of the phase, and G is the number of statistically independent "patches". G represents the region within which the received wavefront is approximately coherent. The parameter K ranges from 0 to ∞. It can be shown that, when the dominant parameter is very weak ($K \rightarrow 0$), the fading intensity α_a becomes negatively-exponentially distributed. When K is large, it can be shown that the PDF of α_a approximates a Gaussian distribution with mean of $\overline{\alpha_a^2}$.

2.5. K-distribution

The K-distribution is used to model the atmospheric channel in strong atmospheric turbulence. The experimental data of the K-distribution fit well with the theoretical data [18, 20]. The K-distribution is the product of the Negative Exponential distribution, described by (8) and the Gamma distribution described by (2), so its PDF is:

$$f_I(I) = \frac{2\alpha^{\frac{\alpha+1}{2}}}{\Gamma(\alpha)} I^{\frac{\alpha-1}{2}} K_{\alpha-1}\left(2\sqrt{\alpha I}\right), \tag{13}$$

where the parameter α is defined by Eq. 3. The scintillation index predicted by the K-distribution, takes the form σ_I^2=1+2/α. It always exceeds 1, but approaches it when α → ∞. When α → ∞, the Gamma distribution approaches the delta function and the K-distribution reduces to the Negative Exponential Distribution. Therefore, the K-distribution is not valid under weak radiation fluctuations, for which the scintillation index is less than 1. One attempt to extend the K-distribution for the case of weak fluctuations led to the I-K distribution. When comparing these PDFs with measured radiation data in atmospheric turbulence, deficiencies are noted in both the K and I-K models. It was not easy to relate mathematical parameters to atmospheric turbulence and therefore it has limited application and use.

2.6. I-K distribution

The I-K distribution is generalized form of the K-distribution that is applicable to all conditions of atmospheric turbulence, including weak turbulence (for which the K-distribution is not suitable). For the I-K distribution, the optical wave field is modeled as the sum of a coherent (deterministic) component and a random component. The I-K distribution is used to model the atmospheric channel in weak and strong atmospheric turbulence. The I-K distribution, as a function of intensity, is given by the expression:

$$f_I(I) = \begin{cases} 2\alpha(1+\rho)\left(1+\frac{1}{\rho}\right)^{\frac{\alpha-1}{2}} I^{\frac{\alpha-1}{2}} K_{\alpha-1}\left(2\sqrt{\alpha\rho}\right) \times \\ \times I_{\alpha-1}\left(2\sqrt{\alpha(1+\rho)I}\right), \qquad 0 < I < \frac{\rho}{1+\rho} \\ 2\alpha(1+\rho)\left(1+\frac{1}{\rho}\right)^{\frac{\alpha-1}{2}} I^{\frac{\alpha-1}{2}} I_{\alpha-1}\left(2\sqrt{\alpha\rho}\right) \times \\ \times K_{\alpha-1}\left(2\sqrt{\alpha(1+\rho)I}\right), \qquad I > \frac{\rho}{1+\rho} \end{cases}, \tag{14}$$

where $I_u(\cdot)$ is a modified Bessel function of the first kind of the u-th order. The normalized I-K distribution, in Eq. 14, includes two empirical parameters ρ and α, whose values are chosen by matching the first three normalized moments of the distribution. The parameter α is defined by Eq. 5. The parameter ρ is a measure of mean intensities power ratio of the coherent and random field components. For extremely weak scattering the field is dominated by the coherent component, leading to relatively large ρ. The weak and strong scattering mode can be obtained by properly choosing the values of α and ρ. Due to the symmetry of functional forms, that include Bessel functions of the first and second kind (I and K), this distribution was named the I-K distribution. The I-K distribution reduces to the K-distribution when ρ = 0.

2.7. Inverse-Gaussian (I-G) distribution

The Inverse-Gaussian distribution (I-G) is modeled as a Log-Normal distribution alternative. The I-G distribution is used to model the atmospheric channel in weak atmospheric turbulence. The PDF of the I-G distribution is given as:

$$f(I) = \sqrt{\frac{\lambda}{2\pi I^3}}\, e^{-\frac{\lambda(1-\mu)^2}{2\mu^2}}, \qquad I > 0, \tag{15}$$

where $\mu > 0$ is the mean value of the fluctuation parameter and $\lambda > 0$ is the scale parameter of the distribution. For a MIMO (Multiple-Input Multiple-Output) FSO system, with scintillation index less than 0.35, the Log-Normal model is effectively approximated by the Inverse-Gaussian model. As the number of receive and transmit apertures increases, the accuracy of the I-G model also increases. The Gamma distribution does not fit the values of the Log-Normal distribution, but in large-scale fluctuations, the I-G distribution fits well with the values of the Log-Normal distribution.

2.8. Double Weibull distribution

The double Weibull distribution is the product of two Weibull variables, that are random in nature. The double Weibull distribution is used to model the atmospheric channel in moderate and strong atmospheric turbulence. The Weibull distribution statistically defines the small-scale and large-scale fading associated with scintillation and Rytov approximation. The PDF of the double Weibull distribution is given by the expression:

$$f(I) = \frac{\beta_2 k (kl)^{\frac{1}{2}}}{(2\pi)^{\frac{l+k}{2}-1}} I^{-1} G_{k+l,0}^{0,k+l}\left[\left(\frac{\Omega_2}{I\beta_2}\right)^k k^k l^l \Omega_1^l \left| \begin{matrix} \Delta(l;0), \Delta(k;0) \\ - \end{matrix} \right.\right], \tag{16}$$

where $G_{p,q}^{m,n}[\cdot]$ is Mayer's G function, $\Delta(j;x) \triangleq \frac{x}{j}, \ldots, \frac{x+j-1}{j}$, k and l are positive integer values satisfying the condition $\frac{l}{k} = \frac{\beta_2}{\beta_1}$. The parameters β_1 and β_2 are parameters that describe the strength of the optical radiation of large- and small-scale turbulent effects. The Ω_1 and Ω_2 represent the average power of the channel. When values of $\beta_2 = 1.318$, $\beta_1 = 1.522$, $\Omega_1 = 1.171$ and $\Omega_1 = 1.114$ are observed at low logarithmic radiation probability, the double Weibull distribution gives better results in terms of matching the experimental data in moderate atmospheric turbulence.

2.9. Exponential Weibull distribution

The optical field size is comparable to the size of the receiver aperture, since the range of urban FSO links is hundreds of meters to several kilometers. This range is much shorter than the range of spatial FSO links. In this case, for characterizing the propagation properties of the transmitted optical wave, the finite-width Gaussian beam model is more suitable. Considering the beam width at the receiver, the aperture size of the receiver cannot be negligible. The exponential Weibull distribution is distribution that gives good results, among PDFs of radiation fluctuations for finite-size receiver apertures. The exponential Weibull distribution is a generalization of the Weibull distribution with the addition of one more parameter. This distribution is used for modeling the distribution of received optical power in free space optical links. The PDF of the Exponential Weibull distribution is described as:

$$f(I) = \frac{\alpha\beta}{\eta}\left(\frac{I}{\eta}\right)^{\beta-1} e^{-\left(\frac{I}{\eta}\right)^{\beta}} \left\{1 - e^{-\left(\frac{I}{\eta}\right)^{\beta}}\right\}^{\alpha-1}, \quad (17)$$

where $\eta > 0$ is the mean value of the intensity (depends on β), $\beta > 0$ is the shape parameter (depends on the scintillation index), and $\alpha > 0$ is an additional shape parameter (depends on the receiver aperture size). When $\alpha = 1$, exponential Weibull distribution reduces to Weibull distribution. This distribution is suitable for modeling the atmospheric channel in all atmospheric turbulence catches.

2.10. Double-generalized Gamma distribution

The Double Generalized Gamma Distribution (Double GG Distribution) is the product of two generalized Gamma distributions which are small- and large-scale vortex fluctuations. This distribution corresponds to all turbulence conditions and contains most of the existing channel models in the literature, as its special cases. The PDF of the double GG distribution is given as:

$$f(I) = \frac{\gamma_2 p p^{\beta_2-\frac{1}{2}} q^{\beta_1-\frac{1}{2}} (2\pi)^{1-\frac{(p+q)}{2}} I^{-1}}{\Gamma(\beta_1)\Gamma(\beta_2)} \times$$
$$\times G_{p+q,0}^{0,p+q}\left[\left(\frac{\Omega_2}{I^{\gamma_2}}\right)^{p} \frac{p^p q^q \Omega_1^q}{\beta_1^q \beta_2^p} \middle| \begin{matrix} \Delta(q:1-\beta_1), \Delta(p:1-\beta_2) \\ - \end{matrix}\right], \quad (18)$$

where p and q are positive integer values that satisfy the condition and γ_1 and γ_2 represent distribution parameters for the GG distribution. The parameters β_1 and β_2 describe the strength of the optical radiation of large- and small-scale turbulent effects, while Ω_1 and Ω_2 represent the average power of the channel. Due to the variation in parameters, the double GG distribution can match other channel models. When γ_i tends to 0 and β_i tends to 1, double GG distribution reduces to Log-Normal distribution. When $\gamma_i = 1$, $\Omega_i = 1$, $\beta_2 = 1$, double GG distribution becomes K-distribution. For $\gamma_i = 1$, $\Omega_i = 1$, it becomes Gamma-Gamma distribution, and when $\beta_i = 1$, it is reduced to double Weibull distribution.

3. Conclusion

The main challenges of RF wireless communication systems, that arise in agricultural areas, is a lack of connectivity or poor connection quality. Unlike radio and microwave systems, FSO is an optical technology without requirement of spectrum licensing or frequency coordination with other users. Therefore, it has a great application in smart agriculture. The aim of this paper is to facilitate the performance prediction of an FSO communication link by giving the basic characteristics and mathematical models as a function of signal intensity. This paper provides an overview of the most popular statistical models for describing signal propagation in FSO systems. Also, reducing one model to another, for general models, is given.

The design of reliable next-generation communication networks is recognized as a major technical challenge facing researchers. The development of new and efficient wireless technologies is essential for the construction of future heterogeneous communication networks in agriculture. Due to large optical bandwidth, FSO systems can be used as a powerful alternative in some applications, and in others as a complement to existing RF wireless systems.

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Food production and processing

ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

NATURAL POLYMERS IN FOOD PRODUCTION AND PROCESSING

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INVITED PLENARY LECTURE

Abstract: *Naturally occurring polymers are a diverse group of materials that are currently in the spotlight as a potential solution to environmental and economic problems associated with the use of fossil fuels and synthetic materials. The food industry is also showing interest in the use of natural polymers, particularly as replacements for plastics and synthetic additives. The most promising areas in the food industry showing interest in natural polymers or already using these materials in the production cycle are production of biodegradable packaging materials, encapsulation of food ingredients and additives, separation processes, and food preservation. In addition, plant-based polymers are now being considered as the basis for new, more sustainable products whose processing produces fewer pollutant emissions compared to analogous animal-based products. To further reduce costs and negative environmental impacts, natural polymers can be derived from food and agricultural residues. Considering the importance of natural polymers for food industry and modern society in general, the aim of this paper is to present the latest trends in technology and application of natural polymers in food sector*.

Key words: *Polymers, Polysaccharides, Proteins, Encapsulation, Packaging*

1. NATURAL POLYMERS: SOURCES AND PROPERTIES

Natural polymers have always been used in traditional cuisine as thickeners (e.g., starches and flours), emulsion stabilizers (various plant and animal proteins), nutrient sources (plant proteins), and so on. With the significant geographical discoveries, new natural polymers were introduced and specific sources, especially plants, were cultivated in the new areas to meet the increased demand for these valuable resources. Depending on the literature source, natural polymers are usually defined by two main groups of compounds, polysaccharides and proteins.

Two main sources of natural polymers are plants and microorganisms. Microbial cells produce different natural polymer compounds depending on the species and cultivation conditions. Some of the most economically important natural polymers from microbes are gellan, pullulan, and xanthan. The most important natural polymers from plants are cellulose, alginates, carrageenan, pectin and starch. Chitin and chitosan are polysaccharides isolated from some marine organisms and insects; chitosan is produced from chitin and exhibits antimicrobial properties. Proteins are usually classified according to their origin into plant proteins (wheat, soy, and pea proteins) and animal proteins (casein, collagen, and gelatin) [1].

As can be seen, natural polymers are a broad group of compounds that come from different sources and therefore have different properties. One of the most important properties of these compounds is their ability to form gels and viscous dispersions in water. The ability of polymer chains to absorb water and form gels depends on the chemical structure and modifications of the polymer. In the literature, the natural compounds with high water absorption capacity are sometimes referred to as hydrocolloids [2]. Because they are derived from different sources, their chemical, physical, and nutritional properties can vary widely. For example, alginates derived from brown algae must be in the form of sodium alginate to form water-insoluble gels with divalent cations (e.g., Ca^{2+}) [1,3]. Other compounds such as chitosan require an acidic solution to dissolve [1].

The popularity of natural polymers is based on their two main properties, biodegradability and the fact that they come from renewable sources. Therefore, natural polymers can be used without generating additional non-degradable waste, but they can also reduce the overall negative impact on the environment when used as substitutes for synthetic materials [1].

According to McClements and Grossmann [4], the changes in the food industry in recent years are due to several factors:

- Demand for new products with positive impact on consumer health;
- Increased public pressure for more sustainable products and reduction of pollution and waste;
- Substitution of processed foods;
- Ethical demands, especially regarding the treatment of animals.

Some of the major food applications of natural polymers are shown in Fig. 1.

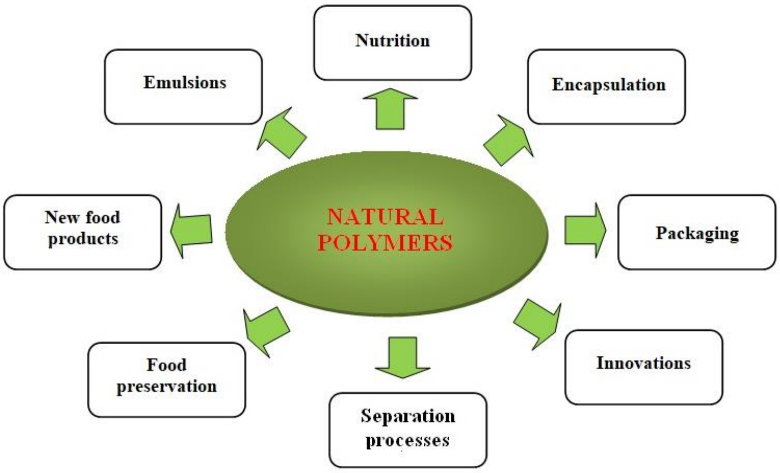

Fig. 1 Schematic representation of the applications of natural polymers in the food sector

In addition to their use in food, natural polymers are being considered as substitutes for synthetic materials in many areas of science and industry. One broad area of application is medicine. Natural polymers have been used in tissue engineering due to their overall safety and biocompatibility with human tissue. More recently, natural polymers have also been proposed as suitable replacements for synthetic materials in the development of medical protective equipment such as air filters and surgical masks. One of the advantages of natural polymers is that they can be directly processed into filter material by electrospinning, either alone or in combination with other compounds [5].

Ecological applications of natural polymers are another area where they can be used in soil management or pollutant control. Khorasani and Shojaosadati [6] prepared a biosorbent from magnetic pectin-*Chlorella vulgaris* biomass for adsorption of various dyes. The biosorbent showed good sorption properties and potential for repeated use after regeneration. Yu et al. [7] fabricated alginate-based membranes and added graphene oxide to modulate the separation properties. The addition of graphene oxide resulted in satisfactory dye separation while the membrane remained stable over a long period of time.

The addition of natural polymers to the soil could be a promising approach to stabilize the soli structure. Xanthan gum showed high potential to bind soil particles, act as a natural adhesive, and effectively stabilize the soil structure [8].

An interesting application of natural polymers is the design of new, more environmentally friendly electronic devices. Wang et al. [9] demonstrated that orange peel could be one of the components of memory storage devices. The preparation method is relatively simple and aims to convert orange peels into a material suitable for forming a film, i.e., a sandwich structure of multiple layers using a spin-coating method. The fabricated memory devices exhibited satisfactory electrical and storage properties.

The main applications of natural polymers in the food industry such as emulsion stabilization, plant-based food products, encapsulation of active ingredients and biocatalysts, and food packaging were presented and reviewed.

2. EMULSIONS

Emulsions are very important systems for the food industry, as many food products rely on the formation of a stable emulsion. Whole milk is an example of a natural emulsion system, while food products such as cream, butter, mayonnaise, margarine, dressings and ice cream are produced by appropriate emulsion stabilization processes. Although the industry has many ways to stabilize emulsions with synthetic emulsifiers, the general public opinion is on the side of natural emulsifiers.

Generally, emulsions are formed by dispersing one liquid in another when the two are immiscible. To prevent coalescence, one or more emulsifiers are added during emulsification. The emulsifiers form an additional phase between the oil and water phases, which effectively participates in the formation of the emulsion system and its stabilization over time. Natural polymers used as emulsifiers are proteins and polysaccharides or their mixtures.

In the food industry, emulsions are usually prepared using various mechanical homogenization processes and equipment. These are classified as high-energy emulsification processes. Low-energy emulsification processes, on the other hand, are based on spontaneous emulsion formation in the presence of surfactants. High-energy processes are generally more expensive, but offer the possibility of forming different types of emulsions [10]. In addition, high-energy emulsification offers opportunities to further improve emulsion properties and preserve sensitive food components. Fernandez-Avila and Trujillo [11] showed that ultra-high pressure homogenization improved the oxidative stability of emulsions. According to the same authors, the high pressure resulted in better contact between the phases, which had a positive effect on product stability. Another advantage of this process is the use of soy protein isolate as emulsion stabilizer.

More recently, natural polymers, especially polysaccharides, have been recognized as suitable substitutes for synthetic emulsifiers. Due to their chemical properties, polysaccharides behave differently in emulsion systems than “conventional” emulsifiers. However, this is not an obstacle to their use in the formation of stable emulsions, as polysaccharides form stable gel systems that stabilize the system and separate the liquid droplets to prevent contact and phase separation. In addition, polysaccharides were found to be suitable stabilizers for emulsions prepared using innovative, low-energy emulsification methods such as the microchannel emulsification method [12].

Various structural modifications have been proposed to enhance the emulsification potential of natural polymers, especially polysaccharides. Modification of polysaccharides as emulsifiers can be divided into the following methods:

- Physical methods: reduction of molecular weight of polysaccharides by heat or radiation treatment;
- Chemical methods: acid treatments, esterification modifications, and protein/polysaccharide based-emulsifiers;
- Biological methods: enzyme treatments of polysaccharides (e.g. hydrolase and oxidase treatments).

The main obstacles to wider application of polysaccharide modification methods are related to the complex purification steps required to remove residual reactants [13].

Some natural polymers in the form of small particles could also provide high emulsion stability. This is because these particles form a layer around oil droplets, preventing coalescence and phase separation. In the literature, these systems are commonly referred to as Pickering emulsions. Many natural compounds can be used to form Pickering emulsions, and some of the most commonly used are various starches, cellulose, various plant proteins, etc. To meet the various criteria for efficient emulsion stability, these compounds are formed into fine particles (much smaller than the liquid droplets to be stabilized) and usually require some modifications (e.g., chemical or physical modifications) to improve the emulsification properties [14].

The emulsion should remain stable, i.e., without phase separation for a period defined by the shelf life of the product. However, some processes also require a stable emulsion, but only for a short period of time until the specific process involving the emulsion is completed. A good example is the encapsulation of various hydrophobic liquids such as flavors or vegetable oils, where a stable emulsion is only required until the capsule is formed. Therefore, there is no need for complex emulsifiers or high pressure homogenization. It has been shown that by combining alginate (as an emulsifier and encapsulation carrier), stable encapsulated forms of active ingredients can be formed with high encapsulation efficiency [3,15,16].

3. NATURAL POLYMERS IN PLANT BASED FOOD PRODUCTS

In recent years, foods based on natural polymers as main ingredients have attracted a lot of attention. This trend in food science and technology is primarily due to the popularity of new foods that reduce (or eliminate) synthetic ingredients and additives. In addition, natural polymers could provide health benefits to consumers, which is an additional positive aspect of their use in foods, especially when added in sufficient quantities and consumed regularly. In addition, consumers are constantly demanding new foods that are produced with low environmental impact and under more ethical conditions. Thus, concern about the treatment of animals in meat production is now one of the main reasons for replacing animal products with analogs based on plant macromolecules [4].

Cereal proteins are suitable substrate that could be used as meat analogs. However, these proteins do not have structural characteristics preferred by consumers that are similar to the structure of animal meat. Therefore, modification of protein structure is the only approach that can lead to a desirable structure of meat analogs. For example, wheat gluten can be easily converted into the desired structure that is close to the structure of animal muscle tissue by extrusion with high moisture content. Since the extrusion depends on the applied temperature, different structural properties of the extruded protein can be obtained. Primarily, the polymerization of the protein chains and the changes in the overall appearance are controlled by controlling the extrusion conditions [17].

Stajić et al. [15] showed that a significant portion of animal back fat (up to 20%) can be replaced by grape seed oil in recipes for dry-fermented sausages. This was achieved by combining natural polymers such as alginate (gel matrix and spherical encapsulates) and soy protein isolate. The natural polymers stabilized the oil particles and modified the product properties while maintaining overall product quality. The use of ingredients with unfavorable sensory properties could be a major challenge. For example, the introduction of flaxseed oil (which is widely known for its beneficial nutritional properties) into food products may result in a food product with an unpleasant taste and aroma. Therefore, masking unpleasant sensory properties is the solution for incorporating flaxseed oil into food products through its inclusion in the matrix of natural polymers [16].

4. ENCAPSULATION

Encapsulation has been used in many food applications as a reliable means of delivering and protecting active ingredients. In addition, encapsulated microorganisms and enzymes are used in biotechnological processes where the conventional use of free biocatalysts is limited. To protect the active ingredient, a suitable carrier material is used during the encapsulation process to create a protective barrier between the active ingredient and the environment. Consequently, the properties of this new system (i.e. encapsulate) depend on the properties of the carrier material [18]. Some of the most important carrier materials for food-related encapsulation processes are listed in Table 1.

The carrier materials used in food encapsulation can be classified into different groups, primarily based on their origin and general chemical properties. Polysaccharides, proteins and lipids are used alone or in combination to meet different encapsulate property requirements. Consequently, the use of carrier materials with different properties usually requires the combination of different encapsulation techniques.

Table 1 Application of natural polymers in food encapsulation processes

Natural polymer	Encapsulation process	Active compound	Comments	References
Alginate	Electrostatic extrusion	d-limonene	Encapsulates dried after encapsulation. High content of active compound	[3]
Maltodextrin and gum Arabic	Freeze drying	Bilberry extract	Preserved color of natural extract	[19]
Whey protein isolate	Freeze drying and spray drying	Red pepper waste	Used as yogurt ingredients	[20]
Alginate	Electrostatic extrusion	Probiotic cells	Used for milk fermentation	[21]
Alginate Alginate/gelatin	Electrostatic extrusion Coacervation	Peppermint essential oil	Applied in ice cream	[22]
Alginate/chitosan	Extrusion, emulsion, and spray drying	Probiotic cells	Double coating provided better preservation of probiotic cells	[23]
Glucomannan	Spray drying	Mineral iron source	Iron protection from oxidation	[24]
Ovalbumin-pectin	Antisolvent precipitation/complex coacervation	Vitamin D_3	Controlled release of vitamin D_3	[25]

Nevertheless, the different types of encapsulates can be divided into two categories, depending on the carrier material:

- Water-soluble encapsulates: These systems are usually produced by spray drying or freeze drying. Various types of starches and starch derivatives (e.g., maltodextrin), gum Arabic, inulin, alginate, pectin, etc. are used as carrier materials in these encapsulation processes;

- Water-insoluble encapsulates: In this case, encapsulates are formed from water-insoluble materials (e.g., lipids) or the carrier material is converted to an insoluble form by chemical or physical processes. For example, sodium alginate reacts with Ca^{2+} ions to form an insoluble Ca-alginate.

In general, encapsulation consists of several steps: preparation of the carrier, mixing of carrier and active ingredient, encapsulation process, and finishing [3].

Spay drying is one of the most commonly used encapsulation processes. It requires relatively high temperatures for water evaporation and the formation of fine particles and powders. Moreover, spray drying is a suitable encapsulation method because various food-grade carrier materials can be used [20]. Freeze-drying, on the other hand, is based on water evaporation by sublimation at low temperatures and pressure. The resulting encapsulates generally exhibit excellent preservation of the active ingredients [19].

Water-insoluble encapsulates are used in applications where the contents, i.e., the active ingredient of the encapsulation, should remain protected for a longer period of time or to ensure controlled release and delivery. The use of biocatalysts, i.e., cells and enzymes, in some cases requires additional preservation of their bioactivity and facilitates manipulation. Also, the reuse of biocatalysts is sometimes required due to their price. Dimitrellou et al. [21] showed that alginate-based encapsulates successfully protected probiotic bacterial cells during milk fermentation. The fermented milk showed an improved flavour profile for this type of fermented milk product. In addition, the encapsulation provided better storage stability of the encapsulated probiotic cells.

A particular challenge in encapsulating active ingredients in a hydrophilic matrix is the relatively rapid release of the active ingredients during gel formation. This can lead to low encapsulation efficiency of the encapsulation process and generally low quality of encapsulates. The reason for this is probably due to the hydrophilic properties of many active plant ingredients and the porosity of the polymer matrix. To avoid these negative aspects of the encapsulation process, an alternative method based on the encapsulation of plant active compounds into preformed encapsulates was developed. Trifković et al. [26] encapsulated the aqueous extract of *Thymus serpyllum* L. in preformed chitosan-glutaraldehyde encapsulates. Encapsulates were prepared by emulsion/crosslinking method followed by intensive washing and drying. The dried encapsulates were then immersed in the plant extract to absorb the active ingredients and dried. To avoid the use of chemicals potentially harmful to humans, other types of preformed capsules can also be developed. For example, Fig. 2 shows alginate-based preformed encapsulation carriers that contain an additional adsorbent, such as corn starch. The preparation of these carriers is relatively simple: sodium alginate is mixed with corn starch and then extruded into a calcium chloride solution. The spherical or elongated capsules formed (depending on the amount of starch added) are then heated in water at 80 °C for 15 minutes to gelatinize the starch. Finally, the capsules were removed from the water and dried to constant mass. The dried encapsulates showed good water adsorption properties and satisfactory mechanical stability. Encapsulates shown in Fig. 2 can potentially be used for the encapsulation of plant polyphenols, fruit and herbal water extracts, and generally water-soluble compounds without significant losses during encapsulation. In addition, such encapsulates could be dried using a freeze-drying process to preserve sensitive active compounds.

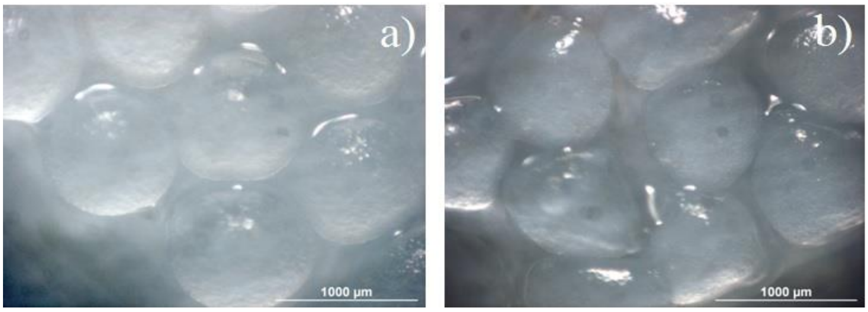

Fig. 2 Alginate/starch preformed encapsulates: a) 5% and b) 10% of starch

5. FOOD PACKAGING

One of the most important applications of natural polymers is food packaging. Due to growing concerns about the impact of plastic packaging on the environment and consumers, major efforts have been made to replace synthetic packaging with natural and renewable materials.

Natural polymers used as packaging materials can be divided into two main categories, edible and non-edible packaging. Non-edible packaging based on natural polymers is usually considered as a substitute for conventional packaging materials (mainly plastic). As such, these materials are removed from the product before consumption. Edible packaging, on the other hand, is essentially part of the food that is consumed together. Therefore, edible packaging must be made of materials that are completely safe for consumption and pose no health risks to the consumer. Edible packaging can be classified as films (which are usually prepared beforehand) and coatings (the food is covered with a coating material, which is then dried to form a solid layer on the food surface) [1].

For packaging materials, it is very important that they can be easily shaped into different forms to adequately protect food, but also to be part of a marketing campaign. Natural polymers are usually formed from their solutions into the desired shape. Some materials, such as zein, require a careful balance of solvents (e.g., water/ethanol) to produce homogeneous solutions and consequently homogeneous packaging films. In addition, low viscosity solutions are suitable for producing compact films by solvent casting or porous films by an electrospinning process. Solvent casting is a relatively simple process in which the polymer solution is poured into a suitable open mold and the solvent is evaporated. The electrospinning process, on the other hand, is based on the rapid evaporation of the solvent under the action of electrostatic forces, which split the solution into a liquid jet (or several independent streams) and form small filaments, i.e. micro- or nanofibers. The formation of uniform fibers depends on numerous factors, especially the chemical properties of the polymer material and its concentration. Solvent properties, configuration of the electrospinning process, liquid flow, voltage, and environmental conditions also affect the morphology of the obtained fibers and consequently of the packaging films [27,28].

Packaging based on natural polymers could be modified by adding active ingredients to extend the shelf life of the products. This is because many natural polymers have no or limited functional properties (e.g., antimicrobial or antioxidant properties). Fig. 3 shows an alginate film prepared from a 1.5% alginate solution using the solvent casting process. In addition to excellent transparency, such films have limited use because they do not exhibit the desired properties of active food packaging. To overcome this problem, the structure of this film must be additionally modified.

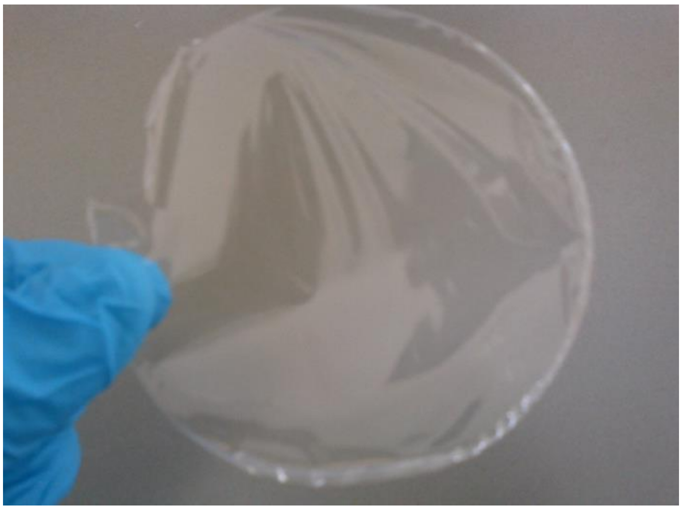

Fig. 3 Alginate film produced by solvent casting method

This could be achieved by incorporating antimicrobial/antioxidant components into the structure of the packaging, creating a new packaging material with active properties [1]. This new form of packaging could contain various active compounds such as plant extracts [29] or be used as a matrix for the formation of active inorganic compounds with significant antimicrobial properties, which become an integral part of the packaging [30]. In addition, natural polymers could be used as carriers for various mineral compounds that form powerful active coatings [31,32]. For the production of packaging films from natural polymers, plants are the main source of active compounds. Before the plant active compounds are incorporated into the mixture for film casting, they are usually extracted using suitable extraction methods and solvents. The aim is to achieve high yield and preservation of the active compounds. Then, the extract (in solvent or solvent-free) is mixed with a solution of natural polymers and molded into the desired form (e.g., films). Karača et al. [33] showed that edible films can contain cocoa powder extract as a source of active ingredients to improve the properties of packaging materials. They used alginate, pectin, and chitosan and combined them with various proteins such as whey protein isolate and proteins from hemp and soy. The solvent casting method was used for film formation. According to the same authors, this approach is promising for the preparation of functional edible films, with some interesting interactions between proteins and phenolic compounds affecting the film properties.

In addition to active properties, biodegradability is another important property of natural polymers used in food packaging. Indeed, it is necessary that once used packaging materials are removed without generating additional waste. Therefore, biodegradation under the action of microorganisms and their enzymes is the preferred method for the final disposal of food packaging. To determine the potential pathways of biodegradation, several tests are generally performed. These tests are usually conducted in compost model systems at controlled temperature and humidity. Samples are taken from the compost at a predefined time and analyzed visually, while mass measurement after careful washing is also used to estimate biodegradation [29].

6. CONCLUSION

The food industry has been constantly changing and introducing new technologies and materials. Consumer demands are driving force for innovation in the food sector, as is the growing awareness of environmental issues related to food production. Some of the natural polymers are already being marketed as biodegradable packaging materials, encapsulates, and substitutes for animal products. Other promising areas for the use of natural polymers include active packaging and separation processes. As public pressure to replace synthetic materials grows, it is expected that more innovations involving natural polymers will be used in the food sector.

Acknowledgement*: This work was supported by Ministry of Science, Technological Development and Innovations of the Republic of Serbia (Contract number 451-03-47/2023-01/200116).*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

TESTING OF AN INDUSTRIAL CAPACITY LABORATORY CONDENSATION DRYER

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Abstract. *Drying is one of the most important preservation methods in the food-processing industry. The complete or partial extraction of water from biological materials is an extremely complex process that consumes a large amount of energy. The drying regime that will be applied for any specific case is determined by several influencing factors such as the дуратион of the drying process, the product quality, the dried biological material thermal sensitivity, etc. Traditional methods of agricultural products drying and consumption of a large amount of energy in conventional dryers significantly lowers the final product quality and increases its final price. Applying alternative technologies in the drying process is the focus of many projects. Research in the field of drying systems that is focused on solving these problems is quite justified.*

In conventional dryers the air is heated to the drying temperature by electric heaters or heat exchangers, which intensifies the exchange of heat and matter. In condensation dryers combined with a heat pump, a significant amount of energy can be saved by keeping the latent and sensible heat of the product within the chamber. Condensation dryers operate as heat exchangers using both high and low temperature sources of a heat pump. These dryers reach slightly lower temperatures, up to 60ºC, and are suitable for drying chopped fruits and vegetables, as well as herbs. The drying quality in such dryers is exceptional, although somewhat slower than in conventional dryers.

This paper presents the test results of drying carrots, as a representative of root vegetables. Laboratory condensation dryer with 100kg capacity was used, a product of the company NIGOS - Niš. The incentive for this research lies in the fact that this method of drying has numerous advantages: high quality of the material is maintained in terms of color, taste, smell, nutritional value, etc.; electricity consumption is 3-5 times lower; achieving very low humidity is possible; there is a high degree of automation of the process; high hygiene of the product (in accordance with the HASAP standard); there is no air exchange in the closed system, and the product is not covered with dust; the design is efficient and the use and maintenance is simple. In addition, the closed system allows it to work indoors and outdoors, since it does not discharge steam (like an open system) but condensate, so it does not humidify the premises.

A detailed schematic of the dryer is presented. All components, corresponding dimensions and a description of its operation are presented. Drying, in this experimental research, was carried out according to the manufacturer's pre-defined regimes. The temperature and relative humidity of the drying agent (air) are defined by the technology requirements of drying. They are fully monitored and maintained at the desired level, according to a predetermined program. With this dryer, there is the possibility of monitoring the dryer efficiency when the process is guided by the pre-set desired drying curve. The drying process is fully automated. As result of the experimental research, a product with a final moisture content of 4% was obtained, which fits the recommended literature data for this type of vegetable.

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Key words (bold): *condensation dryer, carrots drying, air temperature and humidity change, condensate*

1. INTRODUCTION

Drying is one of the oldest and simplest ways of ensuring the durability of fruits and vegetables. It aims to remove larger amounts of water (70 to 80%) from the fruits, while minimizing the change of their composition. In such a state, the fruits are lighter and occupy a smaller volume, and drying ensures cheaper transportation even to the most distant regions. Dried fruits and vegetables are incomparably more durable than fresh ones, not only because of the much lower water content, which, in addition to heat, is the most important condition for successful development of microorganisms, but also because of the higher concentration of sugar and acid.

Water in fruits, which determines the juiciness, is harmful in large quantities. Increasing durability and reducing weight and volume are not the only advantages. Drying makes it possible to save huge amounts of perishable fruits and vegetables from decay and use them for food. It can be used directly for food without any further processing [1,2].

Condensation dryers belong to modern technologies for drying various types of materials, with the certainty of preserving the quality of the dried product. They use the principle of condensation to remove moisture from the material. The development of condensation dryers is conditioned by more efficient drying of materials, reduced energy consumption and environmental protection. They are increasingly popular in the market due to their efficiency, ease of use and adaptability. They can be of smaller or larger capacity.

They are used in various industries, including food, textile, wood and pharmaceutical. They are mostly used for drying fruits, vegetables, grains, meat and other foods, as an important part of the processing of these foods. This way, they are prevented from spoiling and their shelf life is extended.

This paper presents the results of carrots drying testing, as a representative of root vegetables, using a laboratory condensation dryer with a capacity of 100 kg, manufactured by the company NIGOS - Niš. The research is motivated by the numerous advantages that this drying method provides, including the preservation of the high quality of the material in terms of color, taste, smell and nutritional values, a significant reduction in electricity consumption, the possibility of achieving very low humidity, a high degree of automation of the process, as well as high hygiene standards.

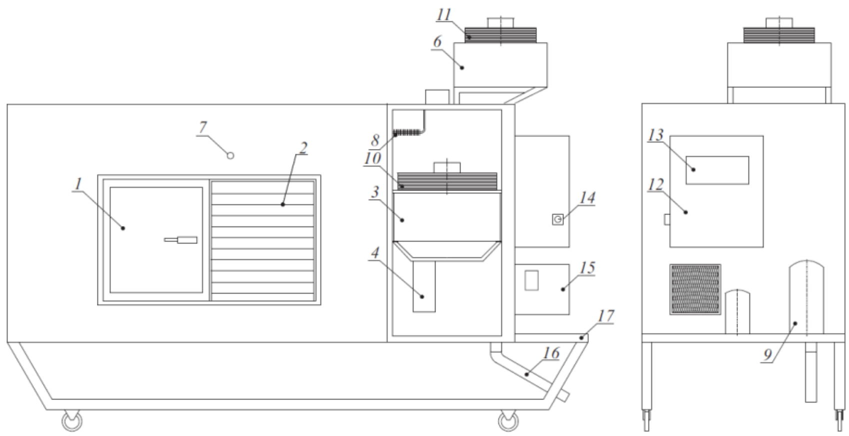
A detailed scheme of the dryer, with all components, dimensions and description of operation, provides an insight into the technological aspects of the experimental research. The temperature and relative humidity of the air are defined according to the technological requirements of drying. During the process they are fully monitored and maintained at the desired level.

The results of the experimental research show a product with a final moisture content of 4%, which fits perfectly with the recommended literature data for this type of vegetable. This research contributes to the understanding of the potential of heat pump condensing dryers in improving the drying process. The obtained results may have significant implications for industrial practice and the development of food preservation methods.

The goal of existing research is to compare the experimental results of a heat pump dryer and a heat pump dryer assisted by an infrared lamp, in order to determine the energy efficiency of the dryer and analyze the drying kinetics of grated carrots. The samples were dried at set temperatures of 45°C and 50°C [3]. In some research, the influence of water blanching treatment and inlet air temperature on the drying kinetics, as well as on the qualitative characteristics of carrot cubes dried in an external fluidized dryer at temperatures of 60, 70, 80 and 90°C, was analyzed. [4]. In other research, the mathematical modeling of the drying process in a semi-industrial continuous belt dryer for drying of 5 mm thick carrot rings was presented. The experiments were conducted at three air temperatures, 50, 60 and 70°C [5].

2. DRYER SCHEMATIC AND THE DESCRIPTION OF OPERATION

Condensing dryer schematic is presented in the following figure:



1. Chamber, 2. Shelves (in the chamber), 3. Internal condenser, 4. Evaporator, 5. Wheels, 6. External condenser, 7. Aditional probes inlet, 8. Electrical heaters, 9. Compressor unit, 10. Internal fan, 11. External condenser fan, 12. Control board, 13. Display, 14. Main power switch, 15. Refrigerant collector, 16. Condensate drain, 17. Support.

Fig. 1 Condensing dryer schematic

This dryer circulates the air through the dryer chamber using a fan. The fan draws air from the environment and push it into the chamber. The fan also sucks the air from the dryer chamber. Air passing through the material absorbs its moisture. This air is further supplied to the cooling part of the heat pump. In this section, the freon circulating through the pipes absorbs heat from the air and moisture condenses. As a result, the air humidity changes to liquid state, forming condensate. Collected moisture is drained from the dryer through the condensate drain and collected in a separate container. After the moisture is removed, the cold air passes through the heat pump's condenser. The air is heated, its relative humidity decreases, and the residual moisture is removed from the air. The heated air returns to the chamber. This cycle is repeated until the desired dryness of the material is achieved. The dryer has a control panel that enables the adjustment of parameters, such as temperature and equilibrium air humidity. It also contains information about the state of drying and displays real time process data of drying. This type of condensation dryer operates with heat exchange assisted by a heat pump.

3. METHODOLOGY

Fresh carrots, procured from local markets, were carefully washed to remove dirt and dust. Carrots were peeled and chopped into sticks of approximately the same size in this experiment. After the preparation, the carrot samples are placed evenly on the trays, with enough space between them to allow air to circulate freely, and to ensure even drying of the samples. Manufacturer's predefined modes were used for drying of the prepared carrots. For this experiment, mode 1 was used, in order to achieve optimal drying conditions, predefined by the company Nigos electronics. The maximum air temperature is set to 55°C, while the equilibrium air humidity in the dryer is set to a final value of 4%. Carrots were bought and dried the same day. The following figures show the fresh carrots disposition on the trays and the arrangement of the shelves in the condensation dryer.

Fig. 2. Fresh carrots disposition on the trays (left) and the shelves arrangement in the condensation dryer (right).

During the drying process, the drying parameters, such as temperature, relative humidity, duration of the process, were monitored and recorded every half hour, and the amount of condensate was also recorded. All drying parameters can be found in Table 1.
The initial moisture content of carrots was 80%. The amount of carrots to be dried was 60 kg. The final drying results, including the moisture content of carrots, which was 4%, were analyzed and compared with the recommended literature data for this type of vegetable. The drying of carrots in this experiment lasted 17h.

Table 1 Measured drying parameters

Time	Temperature [℃]	Air humidity[%]	Condensate (l)
16:00	25.5	18	0
16:30	36	10	0
17:00	35.8	14.7	2
17:30	35.9	11.1	1.5
18:00	41.2	10.2	1.5
18:30	41.9	10.6	1.2
19:00	45	9.4	1.2
19:30	45.2	8.8	2
20:00	45.8	10	1.5
20:30	50.1	8.1	2
21:00	52.5	7.4	2
21:30	54	7	1.5
22:00	53.9	6.6	1.5
22:30	55	6.3	1.25
00:00	53.6	5.2	3.75
02:30	54	4,2	2,5
09:30	55.9	2.8	2,5

4. RESULTS

The drying results, shown in the following figures, provide an insight into the dynamics of the drying process using hot air with different air temperatures. The Fig. 3 shows the air humidity curve in relation to drying time for samples dried at different air temperatures (Fig. 4). The initial moisture content of the samples was 80%, while the final moisture content has reached the level of 4%

Fig. 3 Dependence of air humidity and drying time

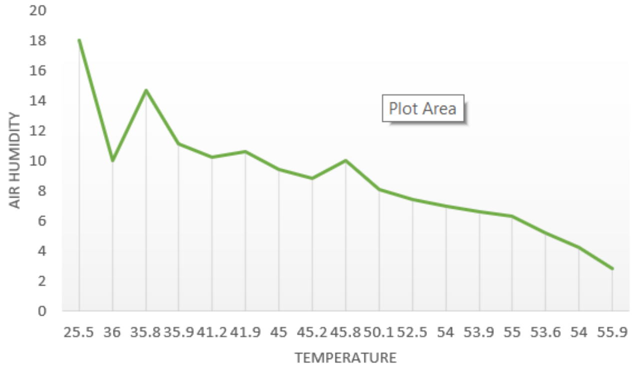


Fig. 4 Dependence of air humidity and temperature

Analysis of the presented results clearly indicates a continuous decrease in moisture content as the drying time progresses. These results reflect the efficiency of the drying process, where increasing the air temperature accelerates the elimination of moisture from the samples. The results confirm the expected decrease in moisture content according to the previously defined drying regimes.

This analysis is not only essential to understanding drying efficiency, but also highlights the importance of air temperature in achieving the desired final moisture content. Samples with an initial moisture content of 80% were dried to a level of 4%, which indicates a high degree of drying efficiency with optimally used air temperatures.

5. CONCLUSION

Research on drying carrots using a condensation dryer with a heat pump represents a significant step towards improving the food preservation process. The analysis of drying results, at different air temperatures, enabled a better understanding of the dynamics of drying and the influence of temperatures on achieving the desired final moisture content.

Figures showing curves of moisture content versus drying time clearly demonstrate that air temperature has a significant effect on the moisture elimination rate from carrots. The achieved final moisture content of 4%, with an initial moisture content of 80%, confirms the efficiency of the heat pump condensing dryer in the root vegetable drying process.

This paper presents the initial research results of the condensation dryers potential. There is considerable room for further development and innovation in this field, with possibilities to expand research into the drying of different types of fruits and vegetables

Future research phases planned will include drying a diverse assortment of fruits and vegetables in order to assess the universality and adaptability of condensation dryers to different types of raw materials. Comparing the drying results of different foods will allow a better understanding of the specifics of the drying process and provide guidelines for optimal setting of drying parameters depending on the type of material.

One of the key goals of future research will be the energy efficiency of condensation dryers improvement, and the innovative approaches that will further reduce energy consumption. This includes research of new technologies, process optimization and the application of renewable energy sources to achieve environmentally sustainable and economically efficient solutions.

Acknowledgement: *The research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract No. 451- 03-9/2021-14/200109)*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

INVESTIGATION OF CONVECTIVE DRYING CHARACTERISTICS AND SPECIFIC ENERGY CONSUMPTION OF APRICOT AND APPLE TREE DISCS

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Abstract: *The aim of this work was to investigate the drying characteristics and specific energy consumption during convective drying of apricot and apple tree. The measurements were performed in an experimental dryer with disk-shaped wood samples of 20 mm thickness at the temperatures of 40, 50, 60 and 70 °C. The velocity of the air during all experiments was set to be 2 m/s. Overall 8 experiments were performed – 4 with each tree type. Drying time and equilibrium moisture content were determined for each experiment. Analysis of drying curves showed that the increase in drying temperature decreases drying time. Based on the results of drying time, air temperature and velocity the specific energy consumption for drying of apricot and apple samples was determined and analysed. Short abstract (Style Abstract: 9 pt, italic, pt, justified, 0.75 pt left and right indentation).*

Key words: *apricot tree, apple tree, thin discs, drying kinetics, specific energy consumption, equilibrium moisture content*

1. INTRODUCTION

In modern technological processes the emphasis is on the energy efficiency and rational use of energy in all industry sectors. One of the industrial sectors with highest energy consumption is certainly drying sector. Drying is one of the energy most demanding processes overall, especially in wood processing industry where the majority of energy is consumed for drying. Therefore, the energy consumption of wood drying is a paramount when assessing the economic value of the dried wood products. Drying is a critical step in wood processing, since a high energy is required to evaporate water [1]. In conventional kiln dryers the energy consumption for wood drying ranges from 600 (2160) to 1000 (3600) kWh/m^3 depending on wood type and thickness. This energy accounts for 50-70% of the total needed energy for wood processing, which is agreement with other reports on energy consumption for wood drying [The CIPEC survey]. According to [The CIPEC survey] on average, softwood lumber production consumes 1514 Megajoules of energy per cubic meter of lumber produced (MJ/m^3). Of this total, drying consumes 1000 MJ/m^3 which is round 2/3 of total energy consumption. For solar drying consumption is a little bit lower round 915 MJ/m^3 [2]. In [3] the specific consumption ranged from 1.15 – 4 kWh/kg 4.14-14.4 MJ/kg, i.e. 2600-8600 MJ/m^3. 4.5 to 5.6 MJ/kg [4] i.e. 2700 – 3360 MJ/m^3 if we assume the density of the wood to be 600 m^3/kg. Thus, optimization of energy consumption, together with drying time and quality of dried wood are the main priorities in wood industry.

Common types of wood in Serbia are analyzed – apple and apricot tree. The goal of this investigation was to evaluate the specific energy consumption of wooden discs of apricot and apple tree based on drying time measurements. Furthermore, the drying kinetics of apricot and apple tree discs was determined and compared to each other. This study aims to investigate the energy consumption of thin wooden samples under different drying temperatures.

2. MATERIAL AND METHODS

The material was acquired from local tree plantation in Serbia. The apricot and apple tree branches were first cut from the tree, then brought to the laboratory and chopped into thin wooden discs of the 20 mm thickness and approximately 100 mm in diameter (Fig.1). Two identical samples were cut at the beginning of the measurements process, one of which was placed in the oven at 105°C for moisture content investigation, while the other was placed in the laboratory dryer at predefined drying regime.

Fig.1. Samples of apricot and apple wood discs

Initial moisture content was determined as follows (Eq.1):

$$M_0 = \frac{m_w(\tau_0)}{m_{dm}} \left[\frac{kg_w}{kg_{dm}}\right] \quad (1)$$

For both apricot and apple samples, drying regimes were as follows: air velocity was kept at 2 m/s while the air temperature ranged from 40 to 70 °C with 10 °C step. The drying was stopped when the sample reached the equilibrium moisture content at particular drying regime, i.e. when the mass of the sample was not changing anymore. Equilibrium moisture content is defined by the ratio between initial mass of the samples and mass of the samples at the end of the drying process (Eq.2).

$$M_e = \frac{m_e}{m_{dm}} - 1 \left[\frac{kg_w}{kg_{dm}}\right] \quad (2)$$

2.1. Evaluation of drying time and equilibrium moisture content of the samples

Drying time was measured from placing the samples into the drying chamber until the samples reached equilibrium moisture content. Equilibrium moisture content was calculated with Eq. 2 for all regimes.

2.2. Evaluation of specific energy consumption for drying

The specific energy consumption for drying was calculated based on the dryer specifications, which are investigated in [5]. The specific energy consumption depends on the drying regime, i.e. drying temperature and it was evaluated with Equation 3:

$$Q_V = a \cdot \tau + b \quad (3)$$

Where τ represents drying time and the coefficients a and b are given in Table 1 as function of drying temperature.

Table 1. Coefficients for determining the dryer energy consumption

Temperature [ºC]	30	40	50	60	70
a	15.12	28.08	43.56	57.60	74.88
b	230.4	167.04	782.64	1008	991.44

Based on the drying temperature and time, the total energy consumption was calculated for each experiment.

The specific energy consumption is then evaluated by dividing the total energy consumption with the mass of moisture evaporated during drying, i.e. Equation 4

$$q_V = \frac{Q_V}{m_w} \left[\frac{kJ}{kg_w}\right] \quad (4)$$

2.3. Evaluation of drying kinetics of the samples

For determination of drying characteristics, the mass of the samples was continuously measured during the experiments using specialized equipment and software with KERN precision balance with accuracy of 0.01 g and measuring range up to 3600 g. From the mass measurements, knowing initial and equilibrium moisture content values (Eq.1 and Eq. 2), the dimensionless moisture ratio (MR) is then calculated (Eq. 5) and plotted against the experiment time.

$$MR = \frac{M - M_e}{M_0 - M_e}\ [-]$$	(5)

Also the Drying rate (DR) was calculated as the ratio between the moisture loss and time span between two consecutive measurements - Equation 6.

$$DR = \frac{M(\tau_{n+1}) - M(\tau_n)}{\tau_{n+1} - \tau_n}\left[\frac{kg_w}{kg_{dm}\ s}\right]$$	(6)

3. RESULTS AND DISCUSSION

3.1. Evaluation of drying time and equilibrium moisture content of the samples

Drying time was measured from placing the samples into the drying chamber until the samples reached equilibrium moisture content and the results were given in Table 2.

Table 2. Drying time in minutes

Temperature	Apricot tree discs	Apple tree discs
40	3292	3091
50		
60		
70	689	650

As it could be seen from the measurements of drying time, the longest drying times are recorded for drying temperature of 40 °C and the shortest drying times are recorded for temperatures of 70 °C.

Equilibrium moisture content was calculated with Eq. 2 for all regimes and it is presented in the Table 3.

Table 3. Equilibrium moisture content [-]

Temperature	Apricot tree discs	Apple tree discs
40	0.30	0.32
50	0.20	0.22
60	0.14	0.15
70	0.04	0.05

3.2. Evaluation of specific energy consumption for drying

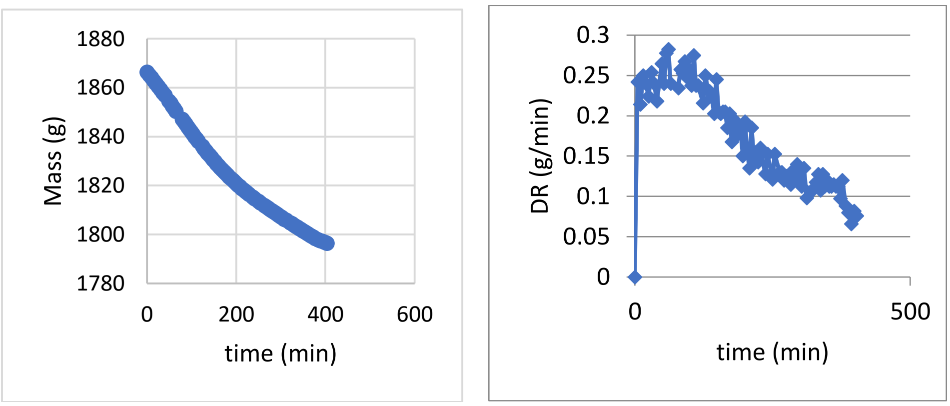
The specific energy consumption for drying was calculated using Eq. 3. The specific energy consumption for each experiment is given in Table 4.

Table 4. Specific energy consumption [kJ/kg$_w$]

Temperature	Apricot tree discs	Apple tree discs
40	91654	86962
50		
60		
d70	79567	77158

3.3. Evaluation of drying kinetics of the samples

For determination of drying characteristics, the MR was plotted against experiment time for all experiments for apricot and apple tree discs and shown in Fig. 2a and In Fig. 2b the DR was plotted against time.



(a) (b)

Fig. 2. (a) Mass vs time (b) Dr vs time

As it could be seen from Fig. 1. the drying takes place first in short constant rate period and then in falling rate period, which is characteristic for wood drying. This also means that both internal and external resistances to moisture transfer play important role for wood discs drying (Ivan Susenje). The maximal values of DR are observed with drying temperatures of 70 ^oC and minimal with milder drying regimes at temperatures of 40 ^oC.

4. CONCLUSIONS

In modern technological processes the emphasis is on the energy efficiency and rational use of energy in all industry sectors. One of the industrial sectors with highest energy consumption is certainly drying sector. Drying is one of the energy most demanding processes overall, especially in wood processing industry where the majority of energy is consumed for drying. Therefore, the energy consumption of wood drying is a paramount when assessing the economic value of the dried wood products.

Acknowledgement: *The paper is a part of the research done within the project No. 451-03-47/2023-01/200116, Faculty of Agriculture, University of Belgrade*.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

LOW-COST ARDUINO-CONTROLLED SOLUTION FOR AUTOMATION OF MASS MEASUREMENT IN LABORATORY DRYERS

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Abstract: *In this work, the solution for the automation of samples' mass measurement during drying process in laboratory conditions was presented using open-source electronics platform Arduino and programming language Python. Special mechanism designed and constructed for this purpose was incorporated in existing laboratory dryer. The goal of the work was to automate otherwise tedious and time-consuming measurement of a mass of the samples during drying process without compromising the interior drying conditions within the drying chamber. The system is realized with a lifting platform using two Arduino-controlled stepper motors. The whole process of mass measurement could be externally controlled by Python programming language from PC. It is showed that this idea could be easily implemented in laboratories and/or research centres with limited budget.*

Key words: *Arduino platform, Python, drying process automation, mass measurement, low-cost solution*

1. INTRODUCTION

Technological advances create new possibilities for scientific and industrial research. It is hard to imagine modern factory or industrial facility without automated process control. Similarly, in scientific research it is almost unimaginable to perform certain types of experiments manually, because they are time-consuming and also require human resources. Repetitive tasks are therefore replaced with automated systems and machinery, while researchers could do more creative and meaningful work. This increases the efficiency of the research greatly, has positive impact on results and motivation of the researchers. However, the up-to-date scientific equipment is often too expensive to purchase and the acquirement of spare parts usually presents tedious task with long waits. While the big, on the one hand companies with high budget could cover all expenses and unpredicted cost of maintenance and reparation of the equipment, institutes, faculties and organizations with limited budget on the other hand, could face huge problems and even have to stop investigation process because of equipment failure and maintenance costs. This is a common problem, especially in Serbia, where failure of the equipment often leads to abandonment of the research. Secondly, industrial equipment is often non-programmable and not an open source which makes it difficult to adjust if you need. Therefore, the low-cost solutions using open-source software that are easy to customize, repair and maintain are of enormous importance for these institutions, since it allows them to continue the research. Main advantages of low-cost open-source solutions are [1]:

- Low cost
- Portability
- Upgradability and scalability
- Programmable interface

Among experimental investigations, drying experiments are one of the most time-consuming with drying taking up to several days depending on the material and drying method [2]. During drying, the mass measurement is the basis for determination of most influential drying parameters. Usually, the mass measurements of the samples are done manually – i.e. by taking the sample out of the dryer at specific time intervals and placing them on the balance [3]. This is still the most common way of conducting the change of the mass during drying. Alternatively, continual mass measurement during drying is possible with balance being connected to logging device such as PC. The most common technical solutions are with the balance placed above [4], [5] or below [6] the drying chamber, or using weighing load cell [7]. However, continual mass measurements have their limits in terms that the tray with the samples is places on the balance, which is in this case constantly loaded. This could lead to measurement errors and damaging the balance. Furthermore, for convective drying with higher velocities the measurements become very unprecise because of the vibrations caused by the air flow over the samples.

In order to solve the problems mentioned above, the solution proposed in this work is to use automated mechanical platform which at specific time intervals places the tray with samples on the balance and measures the mass. Our solution offers automated drying process parameters monitoring with easy to use, cheap and readily available parts and equipment. The significance of this solution is that every institution, individual or group of researchers could implement the solution presented here because all parts and materials are readily accessible almost everywhere in the world and the software used and code are fully open source.

2. MATERIAL AND METHODS

2.1. Hardware description

The platform for automation of mass measurement during drying experiments is mounted on the existing experimental dryer shown in Fig. 1. The platform is not interfering with the work of the dryer and hence it represents an improvement in measurement process. Hardware used for the platform was purchased from the local electronic and tool stores. The automation electronics is based on Arduino components. The platform comprises mechanical and electronical parts.

Fig. 1: Laboratory dryer

2.1.1. Platform description

The platform comprises of static wooden frame and moving wooden platform (Fig. 2). Frame and platform are connected together by the threaded rod – screw mechanism which is moved by stepper motors controlled by Arduino Uno board. The platform consists of the rigid frame made of wooden boards. On the wooden frame the two stepper motors and Arduino Uno board were fixed. With two flexible couplings, the stepper motors are connected to the threaded rods at one end and fixes onto axial bearings on the other end. With lead screw a moving platform is connected to the threaded rods, allowing the frame to go up and down. The tray for samples is made of two parts, such it resembles the marionette. Upper part is on the top of the platform and the other part is in the drying chamber, and the samples are placed on this tray. Two parts of tray are connected with thin rigid metal rods, which pass through the holes in the wooden frame and sheet metal of the dryer channel. By lowering the platform, the tray is left on the electronic balance, the mass of the samples together with the tray gets measured and then the platform with tray and samples is lifted up to the initial position.

Fig. 2: Automated platform for mass measurements during drying

2.1.2. Mechanical parts

Mechanical parts used for the platform were purchased from local tool store and the wooden boards were obtained in specialized woodstore. The specifications of mechanical parts are given in Table 1.

Table 1. Electronic components

No.	Component	Number	Price	Description
1.	Wooden frame	1		Wooden frame made of a couple of wooden boards assembled together
2.	Wooden platform	1		Platform for moving the tray with the samples up and down
3.	Threaded metal rods	2		Threaded rods connected to a moving platform
4.	Lead screws	2		Screws fixed to a moving platform
5.	Flexible Couplings	2		Couplings to connect the stepper motor and threaded metal rods

2.1.3. Electronics

Electronic components used for the platform were purchased from local electronic store. The system is based on Arduino components. The specifications of the electronic components are given in Table 2.

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Table 2. Electronic components

No.	Component	Number	Price	Description
1.	Arduino Uno	1		Micro controller and USB wire to communicate with the PC
2.	Arduino CNC Shield	1		Shield mounted on Arduino Uno for stepper motor control
3.	Stepper motor driver A4988	2		Stepper motor driver mounted on Arduino CNC shield
4.	One channel relay module	1		Relay used as a switch for stepper motors
5.	Nema 17 stepper motor	2		Stepper motors used to control the platform
6.	Switch	1		Ordinary current switch

2.2. Software description

Python programming language was used for PC programming, while Arduino platform was used to program the Arduino Uno board.

2.2.1. Arduino

Arduino is an open-source hardware and software platform designed for building and prototyping electronic projects. It consists of a microcontroller board and an integrated development environment (IDE), which is a crucial component of the Arduino platform. It is the software interface that allows user to write, compile, and upload code to Arduino microcontroller boards. Arduino is open-source, meaning the hardware designs and software code are freely available to the public.

2.2.2. Python

Python is a high-level, versatile, and interpreted programming language known for its simplicity and readability. It was created by Guido van Rossum and first released in 1991. Python has gained widespread popularity in various domains, including web development, data science, machine learning, automation, scientific computing, and more.

3. RESULTS AND DISCUSSION

3.1. Evaluating the work of the platform

3.2. Controlling the Arduino by Python from PC

```
# Arduino with Python
import time
import serial

arduinoData=serial.Serial("COM6", 9600)

for i in range(3):
    myCmd = str("ON")
    myCmd = myCmd + "\r"
    arduinoData.write(myCmd.encode())

    time.sleep(5)
```

Fig. 3: Desktop application for data acquisition

3.3. Reading and writing data to the PC

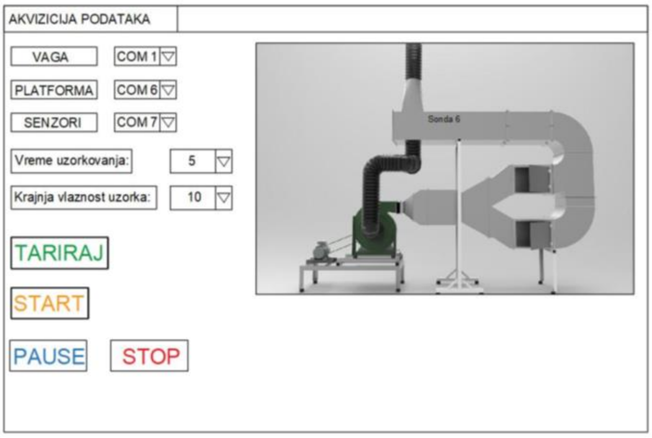

Fig. 4: Desktop application for data acquisition

4. CONCLUSIONS

Repetitive tasks are therefore replaced with automated systems and machinery, while researchers could do more creative and meaningful work. This increases the efficiency of the research greatly, has positive impact on results and motivation of the researchers. However, the up-to-date scientific equipment is often too expensive to purchase and the acquirement of spare parts usually presents tedious task with long waits. While the big, on the one hand companies with high budget could cover all expenses and unpredicted cost of maintenance and reparation of the equipment, institutes, faculties and organizations with limited budget on the other hand, could face huge problems and even have to stop investigation process because of equipment failure and maintenance costs. Therefore, the low-cost solutions using open-source software that are easy to customize, repair and maintain are of enormous importance for these institutions, since it allows them to continue the research.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

MODELING HEAT–FLOW PROTOTYPE DRYER USING ANFIS OPTIMIZED BY PSO

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Abstract: *Chamber dryers are widely used in various industries in order to remove the moisture from solid materials efficiently. Optimizing the design and operational parameters of chamber dryers plays a crucial role in enhancing their performance and energy efficiency. In order to maintain the temperature at the desired level, it is necessary to implement a good control system. To be able to facilitate the process of finding and setting parameters of the controller, for many control algorithms it is essential to make the reliable model of the object. The aim is to develop both reliable and accurate predictive model that can assist in optimizing the design, structures, and inspection processes of chamber dryers, which will lead to enhanced energy efficiency, harvesting and improved drying performance.*

In this paper, the authors propose a novel approach for modeling heat flow transfer in chamber dryers using an Adaptive Neuro-Fuzzy Inference System (ANFIS). The Quanser chamber was selected as the object of the research because of how closely its geometry, material choice, and air flow resemble the structural properties of a dryer. To obtain the most realistic model possible, parameters of ANFIS were found using Particle Swarm Optimization algorithm. By incorporating historical operational data of experimental measurements, the ANFIS model can learn and adapt to the dynamic behavior of the dryer system.

Key words: *Design and Structures, Optimization, ANFIS, PSO, Heat-Flow Chamber Dryer, Energy Efficiency*

1. INTRODUCTION

The indoor environmental parameters such as temperature, ventilation, pollution and humidity are governed by airflow patterns. These airflow patterns form the essential link between the outdoor environment and the chamber microclimate; thus an understanding of the principles of air movement is necessary in order to provide the correct quantities of air and the proper distribution patterns to meet the needs of the application [1]. Temperature control is considered to be one of the crucial parameters [2] in numerous industries, including agriculture, where identifying heat transfer within a room or chamber is essential for designing an efficient Heating, Ventilation, and Air Conditioning (HVAC) system. Some research papers have explored this topic using fuzzy and predictive radial basis function (RBF) [3], neural networks [4], or even hybridizing those models [5] and [6].

Developing accurate heat transfer models can assist researchers and engineers in comprehending the physical mechanisms involved in energy conversion processes and enhancing the efficiency of control systems. System identification is a vital tool for creating a mathematical model that accurately represents the behavior of a physical system based on experimental data. This process is particularly important when the mathematical relationships between input and output are unknown or too complex to be easily expressed and understood. By gathering experimental data that describe the object's behavior, the created model can predict the system's output not only under the conditions in which the data was collected but also under various unknown conditions.

As already mentioned above, various techniques, including artificial intelligence, fuzzy logic, machine learning, and optimization algorithms, are widely utilized for system identification and can be found in the literature. For instance, in two studies, the authors proposed an ensemble of various neural networks and an Adaptive Neuro-Fuzzy Inference System (ANFIS) model for the prediction of heating energy consumption in NTNU campus Gløshaugen [7], [8].

Additionally, there are approaches that employ some of the metaheuristic algorithms in order to optimize the parameters of ANFIS. In [9] Authors used Particle Swarm Algorithm (PSO) and Genetic Algorithm (GA) for the time-series prediction of wind speed in Brazil. The results demonstrated that the combination of ANFIS models with these two metaheuristic algorithms can increase the prediction accuracy of the ANFIS model for all time intervals. Similarly, in another study, ANFIS-PSO model was created to improve the ability of the neuro-fuzzy approach in the prediction of agricultural drought [10].

Metaheuristics, which encompass abstract stochastic optimization methods, are frequently employed in solving both constrained and unconstrained nonlinear system problems. In this paper, system identification is performed using both linear methods, such as time-delayed transfer functions, and nonlinear methods, such as an ANFIS optimized with the PSO. This approach allows for a comprehensive analysis of system behavior.

2. OBJECT DESCRIPTION

The structural aspects of an agricultural dryer, including its geometry, material selection, and insulation properties, can vary depending on the specific design and intended application. Agricultural dryers typically consist of a chamber or enclosure where the drying process takes place. The chamber can be cylindrical, rectangular, or any other suitable shape, depending on the dryer's design. The geometry of the airflow path typically includes inlet and outlet openings, air distribution channels, and baffles to guide the airflow evenly through the drying material. The frame and structure of the agricultural dryer are often made of sturdy materials such as steel or aluminum. These materials provide strength, stability, and durability to support the weight of the drying material and the operational stresses [11]-[13]. Drying chamber walls, the air distribution system, and insulation properties can vary depending on factors such as the type of crop being dried, the scale of the operation, the available energy sources, and the desired drying efficiency. Design considerations should also take into account factors such as safety, maintenance, and cost-effectiveness. In this paper the Quanser chamber (Fig. 1) is selected for the heat-flow experiment (HFE), due to its resemblance to the structural characteristics of a typical dryer. The apparatus is essentially a sophisticated rheostat, consisting of an aluminum plate with three temperature sensors uniformly distributed along the conduit, a blower, and a coil-based heating unit. At various points on the plate, the thermocouples measure the temperature. Fast-setting platinum transducers are used in all three sensors. The fan speed (corresponding signal Vt) is determined using the tachometer on the blower. The provided power (Vh voltage applied to the heater and Vb voltage applied to the blower) is controlled using analog signals (S1, S2 and S3), and Quanser's software is used to gather and analyze the thermocouple data.

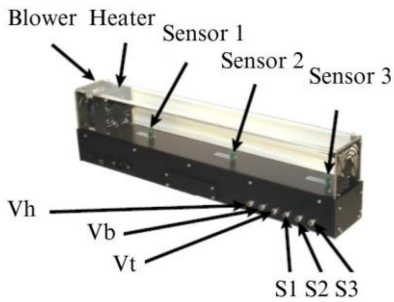

Fig. 1 HFE prototype dryer

3. System modeling

System modeling based on conventional mathematical methods is not adequately adapted for working with poorly defined systems. Important advantages that modern methods can offer comparing to the traditional ones are reflected in situations where: (a) there are many input variables, but few samples; (b) data are heterogeneous and contain multiple types; (v) a nonlinear input-output dependence must be found. Just like traditional models, modern techniques are using well-known statistical methods to evaluate the obtained performance. One of these up-to-date techniques is precisely the artificial intelligence. It includes algorithms that contain elements of the human way of thinking and solving problems, such as fuzzy logic algorithms, artificial neural networks, metaheuristic algorithms, as well as expert systems [14]. In this chapter, two mathematical models of the system will be presented: the first one is a linear model obtained through identification, and the second one is created using ANFIS.

3.1. Linear model: Transfer function with delay

To identify the mathematical representation of the heat flow system, an open-loop experiment was conducted. During the experiment, the voltages of the blower and heater were applied, and three temperature sensors were utilized to measure the temperatures inside the chamber. After five seconds, a step signal of 5V was introduced. The blower input voltage remained at 3V for the entire duration of the experiment. After 120 seconds, the experiment automatically ended. Notably, sensor 1, as being closer to the heater and the blower, showed a faster temperature rise compared to the sensors 2 and 3. Consequently, the rate of temperature increase varied across the chamber. Three models were developed, each corresponding to the temperature readings of the respective sensors. The step responses of heat flow align with the identified first-order transfer functions with delay, as represented by (1). Moreover, Fig. 2 shows the step responses of these models. In terms of the mean square error (MSE) second sensor (s2) gives the best results.

$$W_1(s) = \frac{0.2523}{s+0.03563} e^{-0.198\,s}, \text{ MSE} = 0.2096.$$
$$W_2(s) = \frac{0.137}{s+0.03107} e^{-0.396\,s}, \text{ MSE} = 0.0949. \quad (1)$$
$$W_3(s) = \frac{0.1458}{s+0.03242} e^{-0.594\,s}, \text{ MSE} = 0.1349.$$

3.1.1. Linear model testing

Considering the excessive noise in the output signal of sensor 3 and the larger error exhibited by sensor 1, the transfer function selected to describe the system is derived from sensor 2 (s2) using (1). This particular sensor, located in the middle of the chamber, demonstrates the smallest MSE, as indicated in Fig. 2. (left). Furthermore, a comparison is made between the model and the real object, but with a different input signal. In this case, a 4V step signal was introduced five seconds into the beginning of the experiment.

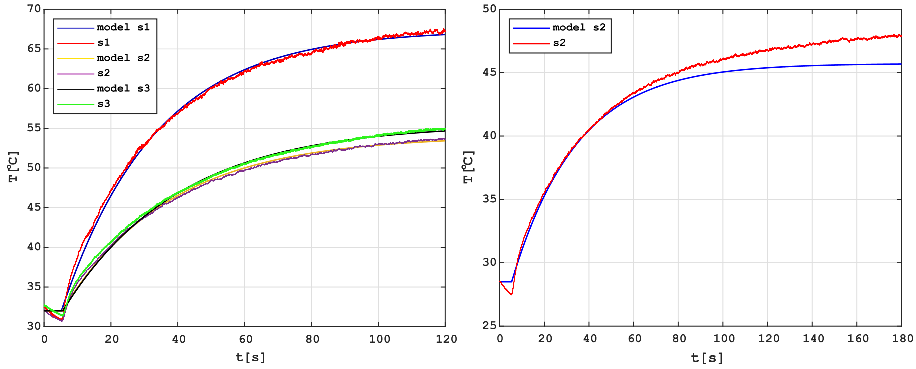

Fig. 2 Linear model: Transfer functions with delay and (left),
Linear model testing with different input (right) [15]

The obtained results, illustrated in Fig. 2 (right), reveal a significantly higher MSE of 1.1888. Moreover, there is an approximate 1.5°C difference between the model and the actual output signal in a steady state, and this discrepancy tends to amplify as we move away from the original identification point.

Consequently, it is concluded that when altering the input, this particular linear model is unsuitable for accurately representing the system.

3.2. Nonlinear model

3.2.1. General architecture of ANFIS

As an exceptional machine learning model that combines the strengths of fuzzy logic and neural networks, ANFIS is capable of creating accurate predictions, classifications, and even control algorithms, which have found applications in various domains, including complex system identification, controllers, as well as image processing.

The neural network component of ANFIS adjusts the fuzzy sets and operator settings to improve prediction accuracy. Typically, the backpropagation algorithm, a gradient descent method, is employed for this purpose to minimize the difference between predicted and actual outputs. One of the key advantages of ANFIS is its capability to handle nonlinear interactions between input and output variables. This is achieved by utilizing fuzzy sets to represent inputs and outputs, capturing complex interactions and nonlinearities. Furthermore, the neural network component of ANFIS can be trained to adapt the parameters of the fuzzy sets and operators, thereby improving the fit of the data and generating more precise predictions. The ANFIS model (with two input variables) consists of five layers, as shown in Fig. 3.

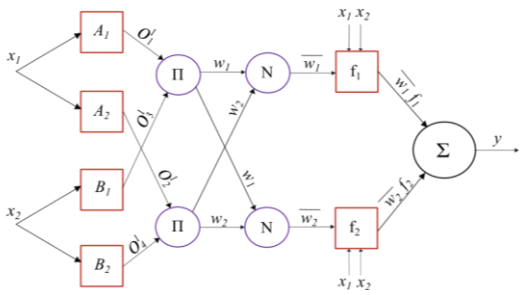

Fig. 3 ANFIS architecture

First Layer: The initial layer calculates the membership degree of the corresponding membership function and outputs it. Each node in this layer is flexible and can adjust its shape during training. Every input node represents an input variable and transfers the input value to the subsequent layer.

$$O_i^1 = \mu_{A_i}(x_1), O_{i+2}^1 = \mu_{B_i}(x_2), i = 1, 2. \quad (2)$$

The membership functions μ_{Ai} and μ_{Bi} correspond to i=1,2. In the literature, Gaussian or bell-shaped membership functions are commonly used, although various other types have also been explored. One specific example is the Gaussian membership function, which is defined by two parameters.

$$G(x,c,\sigma) = e^{-\frac{(x-c)^2}{2\sigma^2}}. \quad (3)$$

Second Layer: In contrast to the previous layer, the nodes in the second layer remain constant. The output of each node indicates the firing strength of the corresponding rule,

w_i. A higher firing strength suggests that the rule holds greater influence in determining the final output.

$$O_i^2 = w_i = \mu_{A_i}(x_1)\cdot\mu_{B_i}(x_2), i = 1, 2. \tag{4}$$

Third Layer: This layer computes the normalized firing strength of each rule by dividing the firing strength of a rule by the sum of all firing strengths, ensuring that the values fall within the range of 0 to 1.

$$O_i^3 = \bar{w}_i = \frac{w_i}{w_1 + w_2}, i = 1, 2. \tag{5}$$

Fourth Layer: This layer calculates the product of the normalized firing strength and the consequent parameter of each rule, combining them to obtain the weighted consequent values.

$$O_i^4 = \bar{w}_i f_i = \bar{w}_i (p_i x_1 + q_i x_2 + r_i), \tag{6}$$

where: p_i, q_i, and r_i are the consequent parameters.

Fifth Layer: The final layer sums up the weighted consequent values from all rules to generate the overall output of the ANFIS system.

$$O_i^5 = y = \sum_i \bar{w}_i f_i \frac{\sum_i w_i f_i}{\sum_i w_i} = (\bar{w}_1 x_1) p_1 + (\bar{w}_1 x_2) q_1 + \bar{w}_1 r_1 + (\bar{w}_2 x_1) p_2 + (\bar{w}_2 x_2) q_2 + \bar{w}_2 r_2. \tag{7}$$

3.2.2. PSO algorithm

The Particle Swarm Optimization (PSO) algorithm is a metaheuristic technique inspired by swarm behavior, aiming to find optimal solutions by simulating particle movement and interaction in a search space. Each particle represents a potential solution and adjusts its position based on local and global best-known positions. Particle movement follows the principles of exploration and exploitation. Exploration occurs through random velocity adjustments, allowing particles to explore different areas. Exploitation involves particles being attracted to the best-known positions, converging towards promising areas. In each iteration, particles update their velocities and positions using mathematical formulas based on their current state and best-known positions. The process continues until a stopping criterion, like a maximum iteration limit or satisfactory solution, is reached, as shown in Fig. 4. PSO has been successfully applied to a wide range of optimization problems, including engineering design, scheduling, data clustering, and neural network training. This algorithm was introduced by Dr. James Kennedy and Dr. Russell Eberhart in 1995. and since then, the PSO has gained popularity as an effective optimization technique and has been further developed and extended by various researchers [16]. There have even been instances where some new metaheuristic algorithms have been accused of bearing similarities to PSO in terms of population-based search and the concept of updating solutions based on local and global information [17] and in terms of the concept of attraction and movement of individuals within the population [18].

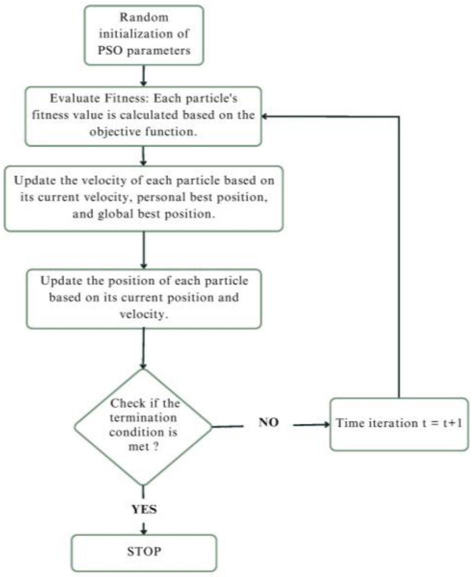

Fig. 4 Flowchart of PSO algorithm [16]

The ANFIS structure comprises two sets of parameters: premise parameters and rule consequence parameters. The process of training the ANFIS network involves determining these parameters through an optimization algorithm. Over time, various training approaches have been proposed for ANFIS, including derivative-based (gradient), heuristic, and hybrid methods. There are two possible strategies for parameter setting: using a single optimization algorithm to set all parameters or employing different algorithms for setting the premise and consequence parameters separately. In this research, the first approach is used, where PSO is combined with ANFIS in order to obtain the best possible results.

Gradient algorithms, while effective, can be susceptible to getting trapped in local minima. This limitation has paved the way for the emergence of metaheuristic algorithms. A comprehensive analysis of recent literature reveals that metaheuristic algorithms are more prevalent than gradient algorithms, and their popularity continues to grow (as depicted in Fig. 5 [14]). Some of the widely known and frequently used metaheuristic algorithms include Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Grey Wolf Optimization (GWO), Whale Optimization Algorithm (WOA), Differential Evolution (DE), Harmony Search (HS), Firefly Algorithm (FA), Mine Blast Algorithm (MBA), Cuckoo Search (CS), and Artificial Bee Colony (ABC).

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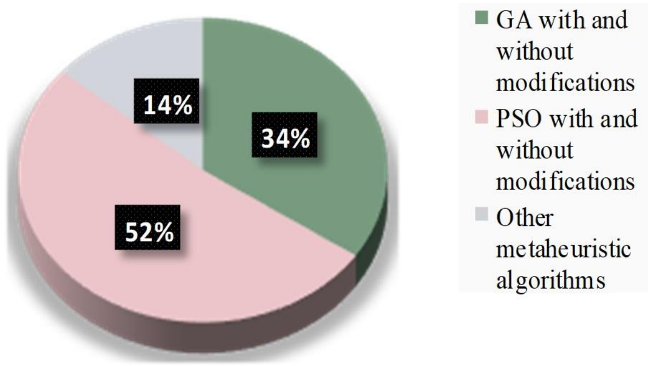

Fig. 5 Percentage of papers on KOBSON when ANFIS and metaheuristic algorithms are set as keywords [14]

3.2.3. ANFIS optimization and experimental results

To avoid an infinite number of identification points and models, an alternative model for heat flow exchange in the chamber is created. This model is nonlinear and it is intended to be valid for the entire state space. For this purpose, ANFIS is particularly suitable.

In this paper, ANFIS utilizes Gaussian membership functions, as shown in (3), where the premise parameters are represented by σ_i (standard deviation) and c_i (center). The total number of underlying parameters is determined by the sum of parameters across all membership functions. In this case, there are 40 premise parameters (2 inputs, 10 Gaussian membership functions with 2 parameters). Additionally, the consequent parameters, denoted as p_i, q_i, and r_i, are identified from the fourth layer, as indicated in (6). The ANFIS structure in this paper encompasses a total of 30 consequent parameters (3 parameters per rule, with a total of 10 rules). To summarize, the ANFIS architecture presented in this paper involves a total of 70 parameters that need to be optimized using the PSO metaheuristic approach. Evaluating the effectiveness of the ANFIS model on a specific dataset is done through a fitness function, with the MSE being commonly used for comparison with linear identification approaches. The ANFIS model was constructed by employing various input voltages, including 1.5V, 2V, 3V, 3.5V, 4.5V, and 5V while maintaining a constant blower input voltage of 3V. To assess its performance on an untrained input of 4V, the same input was also applied to the linear model utilizing the second transfer function from (1). Fig. 6 presents the performance of both models under these conditions, with the ANFIS model yielding a MSE of 0.0003 (blue line). The results demonstrated that the ANFIS model optimized by PSO outperformed both the standard linear model (which MSE, in this case, is 1.1888, green line) and even ANFIS – GA model that has been made in previous research [15] for the same purposes (which MSE was 0.009864). This case study showed that combining ANFIS with PSO algorithm can provide excellent results in the real world problem of identification dryer model.

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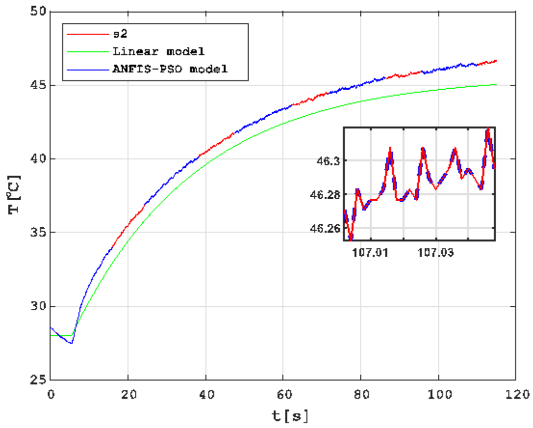

Fig. 6 Comparison of the linear model and ANFIS optimized with the PSO algorithm

4. Conclusion

After conducting experiments outlined in this paper, it becomes evident that the ANFIS nonlinear identification method exhibits superiority over standard identification approaches. The standard method relies on a linear model with a transfer function and delay, which only operates effectively around a specific point. In contrast, ANFIS possesses the capability to handle highly nonlinear systems and this flexibility is crucial for decision-making in intricate systems. To ensure optimal performance, the parameters of the ANFIS model, both premise and consequent, are determined using a well-known metaheuristic method called Particle Swarm Optimization. The improvement that this paper provides to the problem of finding the dryer model is reflected in the MSE, which drops from 1.1888 with the classical method to 0.0003 with ANFIS. Therefore, it can be concluded that the ANFIS model outperforms basic models, even when faced with input voltages that were not included during training.

This research could contribute not only to the identification of dryer models, but also to temperature control in them. Enhancing the performance and energy efficiency of chamber dryers heavily relies on optimizing their design and operational parameters. An effective control system is crucial for maintaining the desired temperature levels. To facilitate the parameter configuration process for the controller, it is imperative to establish a reliable model of the object. This model will aid in optimizing the processes of chamber dryers, ultimately resulting in improved energy efficiency, increased yield, and enhanced drying performance.

Acknowledgement: *Here shown conclusions are the result of research supported by the Ministry of Science, Technology and Innovations Republic of Serbia under contract 451-03-47/2023-01/200105, subprojects TR-35043 and TR-35004, from 03. 02. 2023. year. Also, this article is based upon work from COST action CA18203 (ODIN – www.odin-cost.com), supported by COST (European Cooperation in Science and Technology).*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

OPTIMIZATION OF YIELD OF A FLAT PLATE SOLAR WATER COLLECTOR BY SIMULATION WITH MATLAB

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Abstract: *This study consists at the modeling and the application of numerical methods in order to optimize the performance of a flat-water solar collector under the meteorological conditions of Mali, particularly in the month of January when the sunshine is low and hot water consumption significant. The results obtained show that when the thickness of the glass pane is increased from 2mm to 5mm, the instantaneous efficiency of the solar collector at the beginning increases from 41.46% to 41.49% with a maximum solar radiation intensity of 462 W/m^2 and an average wind speed of 3.5 m/s. When the thickness of the absorber is increased from 4mm to 5mm, the instantaneous efficiency of the solar collector can reach from 40.64% to 41.65%. When the absorber thickness reaches 6mm, the instantaneous efficiency of the solar collector decreases from 42.35 to 42.14%. Increasing the thickness of the collector's absorber plate can significantly improve the collector's instantaneous efficiency. Increasing the thickness of the lateral side insulation does not contribute to improving the collector's instantaneous efficiency. When the thickness of the lateral side insulation of the collector increases from 2cm to 8cm, the instantaneous efficiency of the collector increases from 53.13% to 53.0%. When the mass flow rate of the fluid increases from 0.0265 Kg/s to 0.04 Kg/s, the efficiency increases from 53.14% to 59.18%. This study also showed that these parameters have very little influence on the temperature of the heat transfer fluid.*

Keywords: *Optimization, flat plate solar collector, efficiency, simulation*

1. INTRODUCTION

The fossil fuels used for the production of energy are becoming more and more expensive and are tending to run out, while energy needs are increasing day by day with industrialization. What's more, the consumption of these non-renewable resources produces significant negative effects, such as the greenhouse gases emission, pollution, deforestation, land degradation, etc. In this context, African countries have no choice but to diversify their energy sources. Renewable energies then appear as an alternative. These energies, which use natural resources such as the sun, wind, water and biomass are clean, inexhaustible and available. This energy such as solar power is available, free, can be used in several areas such as the drying of agricultural produce, generating electricity, solar cooking, heating, the production of hot water.

Indeed, the simplest and most direct use of solar energy is the production of hot water for households and public buildings. In Mali, solar water heating is used very little because of several constraints, including the high cost of installations, the population's unfamiliarity with this type of device and, above all, the aridity of the climate, characterized by a period of cold weather (2 months/year at most), which requires a low need for hot water in homes. Mali's solar deposit is considerable, largely unexploited with very high solar irradiation (on average 6 kWh/m2/d), distributed over the entire territory for a daily sunshine duration of 7 to 10 hours [1]. Exploiting solar energy to heat water requires devices that convert solar radiation incident on the earth's surface, such as photovoltaic panels, flat plate collectors, evacuated tube collectors and concentrator collectors. Several works have been carried out on the optimization of flat-plate solar collectors, with the main aim of improving their instantaneous efficiency, which is the most significant performance [2],[3] and [4]. [5] have shown that numerical simulation methods could be applied to the study of solar collectors and obtain results very close to the experiment.

The objective of this work consists at the modeling and the application of numerical methods in order to optimize the performances of a flat-water solar collector under the meteorological conditions of Mali, particularly in January where the sunshine is very low and high hot water consumption.

The effect of parameters such as glass thickness, absorber thickness and lateral insulation thickness influencing the efficiency and temperature of the flat plate water solar collector will be studied in order to serve as a reference for an appropriate choice or local production.

2. MATERIALS AND METHODS

The flat-plate solar collector that will be modelled in our work is schematized by there figure 1. It comprises:

- A transparent cover (glazing) made of materials that are transparent to visible radiation but opaque to infrared radiation, enabling a greenhouse effect to be achieved; it also protects the inside of the collector from the effects of the environment.
- An absorber that absorbs short wavelengths solar radiation and converts it into heat. It is usually painted black to absorb virtually all radiation in the visible spectrum. It consists of a plate in which are integrated tubes through which the heat transfer fluid circulates..
- A heat transfer fluid responsible for transporting the heat stored by the absorber to the temperature source.
- Thermal insulation used to limit heat loss from the collector on the rear and lateral sides.

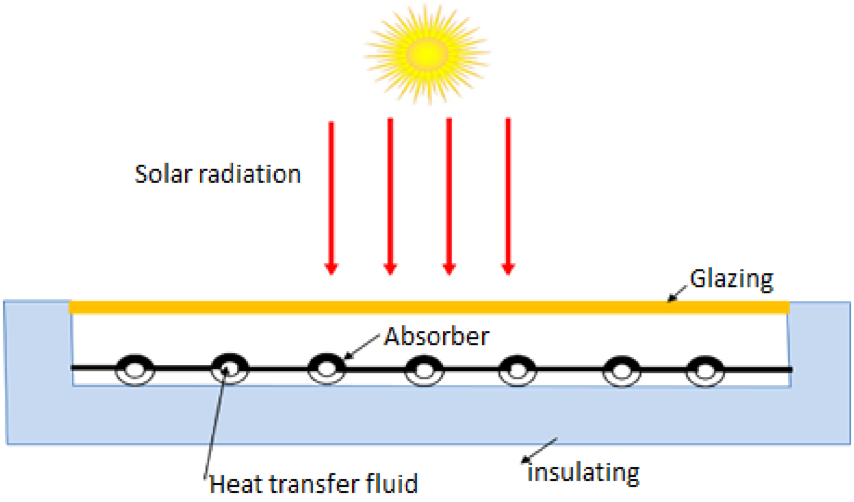

Fig.1 : Flat plate solar collector diagram [6]

2.1. **Assumptions** :

To simplify our study, the following assumptions have been made :

- The sun is assimilated to a black body
- The surface of the collector is uniformly illuminated.
- One-dimensional heat transfer through the layers of the system.
- The mass flow rate is uniform in the collector tubes.
- Heat transfer from the edges of the collector is negligible.
- The external wind speed is assumed to be always parallel to the faces of the collector.
- The heat flux received by the collector is a function of time.
- The physical properties of the materials are not a function of temperature.
- The physical properties of the fluid are not a function of temperature.
- Dust and dirt on the collector are negligible.
- The flow regime is transient.
- The temperature of the absorber plate is assumed to be equal to that of the tubes.
- The ground temperature is assumed to be equal to the ambient temperature.

2.2. **Thermal balance of flat solar collector components**

2.2.1. Energy balance of the transparent cover (glass)

The energy balance of the transparent cover can be written using the following relationship [7],[8] and [6]:

$$m_1 c_1 \frac{dT_1}{dt} = \alpha_1 S_1 I_c + S_2 \left(h_{c12} + h_{r12}\right)\left(T_2 - T_1\right) - h_{c1am} S_1 \left(T_1 - T_{am}\right) - h_{r1ciel} S_1 \left(T_1 - T_{ciel}\right) \quad (1)$$

2.2.2. Energy balance of the absorber plate

The energy balance of the absorber plate is given by [7],[8] and [6]:

$$m_2 c_2 \frac{dT_2}{dt} = \alpha_2 S_2 \tau_1 I_c - (\Psi_1 + \Psi_2)(T_2 - T_{isl}) - S_2 (h_{c12} + h_{r12})(T_2 - T_1) - h_{c23} S_{23} (T_2 - T_3) \quad (2)$$

2.2.3. Heat transfer fluid energy balance

The energy balance for the heat transfer fluid is given by [6], [8]:

$$c_3 \left(m_3 \frac{dT_3}{dt} + \dot{m} \frac{dT_3}{dx} \right) = h_{c23} S_{23} (T_2 - T_3) \quad (3)$$

$\dot{m}$: Heat transfer fluid mass flow rate (Kg/s)

2.2.4. Energy balance for insulation

The energy balance for insulation is [7],[8] and [6] :

$$m_{is} c_{is} \frac{dT_{isl}}{dt} = (\Psi_1 + \Psi_2)(T_2 - T_{isl}) - h_{ris} S_{is} (T_{isl} - T_{sol}) - h_{cis} S_{is} (T_{isl} - T_{am}) \quad (4)$$

The total energy balance which describes the thermal behaviour (heat exchange) of the collector studied is given in the form of equations (1), (2), (3), (4).

2.3. **Determination of Overall heat exchange coefficients with the environment**

Heat losses occur to the front, back and sides of the collector. These losses manifest themselves in all three modes of heat transfer.

The electrical analogy linked to the different thermal resistances during the heat exchanges carried out on the different elements of the collector is illustrated in Figure 2.

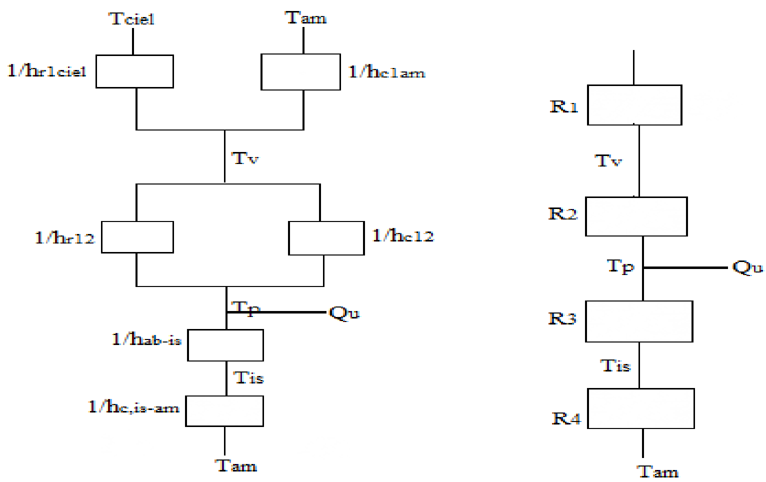

Fig.2: Equivalent electrical circuit relating to a flat solar collector [6]

2.3.1. Loss coefficient thermal to the front

Losses between the glass pane and the outside environment are essentially due to heat transfer by convection and radiation. The overall heat loss coefficient towards the front of the collector is given by the following relationship, as in Figure 2 [9], [7], [3] and [6].

$$U_{av} = \frac{1}{R_1 + R_2} = \frac{1}{\frac{1}{h_{c1am} + h_{r1ciel}} + \frac{1}{h_{c12} + h_{r12}}} \quad (5)$$

2.3.2. loss coefficient thermal to the back

The resistance due to convection is often neglected compared with that due to conduction within the absorber-insulator [9]. The value of this coefficient is less important than that of forward losses, because the collector is very well insulated at the back. Its expression is given by [9], [7], [3] and [6].

$$U_{ar} = \frac{1}{R_3} = \frac{\lambda_{isl}}{e_{isl}} \quad (6)$$

2.3.3. Loss coefficient thermal lateral

This coefficient is lower than that of the rear losses, insofar as the lateral surface of the solar collector is smaller [9], [7], [3] and [6].

$$U_{lat} = \frac{\lambda_{isl} \; \mathrm{S}_{la}}{e_{la} \; \mathrm{A}_c} \quad (7)$$

A_c : Surface of collector exposed to radiation in (m^2).

The overall heat loss exchange coefficient to the environment is the sum of the three coefficients [9], [7], [3] and [6].

$$U_{tot} = U_{av} + U_{ar} + U_{lat} \quad (8)$$

2.4. Solar collector efficiency

The instantaneous efficiency of the flat-plate solar collector is equal to the ratio between the useful flux recovered on the overall incident illumination received by the collector surface [7], [8].

$$\eta_c = \frac{Q_u}{A_c I_c} \quad (9)$$

$$Q_u = \dot{m} c_{pf} \left(T_{fs} - T_{fe}\right) = \rho_f A_f V_f c_{pf} \left(T_{fs} - T_{fe}\right)$$

I_c: incident solar flux received by the collector in (W/m^2)

Q_u: useful flux recovered by the heat transfer fluid (W).

2.5. Numerical resolution

The equations describing the different heat exchanges involved inside a collector in transient state (1) (2) (3) (4) were discretized using the finite difference method. This system of equations and the heat transfer coefficients were then solved numerically with MATLAB software using the iterative Gauss-Seidel method.

The component temperatures were taken to be equal to the ambient temperature (initialization), with the exception of the absorber temperature, which is slightly higher. Ambient temperature and global solar radiation data were collected on 01/01/2019 at the meteorological station of the Faculty of Science and Technology of Bamako.

Table 1: Input parameters for the simulation of the flat collector studied

Setting	Value	Reference
Latitude Bamako	12.65°	
Longitude Bamako	-8°	
Altitude Bamako	$338\ m$	
Dimension solar collector (m)	1.950×1.205×0.105	
β : The angle of inclination	12.65°	
n: number of slices	10	[10], [11] and [12]
D_{in} : Inner diameter of the tube	0.015m	
D_{in} : Outside diameter of the tube	0.017m	
L_{tu} : pipe length	1.8m	
S_{ab} Absorber area	2.07 m^2	
e_1 : Glass thickness _	0.00 4m	
e_2 : Thickness of the absorber	0.005m	
e_{ish} : Insulation thickness _ back	0.05m	
e_{la} : Insulation thickness _ lateral	0.02m	
τ_1 : Pane transmission coefficient	0.9	
ε_1 : Glazing emissivity	0.94	
ε_2 : Emissivity of the absorber	0.09	
ε_{isl} : Emissivity of the insulation	0.05	
α_1 : Glass absorption coefficient	0.06	
α_2 : Absorption coefficient of the absorber	0.63	
ρ_c : Glass density	2700 Kg/ m^3	
ρ_{ab} : Density of the absorber	2700 Kg/ m^3	
ρ_{isl} : Density of the insulation	40 Kg/ m^3	
c_{pc} : Specific heat of glass	840 J/ Kg.K	
c_{pab} : Specific heat of the absorber	879 J/ Kg.K	
c_{pisl} : Specific heat of the insulation	840 J/ Kg.K	

λ_c : Thermal conductivity of glass	0.93 W m $^{-1}$ K $^{-1}$	
λ_{ab} : Thermal conductivity of the absorber	204 W m $^{-1}$ K $^{-1}$	
λ_{isl} Thermal conductivity of insulation	0.041 W m $^{-1}$ K $^{-1}$	
σ : Constant of Stéphane Boltzman	5.67×10^{-8} W/ (m ^{2} K ^{4})	

2.6. Validation of the numerical code

Figure 3 shows the evolution of the different temperatures of the collector as a function of time with a maximum solar radiation of the day 462 w/m^2. The absorber temperature is the highest. Indeed, the absorber absorbs most of the solar radiation thanks to its high absorption coefficient to heat the fluid. The temperature of the heat transfer fluid is fairly high compared to the other components of the collector. The difference between the temperature of the absorber and that the heat transfer fluid is mainly due to the convection coefficient of the latter, which has significant values. The temperature of the insulation is quite low compared with that of the fluid because it resists thermal loss towards the sides of the absorber as well as those due to the action of the wind. The temperature of the glass pane is low compared to the other components of the collector because of heat loss to the outside and its low absorption coefficient. Fluctuations due to solar radiation appear during the first few hours, in agreement with the result of [13], [14].

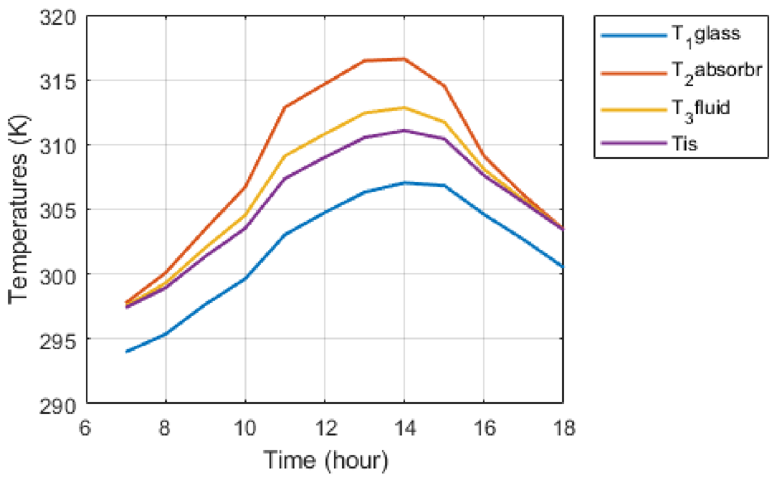

Fig.3: Evolution of the Temperatures of different components of the sensor as a function of time [6].

3. RESULTS AND DISCUSION

In Figures 4-9, we present the numerical results obtained from the flat-water collector with the main characteristics given in Table 1. The temperatures of the fluid, glass and insulator at the collector inlet are taken to be equal to the ambient temperature at initialization, except for the temperature of the absorber, which is slightly higher by one, in order to study the effect of several operating and design parameters on the transient performance of the collector.

3.1. Temporal variation in global solar radiation and ambient temperature

The intensity of solar radiation and ambient temperature as a function of time recorded on 01/01/2019 by the radiometric station located on the site of the Faculty of Science and Technology is shown in Figure 4. At 7 a.m., the intensity solar is 30.90 W/m^2, and increases as time goes by, until reaching the peak with a value of 462.079 W/m^2 around 1 p.m., then decreases about 5.8 W/m^2 at the end of the experiment.

It can be seen that the ambient temperature varied throughout the day. As shown in Figure 4, at the start of the test, the ambient temperature is low, with a value of 297.211 K, and it begins to increase as time passes until it reaches a maximum value of 308.064 K around 3 p.m., then it decreases.

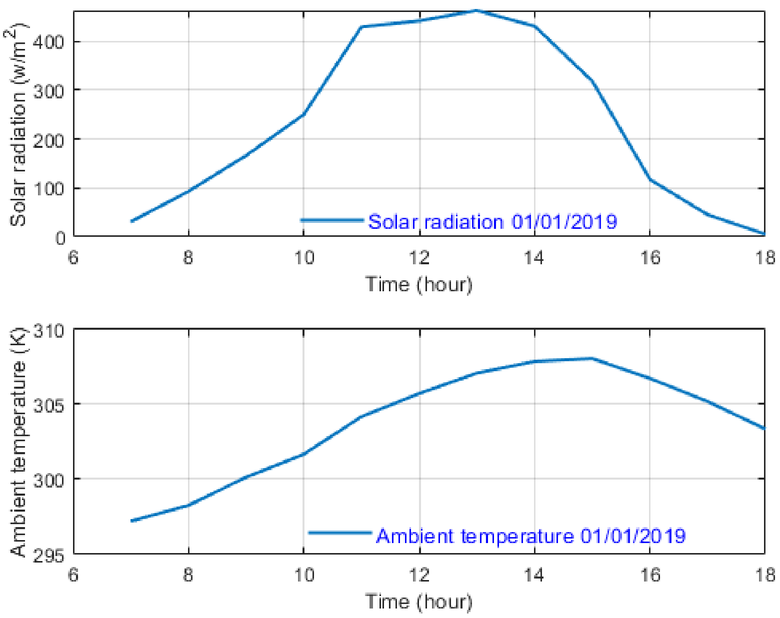

Fig.4: Variation in solar intensity and ambient temperature as a function of time.

3.2. Effect of glass thickness on collector efficiency

According to figure 5, we note that the instantaneous efficiency of the collector increases little at the beginning with the increase in the thickness of the glass pane for a solar radiation lower than 462 w/m^2 and an average wind speed of 3.5 m /s. Indeed, the greater the thickness of the glass, the greater its heat capacity and the better its thermal inertia, consequently a lower transmission coefficient, hence the reduction in collector temperature which results in a lower efficiency.

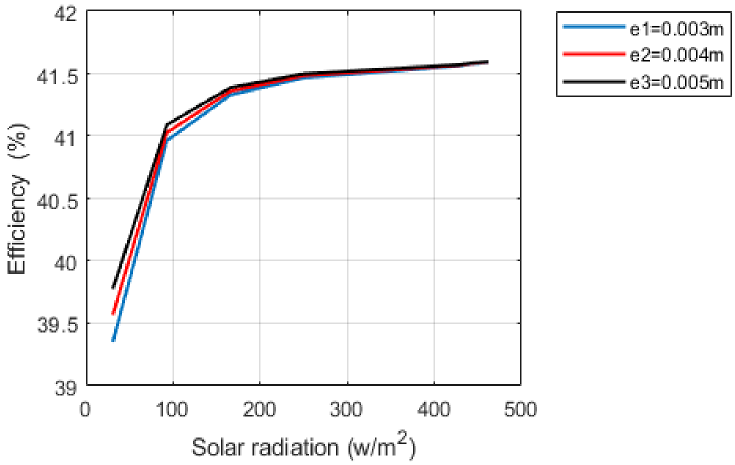

Fig.5: Evolution of efficiency as a function of solar radiation for different values of glass thickness.

3.3. Effect of absorber thickness on collector efficiency

Figure 6 clearly shows that the instantaneous efficiency of the solar collector increases with the first two values of the absorber thickness, then decreases with the last value of the thickness. Indeed, increasing the thickness of the absorber plate increases the contact surface between the absorber plate and the collector tubes, and then reduces the resistance to thermal conduction, so that the heat from the absorber plate is more easily transferred to the working fluid inside the collector tubes, and the instantaneous efficiency of the collector is improved.

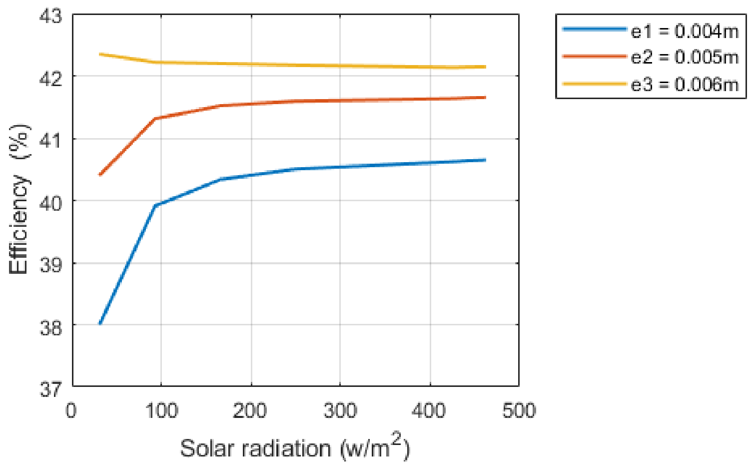

Fig.6: Evolution of efficiency as a function of solar radiation for different values of absorber thickness

3.4. Effect of lateral side insulation thickness on the collector's instantaneous efficiency

Figure 7 shows that there is almost no difference in the variation of the collector's instantaneous efficiency with different thicknesses of the lateral side insulation used in this study. The efficiency increases slightly with decreasing thickness of side insulation. This is because it is less exposed to the thermal fluctuations produced by the direct absorption of solar heat.

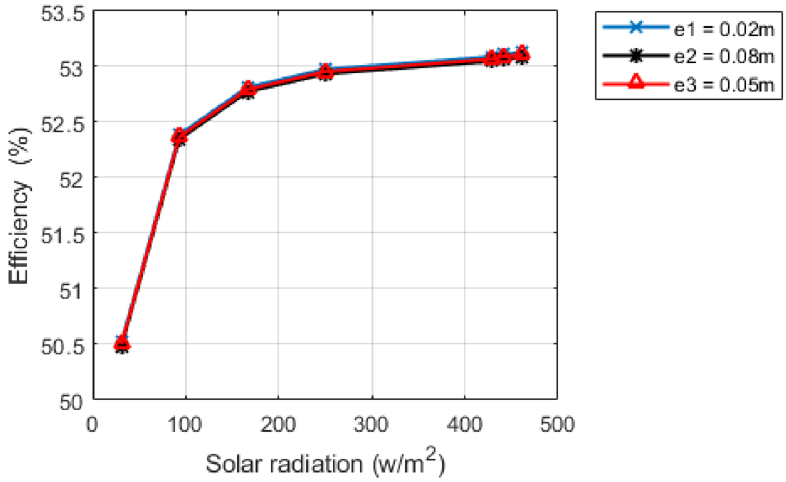

Fig.7: Evolution of efficiency as a function of solar radiation for different values of lateral insulation thickness.

3.5. Effect of mass flow rate on collector efficiency and heat transfer fluid temperature

It appears in figure 8, the evolution of the instantaneous efficiency according to the mass flow of the fluid. Indeed, increasing the mass flow rate of the fluid increases the speed of the fluid flow, promoting heat transfer by convection between the absorber plate and the heat transfer fluid, and therefore increasing the efficiency of the collector. On the other hand, the higher the flow velocity, the shorter the time taken to heat the fluid, resulting in a reduction in the temperature of the heat transfer fluid (Figure 9).

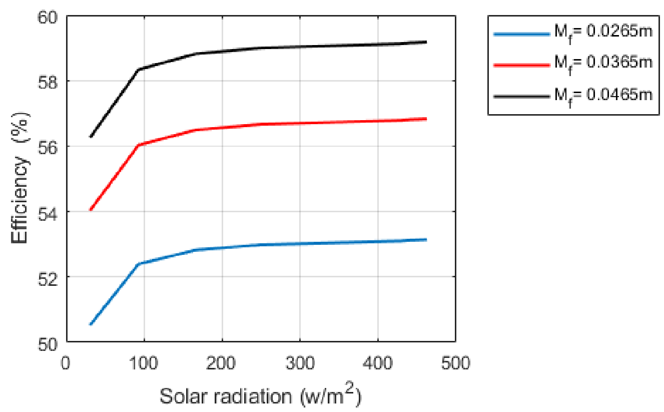

Fig.8: Evolution of efficiency as a function of solar radiation for different mass flow rate values.

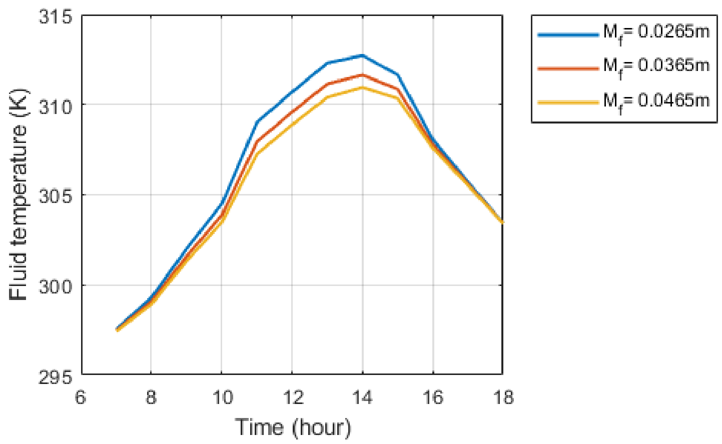

Fig.9: Evolution of heat transfer fluid temperature as a function of time for different mass flow rate values.

4. CONCLUSION

This study made it possible to elaborate a numerical model, to simulate some external (ambient temperature, solar radiation) and internal (thickness of the various components of the collector and the mass flow rate of the heat transfer fluid) parameters influencing the efficiency and the temperature of the heat transfer fluid of the flat-plate water solar collector in January under the weather conditions in Mali. The results showed that for a maximum solar radiation of 462 W/m2 and a wind speed of 3.5 m/s:

- Efficiency increases little at the beginning of the day, when the thickness of the glass increases from 0.003 to 0.005 m ;

- When the thickness of the absorber increases from 0.004 to 0.005 m, the efficiency increases and for 0.006 m, the efficiency decreases;
- LeThe efficiency decreases when the thickness of the lateral insulation increases from 0.02m, 0.05m and 0.08m;
- L'augThe increase in fluid mass flow leads to an increase in efficiency, reaching a maximum value of 59.18%

Acknowledgement: *We would like to thank the Government of Serbia, the Government of Mali and ISESCO (Islamic Educational, Scientific and Cultural Organisation) for their support.*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

ARTIFICIAL INTELLIGENCE METHODS FOR ENERGY USE PREDICTION

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INVITED PLENARY LECTURE

Abstract: *This paper covers the application of artificial intelligence in agriculture. Technology development has enabled measurement, collecting and processing high quality big data. These data can be successfully used to significantly improve numerous segments of agriculture sector. The accent in this paper is given on the models used for energy use prediction. The application of Artificial Neural Networks with different structure is presented, such as Feedforward Neural Network, Radial basis Function Network and Adaptive Neuro-Fuzzy Inference System. Support Vector Machine model is also shown. The improvements of individual models are elaborated, through the analysis of the ensemble and hybrid approach. All of the proposed models are capable of solving complex problem of prediction of energy use based on real, measured data. Ensemble and hybrid models are promising, as it has been shown that the prediction accuracy is improved by combining different single models in proposed manner.*

Key words: *agriculture, artificial intelligence, machine learning, energy use prediction*

1. INTRODUCTION

The agriculture is one the most important components of social and economic development of a country. However, in many countries, farming is still carried out in the still traditional way, while farmers, due to the lack of knowledge, are often unaware of the advantages of using up-to-date technologies. At the same time, the constant growth of population increases the pressure on the agriculture sector, while overall losses in the agriculture processes starting from crop selection to selling of products are still very high. According to the World Bank, the percentage of total land area used for agriculture production has remained at about 37.43% during 2000–2016 while the world population increased by 1.31 billion [1]. Therefore, the increase of productivity, as well as energy efficiency is essential for meeting the future demand. Also, globally, agriculture comprises approximately 12% of GHG emissions [2]. In order to address the issue of increasing global warming, the UN declared a Decade of Sustainable Energy for All from 2014 to 2024 with efforts to achieve energy and food security targets in the agricultural sector. To achieve an energy-smart food system, adequate managerial strategies and energy-efficient technologies in various agriculture sector are essential in order to maximize output and minimize the production costs and environmental emissions [3].

2. ARTIFICIAL INTELLIGENCE IN AGRICULTURE

Artificial intelligence (AI) in various application forms, such as Machine Learning, is intensively developing and bringing significant improvements in almost every sector of human life, including healthcare, agriculture, engineering and automation. Especially, the use of AI techniques in agriculture has significantly increased over the past few years [3]. AI in combination with the technology that allows collecting and processing of big data, highly efficient computing, has created huge opportunities for exploring, understanding and analyzing agricultural processes in order to improve all segments of agriculture sector.

The authors in [1] highlighted that the combination of agriculture with AI has proven to be a promising opportunity area, as it has potential to solve the problems of agricultural production efficiency in numerous ways. Automation has replaced traditional methods of operation in farming and enabled the end user with real-time data analysis for accurate and faster decision-making. These rapidly developing technologies have enabled the agriculture sector to collect, storage, analyze and present data in a highly effective manner with less manual efforts. Additionally, AI methods simplify the data analysis and empower the end user with enhanced decision-making capability as compared to traditional systems of managing agricultural processes.

In [4] the authors presented a comprehensive review of the application of ML in agriculture. The majority of analyzed research papers are dealing with crop quality, while investigating application of AI in areas such as yield prediction, disease detection, weed detection and crop quality. Livestock production and animal welfare are also being intensively improved by using AI, as well as soil and water management sector. Various state-of-the-art ML and deep learning models in different stages of agriculture, including pre-harvesting, harvesting and post- harvesting in different domains are reviewed in [5].

Similarly, in [6] the authors highlight promised area of improvement of agriculture in the exploitation of the data: water quality, air quality, soil health, food quality, food security, biodiversity, quality of life and output. AI in protected cultivation can predict yield, ensure product quality from starting material to harvest, help decide on the planning of time-to-market and resources used and improve efficiency. It can, therefore, contribute to the economic profit of growers and the sustainability of their production. ML tools are currently being used to complement expert-based approaches for supporting yield predictions. Different AI technologies have proven to efficiently contribute to predicting yield, as well as to increase yield and product quality and, at the same time, save resources such as energy, water and nutrients. Descriptive and predictive models have already been successfully implemented as forecasting tools, such as Partial Least Squares (PLS) in [7] and Support Vector Machine (SVM) in [8] and Artificial Neural Networks (ANN) in [9]. Considering that the agriculture is essential for the wellbeing and development of a country, while undergoing increased pressure to maintain the balance between production and raising demand, the achievement of maximum crop is one of the most widespread research topics. The methodology for the prediction of crop yield uses various parameters like rainfall, temperature, fertilizers and pesticides, etc. In this area, ML has widely been used. With the advancement in the information and technology, AI is the emerging field in agriculture and its various usages in this domain are listed as [10]: crop yield and price prediction, intelligent spraying, agriculture robots, predictive insights, crop and soil monitoring and crop disease diagnosis. In [10] the authors proposed using ANN for the crop yield prediction. This approach proved to be effective in distinction between the wheat crops from the other unwanted plants and weeds and is also able to appropriately identify the crop yield age into categorical classes.

All previously mentioned sectors within agriculture are of high importance, however, the consumption of energy for all this tasks should be seriously taken into account. It should be pointed out that energy use in agriculture is increasing due to the population growth, as well as due to changes in technology required to satisfy the continuously raising food demand. Therefore, in order to obtain sustainable agricultural production, the question of energy efficiency is one of the key issues. Higher energy efficiency leads to cost savings, preservation of fossil resources as well as reduction of negative environmental impact of the agriculture sector. Therefore, it is necessary to recognize and study common patterns of agriculture in order to select a suitable energy use pattern for recommendation to farmers [11]. The development of energy efficient agricultural systems – with a low input of energy compared to the output of products – should help to reduce the emissions of greenhouse gasses in agricultural production [12]. Energy use is one of the key indicators for developing more sustainable agricultural practices.

There are many studies that apply Multiple Linear Regression models for the prediction of energy use in the agriculture, such as production of peaches [13], mushrooms [14] and lentil [15]. The study [16] is conducted in order to determine energy consumption, model the input–output and analyze energy efficiency and GHG emissions for watermelon production using ANN with Levenberg–Marquardt learning algorithm. In [17] the aim is to predict wheat output energy consumption using Multi-Layered Perceptron, Radial Basis Function Network (RBFN) and Gaussian Process Regression. In [3] the authors developed Multi-Layered Perceptron to evaluate energy and cost savings strategies in poultry farms The results show that the developed models are capable to successfully address the prediction task. ANNs are efficiently used for the prediction of energy output of various field crop, such as basil [18] and kiwi [19].

In this paper, the application of some of the most often used AI models for energy use prediction are presented. Also, some prominent improvements of the proposed models using newly developed techniques are discussed. For all the models presented in this paper, in the previous research the same historical database was used. The used database consists of measured meteorological and daily energy use data for a group of mixed use buildings. These methods, that are proven to be successful in prediction and solving complex nonlinear problems are expected to be at least equally efficient in the energy use prediction in agriculture, while using relevant input variables.

3. ARTIFICIAL INTELLIGENCE MODELS FOR ENERGY USE PREDICTION

In recent years, considerable attention has been given to a different approach for energy use analysis, which is based on the so called "inverse" or data-driven (“black box”) models. In a data-driven approach, it is required that the input and output variables are known and measured, while the development of the "inverse" model consists of determination of a mathematical description of the relationship between the independent variables and the dependent one. This approach is highly efficient and useful when the investigated object is already in use, so the actual consumption (or performance) data are being measured and available. For this task, different statistical methods can be used.

3.1. Artificial Neural Networks

Artificial neural networks (ANN) are the most often used artificial intelligence models for different types of predictions. The main advantages of an ANN model are its self-learning capability and the fact that it can approximate a nonlinear relationship between the input variables and the output of a very complicated system. The ANNs learn from key information patterns allowing discovering complex relationships between the variables.

3.1.1. Feedforward Neural Networks

ANN is a computational structure inspired by a biological neural system, which consists of very simple and highly interconnected processors called neurons. They are usually arranged in an input layer, an output layer, and one or more hidden layers. The output of a specific neuron is a function of the weighted input, the bias of the neuron and the transfer function. In its simple form, each single neuron is connected to other neurons of a previous layer through adaptable synaptic weights. The neural network training process simply involves modification of weights until the predicted output is in close agreement with the actual output. Defined relations between the input layers, the hidden layers and the output layers determine a particular neural network model. Multi-layer, feedforward neural network (FFNN) with backpropagation learning method is one of the most often used. The backpropagation algorithm utilizes a generalization of the least mean square algorithm. It uses a gradient descent technique to minimize the cost function which is the mean square difference between the desired and the actual network outputs. A schematic diagram of a typical multilayer FFNN architecture is shown in Fig. 1.

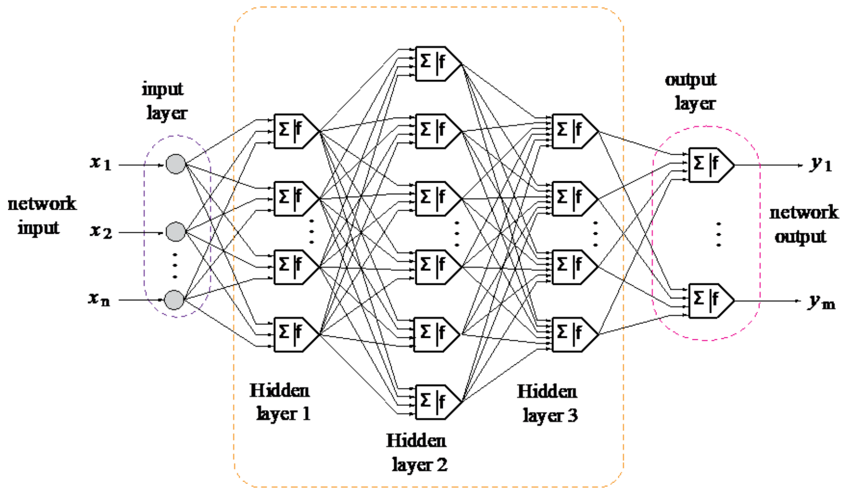

Fig. 1 Feedforward neural network architecture

FFNN models are nowadays widely spread in solving various engineering tasks, while they have proven to be very effective in modeling energy use based on real measured data. In [20] the number of neurons in the hidden layer was varied in order to achieve better performance. In future work, the network parameters can be optimized using some evolutionary algorithm.

3.1.2. Radial Basis Function Networks

A radial basis function network (RBFN), a type of feedforward neural network, consists of three layers including an input layer, a single hidden layer with a number of neurons, and an output layer. The input nodes are directly connected to the hidden layer neurons [20], while the hidden layer transforms the data from the input space to the hidden space using a nonlinear function. The nonlinear function of hidden neurons is symmetric in the input space, and the output of each hidden neuron depends only on the radial distance between the input vector and the center of the hidden neuron. RBFN uses the radially symmetrical function as an activation function in the hidden layer, and the Gaussian function is one of the most commonly used activation functions. The neurons of the output layer have a linear transfer function. In [20] and [21] a customized RBFN function available in MATLAB, which iteratively creates a radial basis network one neuron at a time, is used to develop the model. The number of neurons in the hidden layer is increased automatically until the error goal is achieved, or the maximum number of neurons in hidden layer has been exceeded. The radius value (known as spread) of the radial basis function was varied for the best performance of the RBF network. It can be seen that the RBFN model achieves great accuracy, having comparable, and in some parameters even better results than FFNN.

3.1.3. Adaptive Neuro-Fuzzy Inference System

The process of fuzzy inference involves membership functions, fuzzy logic operators, and if-then rules. Fuzzy inference systems (FIS) have been successfully applied in fields such as automatic control, monitoring and maintenance, data classification, decision analysis, expert systems,and computer vision. The generalization capability of the fuzzy logic is very poor because it uses the heuristic algorithms for defuzzication, rule evolution and antecedent processing. On the other hand, the main disadvantage of neural network is how to determine proper size and optimal structure of the network. Combining fuzzy logic and neural network is preeminent idea to overcome the disadvantages of both techniques. The outstanding property of the Adaptive Neuro-Fuzzy Inference System (ANFIS) is that it compensates the disadvantage of FIS with the learning mechanism of ANN. The architecture of the ANFIS used in [20] is based on the first-order Takagi-Sugeno model. The ANFIS architecture is shown in Fig. 1. It is composed of five layers where each layer contains several nodes described by the node function. More information on the structure and optimization process can be found in [20].

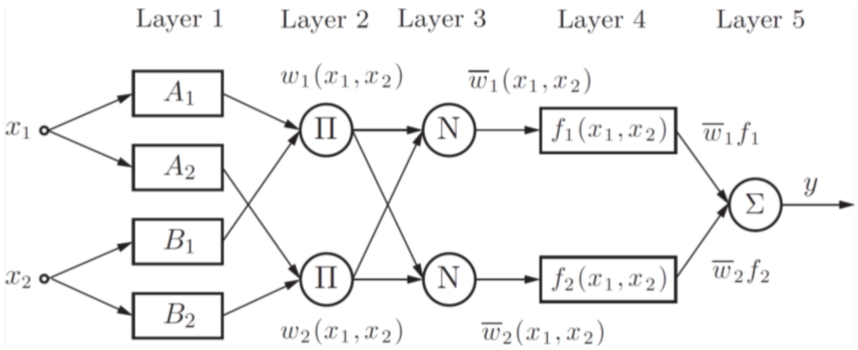

Fig. 2 The ANFIS network structure [20]

In the training process, the least squares method (forward pass) is used to optimize the consequent parameters with the premise parameters fixed. Once the optimal consequent parameters are found, the backward pass starts immediately. The gradient descent method (backward pass) is used to adjust optimally the premise parameters corresponding to the fuzzy sets in the input domain. The output of the ANFIS is calculated by employing the consequent parameters found in the forward pass. The output error is used to adapt the premise parameters by means of a standard back propagation algorithm.

For the case study elaborated in [20] it can be seen that the ANFIS model achieves comparable, and for some cases even better prediction results comparing to networks with other architecture, such as FFNN and RBFN. It is evident that the ANN models are very successful in solving energy use prediction tasks.

3.2. Support Vector Machine

Support Vector Machine (SVM) is the universal approximator of any multivariate function to any desired degree of accuracy, same (or similar) as the ANN [22]. There is a difference in the development between these two most common used statistical techniques. SVM was developed from theory, and later it was implemented in practice and experiments, while the ANN followed the path in reverse order: from application and extensive experiments to theory. The foundations of SVM have been developed by Vapnik and co-workers in 1964/65 [23], but until recently it was widespread the opinion that it was not suitable for practical application. Today, SVMs show better (or comparable) results than ANNs and other statistical models. Traditional ANN approaches have suffered difficulties with generalization, producing models that can overfit the data [24]. This is a consequence of the optimization algorithms used for parameter selection and the statistical measures used to select the optimal model. SVMs are the so-called nonparametric model, which means that their "learning" (training) is the crucial issue. The parameters are not predefined and their number depends on the training data used [25]. Besides great ability to generalize, another key characteristic is that training of SVM is equivalent to solving a linearly constrained quadratic programming problem so that the solution of SVM is always unique and globally optimal, unlike other network's training which requires non-linear optimization with the danger of getting stuck into local minimum. In SVM, the solution to the problem is only dependent on a subset of training data points which are referred as support vectors. Using only support vectors, the same solution can be obtained as using all the training data points. SVMs were developed to solve the classification problem, but recently they have been extended to the domain of regression problems, which is often referred as Support Vector Regression (SVR) [26].

The nonlinear Support Vector Regression is illustrated in Fig. 3. The region enclosed by the tube is called ε -insensitive zone. The values with excess positive and negative deviations are denoted with ξi and,ξi^*, respectively and they are called the „slack variables". The optimization criterion penalizes those data points whose values of *y* lie more than ε distance away from the fitted function *f(x)*. If the predicted value is within the tube, the loss is zero, while if the predicted point is outside of the tube, the loss is magnitude of the difference between the predicted value and the radius ε of the tube. More details on the SVR model development can be found in [22].

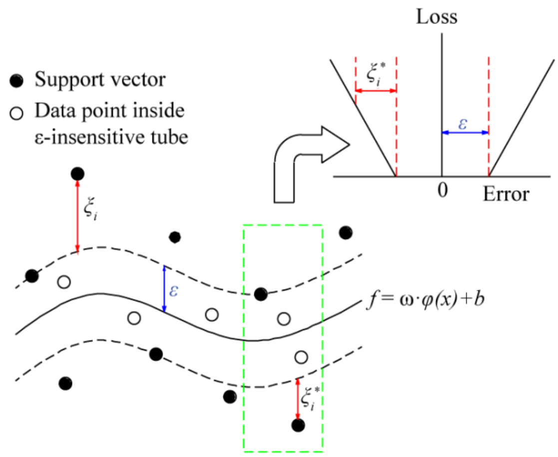

Fig. 3 Support Vector Regression [22]

The parameters that define the nonlinear SVR are the cost constant C, the radius of the insensitive tube ε, and the kernel parameters (in case of RBF kernel γ) [22]. These parameters are mutually dependent, so changing the value of one parameter influences other parameters. The parameter C controls the smoothness or flatness of the approximation function. A greater C corresponds to greater penalty of errors and makes the learning machine more complex. Smaller C may cause the errors to be excessively tolerated, which can lead to learning machine with poor approximation. The parameter ε also affects smoothness and dominates the number of support vectors (smaller ε lead to more support vectors and more complex machine). Training of the SVM model comprises of finding the optimal combination of these parameters. One of the advantages of SVM is the possibility to use the grid search method in order to overcome potential shortcomings of the trial and error method. When using neural networks for prediction, more parameters needs to be known a priori, such as training algorithms, number of layers, number of neurons in hidden layers, etc. The optimal parameters are usually chosen by trial-and-error method. In libsvm library [27], the "gridregression.py", which conducts grid search over the combination of the parameters, in defined range, with specified step is also available. It calculates the training error for all combinations of parameters and picks out the combination achieving the smallest error. On the case study that has been thoroughly studied in previously published papers it can be seen that all the developed AI models (FFNN, RBFN, ANFIS and SVM) achieves very good prediction results.

4. IMPROVEMENTS OF SINGLE AI MODELS

Although all of the presented AI models (FFNN, RBFN, ANFIS and SVM) have shown to be very effective in solving practical energy use prediction problems, by achieving relatively low errors, there is always space for improvements. Since this topic is being of high importance, in recent literature, various successful approaches and attempts of improving the "basic" models can be found. In this paper, the techniques that have been previously developed by the authors and proven to be effective on the same case study are in focus. One of the first ideas of the authors involved in these studies was to investigate possible enhancement of the individual models by combining them into ensemble. Based on available research studies, the ensemble of neural networks appears to be a very successful technique where the outputs of a set of separately trained neural networks are combined to form one unified prediction. Theoretical and empirical work showed that a good ensemble is one where the individual networks have both accuracy and diversity, namely the individual networks make their errors on different parts of the input space. An important issue is, then, how to select the aggregate members in order to have an optimal compromise between these two conflicting conditions. The accuracy can be described by the mean square error (or some other prediction indicator) and achieved by proper training algorithms of neural networks. Diverse individual predictors (members) can be obtained in several ways. The first group of methods refers to training individuals on different adequately-chosen subsets of the dataset. It includes elaborations of several important „resampling" techniques, such as cross-validation, bagging and boosting. These methods rely on resampling algorithms to obtain different training sets for the component predictors. The second group of methods for achieving diversity uses variation of topologies, by varying number of input and/or hidden nodes, initial weight sets, training algorithms, or even different types of networks. The third group is named selective approach group where the diverse components are selected from a number of accurately trained networks.

4.1 Ensemble of different neural network architecture

In [21] the required diversity among ensemble members is achieved using different network architectures for ensemble members: FFNN, RBFN and ANFIS. All networks were trained and tested on the same dataset consisting of real, measured data. In order to create the ensemble, members (prediction results of individual networks) are aggregated using simple, weighted and median based averaging, as it can be seen in Fig. 4

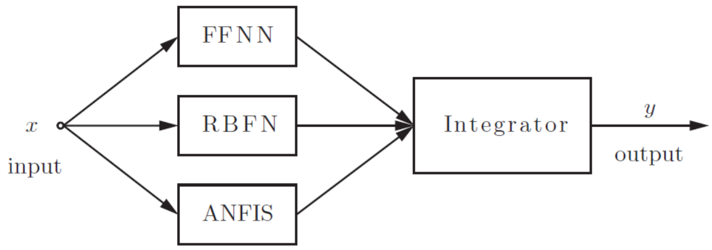

Fig. 4 The neural networks ensemble structure proposed in [21]

The results show that even these „simple“ integrating technique, by using various averaging can lead to the improvement of the prediction results. The results has been encouraging, so the investigation of the ensemble technique is continued in following papers.

4.2 Ensemble with k-means clustering for resampling training dataset

In [21] the authors examined possible improvement of the prediction accuracy by creating ensemble, while using k-means „resampling“ on training dataset in order to achieve diversity among ensemble members. The application of an ensemble technique is divided into two steps, as it can be seen in Fig. 5. First, training data is divided in clusters (training data subsets). Samples from entire training dataset are randomly chosen and added to each cluster until the number of samples in each cluster is equal to total number of samples. This improved method of generating training sample subsets effectively prevents that each individual neural network is trained on too small data subset. The obtained datasets are further used to train individual RBFNs. The second step is the adequate combination of outputs of the ensemble members to produce the most appropriate output. As previously mentioned, in order to obtain ensemble efficiency, it is necessary to ensure both accuracy of networks and diversity between individuals. Accuracy is achieved by appropriate choice of network parameters, while the diversity is achieved by using different training dataset for each member. In previous work [20], the diversity is achieved by using different network architectures (FFNN, RBFN and ANFIS), while the main idea in [21] is to apply k-means for resampling dataset in order to create diversity between members. The outputs of individual networks are aggregated using simple, weighted and median based average.

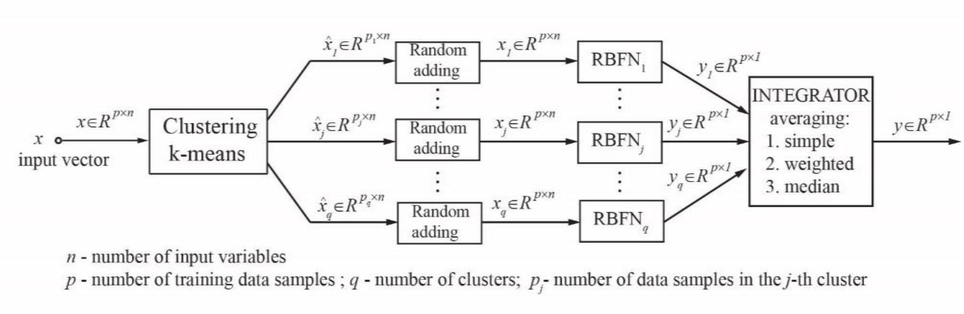

Fig. 5 Neural network ensemble proposed in [21]

The results show that all of the ensembles, even with different number of clusters and different averaging method, achieve better prediction results than the best trained RBFN network.

4.3 Ensemble with k-means clustering of the trained FFNN models for members selection

In [28] the application of an ensemble technique is also divided into two steps. As the first step, after training numerous FFNNs, 50 networks with satisfying accuracy are selected as possible members. The second step is the adequate combination of outputs of the ensemble members to produce the most appropriate output. Again, the goal is to achieve both accuracy and diversity of the individual models, expecting it would improve the prediction quality. The idea is to apply an easier method to gradually achieve both goals. First, the clustering technology was employed in order to divide all networks into some groups (clusters) according to similarity of the networks. K-means, as one of the most used clustering technique is used for separating trained networks Then, one most accurate individual in each group on the validation set is selected. Finally, all selected individuals construct the ensemble, as it can be seen in Fig. 6.

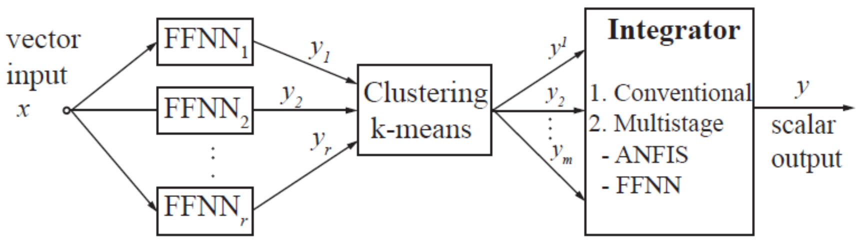

Fig. 6 Neural network ensemble proposed in [28]

There are different methods for combining the outputs. The conventional approach is to use averaging: simple, weighted or median, as shown in [21]. Here, again, the simple and weighted averaging the predictions of the selected networks have resulted in an improvement in accuracy over the predictions of the best trained individual FFNN. In

[28] the authors introduce another idea, the multistage approach, which is expected to give an even better improvement in accuracy. The idea is to use another neural network as an integrator of the individual classifiers. Two different network architectures are proposed in the second stage: FFNN and ANFIS. In [28] different ANFIS models are constructed using three different identification methods: grid partitioning, subtractive clustering and fuzzy C-means clustering. In this case study, the multistage model, using ANFIS in second level is proven to be most effective. It was demonstrated that multistage ensembles, where the adaptive properties of a second layer network are used to combine the outputs of the individual ensemble members, offer enhanced performance over conventional combining methods and best trained single network.

4.4 Hybrid artificial intelligence model

Hybrid modelling is based on the fact that linear models are very successful in describing linear relationships between variables, while resulting poorly while operating with higher number of variables, as well as with outliers. On the other hand, ANN excel in modelling nonlinear relationship among variables, and they are often used to solve various nonlinear problems, such as predictions in different engineering fields. By combining the advantages of linear and nonlinear models, the hybrid approach has the potential to outperform the individual models.

Hybrid model may be described as suggested in [29] as:

$$y_t = G_t + N_t \tag{1}$$

where y_t is the output variable, G_t is the linear component (predicted by the linear model, and N_t is the nonlinear component (predicted by the nonlinear model). After the prediction using the linear model, the residuals are defined as:

$$e_t = y_t - \hat{G}_t \tag{2}$$

where e_t is the residual, and $\hat{G}_t$ is the result of the linear model. The residuals are then predicted using the nonlinear model and finally the hybrid prediction is defined as:

$$\hat{y}_t = \hat{G}_t + \hat{J}_t \tag{3}$$

where $\hat{J}_t$ is the result of the nonlinear model.

In [30] the Multiple Linear Regression (MLR) model was used for solving the linear part of the task, while the non-linearity was expected to be captured in the residuals. These residuals were calculated as the difference between the measured data and the MLR outputs. For the prediction of the residuals (using the same input variables as for the individual models), the residual FFNN and the RBFN networks were created. The hybrid prediction was the sum of the MLR and residuals FFNN (or RBFN) outputs. The results showed that the hybrid approach improved the prediction quality. The hybrid FFNN and the hybrid RBFN models were compared to the single FFNN and single RBFN models, respectively. The hybrid models achieve higher accuracy comparing to the best trained single network. In this case study, it was proven that the combination of the linear and the non-linear models is very successful algorithm for improving prediction accuracy. Further improvements of the model can be investigated by using different linear and non-linear models as members of hybrid model.

5. CONCLUSION

This papers covers the application of Artificial Intelligence methods in agriculture. The pressure on the agri-food sector is constantly increasing, as it is necessary to balance the raising food demand and the production with significant loses. Also, minimizing costs and maximizing energy and other resources efficiency is a key issue. The up-to-date technology enables gathering and processing large amount of high quality data. These data can be used for the development of various machine learning models that can significantly improve numerous segments of agriculture sector In this paper, models for prediction of energy use are elaborated. The FFNN, RBFN and ANFIS are selected as most often used ANNs for solving these tasks. Also, SVM is presented. All of the presented models have proven to be very effective, achieving relatively low prediction errors on the database consisting of real, measured data. However, since the estimation or prediction of energy use is very important, any improvement of the prediction quality is worth investigating. Therefore, the ensemble and hybrid approach are elaborated. For the ensemble, it is necessary to combine the diverse, yet accurate models in order to achieve better results compared to single models. This can be obtained by combining networks with different architecture, using k-means clustering for creating different training subsets or using k-means clustering for selecting ensemble members among previously trained networks. Single models can further be aggregated using averaging methods or even applying some other network to create unified prediction (multistage ensemble). Hybrid modelling combines the linear and non-linear model, while the idea is to overcome shortages and keep the advantages of individual models. All of the proposed algorithms have proven to be effective on the elaborated case study. Therefore, it is very encouraging to continue the work both on improving the existing models, as well as widening their application on other segments of agriculture sector.

Acknowledgement: *The paper is a part of the research supported by the Ministry of Science, Technology and Innovations Republic of Serbia within the project under contract 451-03-47/2023-01/200105, subprojects TR-35043 and TR-35004.*

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BIOMASS-BASED SUSTAINABLE ENERGY: PROS & CONS AND RECOMMENDED OPTIONS

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INVITED PLENARY LECTURE

Abstract (bold). *The topic of biomass and its application in energy production is complex and not always straightforward in terms of sustainability. While the benefits of biomass energy revolve around its potential as a substitute for fossil fuels, the main drawbacks stem from the fact that it is still a fuel that emits certain pollutants and that the current rate of use, primarily of wood biomass, threatens to reduce the area under forests and endanger biodiversity. Biomass, produced by agricultural and forestry sectors, is rarely used for energy generation in Serbia even though it comprises 61 percent of the total potential of renewable energy sources. To encourage more intensive use of this valuable national resource, the paper evaluates the pros and cons of using biomass as an energy source, on the one hand, and provides guidelines for its use sustainably and efficiently, on the other. This was done with a focus on biomass combustion technologies. Ideal biomass users were identified, and recommendations were made on what should be done at the national level to empower and encourage them to greater use this energy source.*

Key words: *combustion technology, biomass, heating, agribusiness product processing*

1. INTRODUCTION

In the family of renewables, hydropower, wind, solar energy and bioenergy have their important place, where biomass overshadows others in terms of its available potential and application independence from weather conditions, time of day or year. Therefore modern bioenergy is the world's leading source of renewable energy, accounting for 55% of RES and more than 6% of global energy supply [1]. At the global level, ambitious plans have been set by the introduction of a normative scenario - the Net Zero Emissions Scenario by 2050 (NZE) - that shows a path for the global energy sector to achieve net zero CO2 emissions by 2050 [2]. Bioenergy use by sector and share of modern bioenergy in total final consumption in the NZS, 2010-2030 is given in Fig.1 [1]. Under the NZS, total global bioenergy use in 2030 will be only about 20% higher than in 2021 (Fig.1). In 2021, biomass provided more than 35% of the bioenergy used for traditional cooking methods, which are unsustainable, inefficient, and polluting. In the NZS, the use of this traditional biomass is reduced to zero by 2030 in order to achieve UN Sustainable Development Goal 7 on Affordable and Clean Energy (SDG 7) [3]. The goal ladder is set high. The diagrams and the following text will show what the current situation is with regard to the use of this energy source.

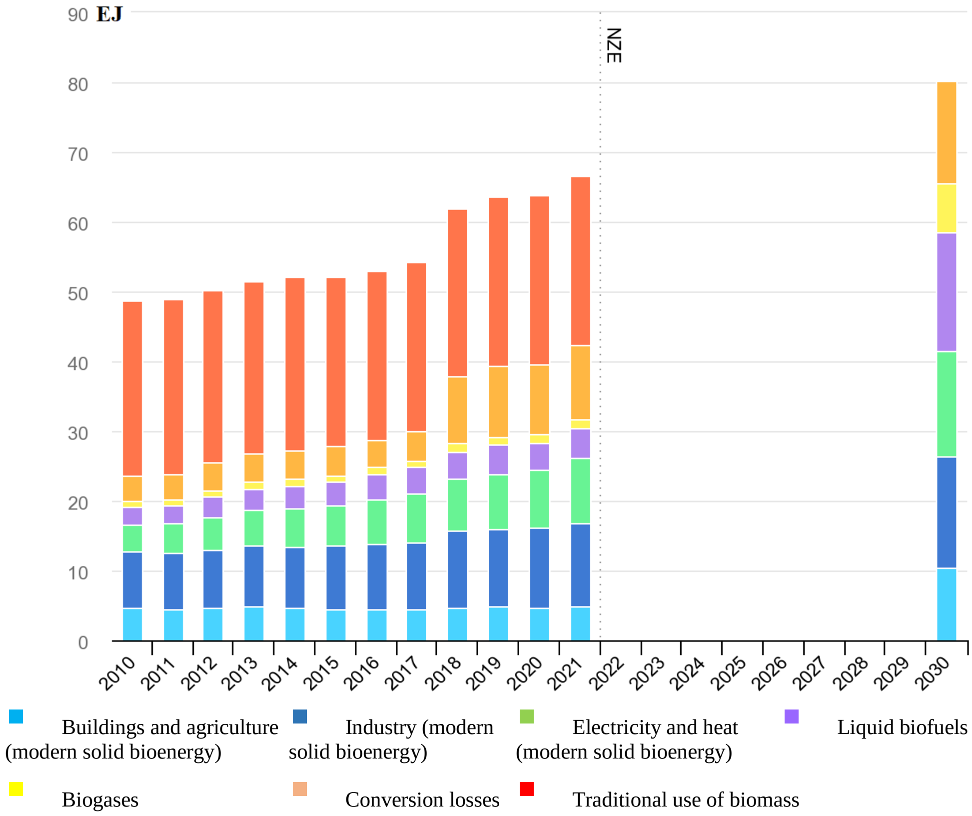


Figure 1. Bioenergy use by sector and share of modern bioenergy in total final consumption

Fig. 2 depicts data on renewable energy sources' participation in energy generation globally, in Europe, and Serbia. It is necessary to keep in mind that modern bioenergy usage excludes traditional uses of biomass. In addition, the biomass combusting: of charcoal, organic wastes and crop residues as an important source in lower-income settings today, is not included eider. High-quality estimates of energy consumption from these sources is difficult to find. So, only modern biofuels are included in this energy data/diagrams (Fig.2), i.e. bioethanol and biodiesel – fuel made from crops. According to the attached diagrams, the modern use of biomass as biofuels lags behind the recent exponential increase in the use of solar and wind energy.

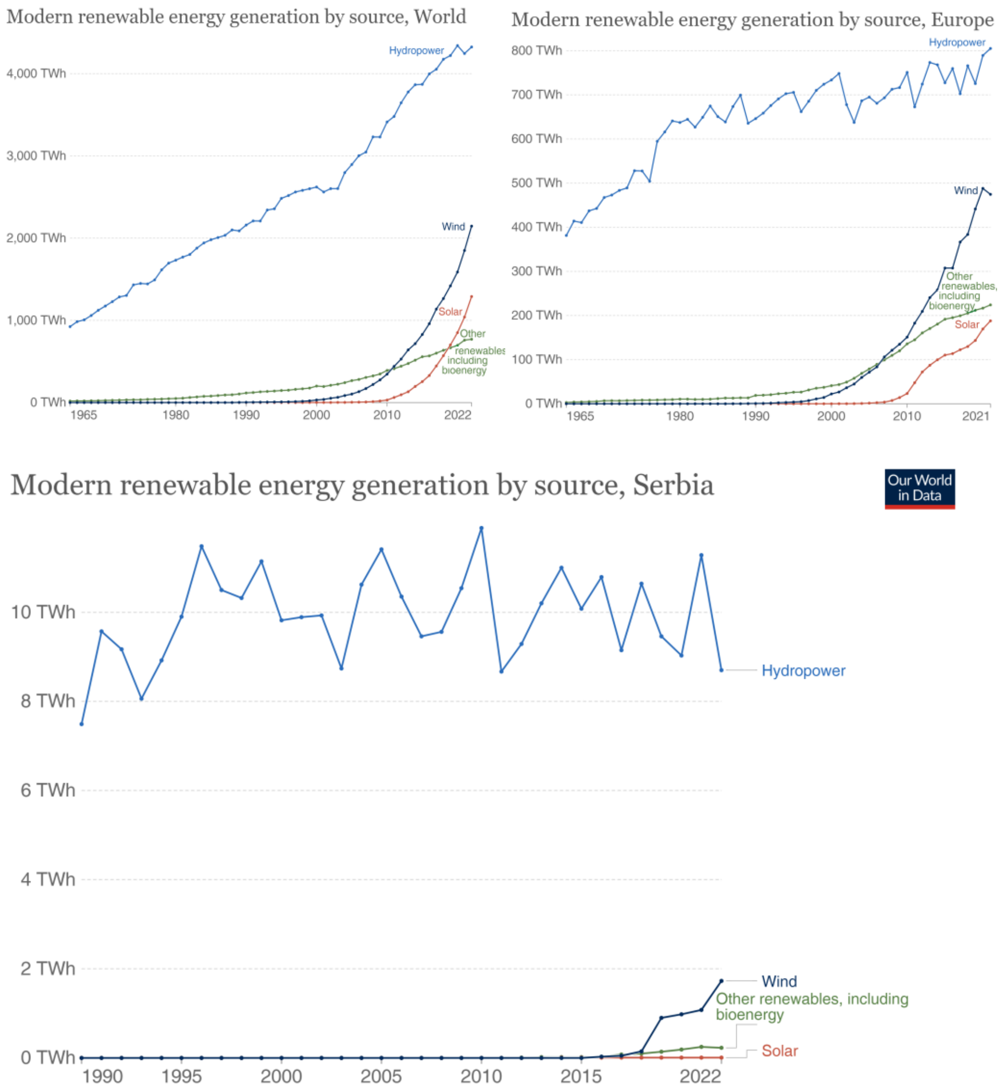


Figure 2. Modern energy generation by RES globally, in Europe and Serbia [4]

Biomass in various forms (liquid, gaseous, solid) and origins (wood, grasses, agricultural residues by-products, etc.) accounts for 50-60% of renewable energy consumption in the EU [5]. The heating sector is the primary application of biomass in the EU, with both centralised district heating plants and networks and decentralized wood stoves. In total, the utilisation of biomass in the heating sector makes up about 75% of its total energy usage in EU as shown in Fig. 3.

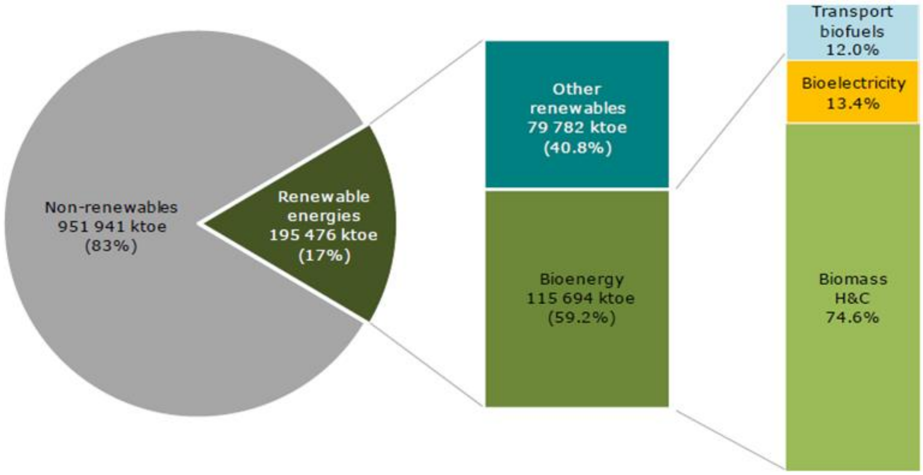


Figure 3. Use of biomass for energy in the EU in 2016 [5]

The greatest renewable energy potential in the Republic of Serbia is in biomass, which accounts for ≈61% (or 3,448Mten) of the total renewable energy potential, of which 48% belongs to agriculture, while ≈44% refers to wood biomass [6]. Despite the significant potential of biomass, both from the point of view of biological diversity and distribution, it is insufficiently used: woody biomass is 66,7%, mostly in the traditional way in households, and agricultural biomass in a negligible percentage of only 2%. In district heating systems, only 1.5% of the heat produced from biomass is used [7].

All of this implies that we are far behind global and European trends in biomass use and that we are still far from the set binding goals.

Because biomass is a somewhat controversial topic in our country, this work aims to highlight its essential features from which the advantages and obstacles (disadvantages) of its use arise, as well as to give some recommendations for its sustainable use. The ultimate goal is, of course, to raise the aforementioned discouraging figures.

2. PECULIARITY OF BIOMASS

When discussing biomass, three essential characteristics must be kept in mind. For starters, it has a regional character: different areas have different types of biomass; the same type of biomass will differ in quality and yield in different regions, or even show disparities in quality within the same area due to natural growth and/or artificial cultivation. Second, an economic issue: in general, biomass has a high geographical dispersion and a low energy density. As a result, only biomass that is easily collected and locally available (within 25-50 km) and generates a profit for the producer can be used as a resource. Third, in order to achieve a win-win situation in terms of economic, environmental, and social benefits, biomass use should be closely integrated with resource recycling and environmental protection. Based on the foregoing, the benefits and drawbacks of using this energy source can be considered.

3. THE BENEFITS OF BIOMASS ENERGY

Well-known and internationally verified benefits

- *Renewable energy source*

Trees and crops can be replanted to compensate for those removed, but sustainable management of agriculture, forests and land is essential to ensure that resources are not depleted faster than they are used.

- *It reduces dependence on imported fossil fuels*

The usual driving force behind the use of biomass is the diversification of energy sources and the reduction of energy imports, i.e. improvement of energy security of supply. Replacing fossil fuels with biomass in tandem with energy efficiency measures contributes to these goals and gains additional importance in the context of the contemporary geopolitical situation and energy uncertainty.

- *Carbon-neutral fuel*

There is a debate about whether biomass can actually be considered a carbon-neutral energy source. The argument in favor is the fact that, although burning releases CO_2, plant material actually removes CO_2 from the atmosphere during its life cycle through photosynthesis. Sustainable and responsible crop/forest management contributes to the balance of this equation. However, the entire supply chain must be taken into account and all emissions associated with the production, processing, transport and use of bioenergy must be included [8].

- *Reduction of waste landfills*

The production of energy from organic waste materials greatly aids waste management, which is a solution to the modern consumer society's growing problem and contributes to the sustainable use of biomass [9, 10]. When bio-waste is used to generate energy, it does not end up in landfills, minimizing their fill-up and does not contribute to associated negative effects such as:
- stench, smoke and water contamination in the vicinity,
- the development of undesirable insect populations
- emissions of methane, CO_2, water vapor and other gases that reduce air quality,
- self-immolation, etc.

- *Environmental Protection*

Based on what has been stated thus far and because sulfur is, either not present in the biomass or is found only in trace amounts.

- *The possibility of returning biomass-burning ash to the ground*

Ash from biomass burning originates from the remains of plants and has no harmful components; it does not harm the soil, water, flora, or fauna. It can also be used to stabilize manure and as a mineral fertilizer for fields and gardens. The exception to this rule is floating ash from the biomass combustion plant's exhaust system, which may contain environmentally hazardous heavy metals [11, 12].

- *A readily available and reliable energy source*

In short, it is everywhere, and the available biomass potential is large and won't go away as long as trees and crops regenerate at the same or faster rate than they are used. Furthermore, organic waste will continue to be produced as long as humans and animals consume food.

- *An energy source with various applications* such as:

- direct combustion to generate thermal energy/power (combustion in heat plants, dedicated power and CHP plants, co-firing with coal)
- digestion - processing waste of animal and vegetable origin into biogas; biomass conversion into biogas can be either from fast thermo-chemical processes (e.g., pyrolysis)
- processing into alcohol (ethanol) as a gasoline substitute, and
- production of vegetable oils as a diesel substitute.

The first two methods of converting energy from biomass are traditional, while the remaining two are very questionable in terms of energy and environmental expediency (ethanol and biodiesel are produced from food, so such use of biomass is questionable in terms of strategic energy logic and ethics), and they will not be considered. The graphs in Fig. 2 support this, as it is clear that the trend of using biomass as a biofuel is not growing at the same rate as it was at the turn of the century. Fig. 4 depicts additional processes of energy conversion from biomass in addition to the aforementioned processes.

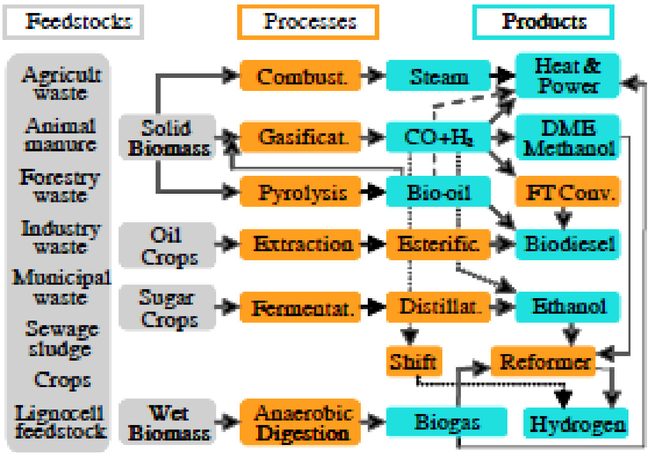


Figure 4. Biomass Conversion Paths

Economic benefits

- *Low-cost energy source*

This is especially true for bio-waste, which has no or little market value. However, for the sustainable use of biomass as an energy source, an appropriate profit for its producer is required, as well as the price of biomass being competitive with other energy sources for the buyer. According to data collected in April of this year, Tab. 1 compares the prices of fossil fuels and the most commonly used biomass fuels in Serbia. Due to the energy crisis caused by the conflict in Ukraine, the prices of fossil fuels in the EU at the time were dramatically higher, especially during the winter.

Table 1. Price of fossil fuels and biomass in Serbia

Fuel	Calorific value	Unit price	€/kWh
Brown coal	4.5 kWh/kg	170 €/t	0.038
Fuel oil	12.6 kWh/kg	1.27 €/l	0.1
Natural gas	10 kWh/m³	0.38 €/ m³	0.038
Agricultural biomass - briquettes	4 kWh/kg	0.2 €/kg	0.049
Wood pellets	4.9 kWh/kg	260 €/t	0.053
Wood chips (35% moisture)	3.1 kWh/kg	60 €/t	0.019
Baled straw	3.9 kWh/kg	50 €/t	0.013
Forest wood (40% moisture)	3 kWh/kg	99 €/t	0.033

The economic parameters presented unequivocally indicate that using biomass, as fuel (bales from agricultural residues and wood chips) is always profitable! Given the obvious rise in oil and gas prices as a result of the current geopolitical situation and the raging energy crisis, the use of biomass will become increasingly important. Only the price of biomass briquettes and pellets is currently higher than the price of fossil fuels.

Socio-economic benefits

It is especially important to highlight the advantages for our country.

- *Restarting the country's dormant economic activities*

- Facilities for converting energy from biomass through combustion are relatively simple and can be entirely manufactured in our country.
- If these plants/facilities were used in district heating systems with the ability to use generating heat energy also for technological processes in agricultural product cultivation and processing outside of the heating season, the application potentials would expand.
- Facilities for the processing and finishing of agricultural products (such as dryers) can also be largely produced in the Republic of Serbia.

All of this could trigger the country's reindustrialization.

- *Other well-known and internationally validated socioeconomic benefits*

- Diversification of agricultural farm business activities;
- Increased profitability in the agricultural sector;
- Population employment opportunities in rural areas; and
- Population health benefits.

4. DISADVANTAGES AND OBSTACLES OF USING BIOMASS FOR ENERGY

- *Not entirely a clean fuel*

Similar to other fuels, burning biomass releases a variety of pollutants into the air, including CO_2, nitrogen oxides NOx [13, 14], volatile organic compounds (VOCs), and particulate maters of $PM_{2.5}$ to PM_{10}. Additionally, carbon monoxide (CO), chlorine compounds, and cyclic hydrocarbons (dioxanes, furans, and polyaromatic hydrocarbons) [15] may manifest in higher concentrations. This is primarily due to technical flaws in the plant, such as improper technology selection or improper combustion device handling.

- *Less conversion efficiency compared to fossil fuel*

This topic expands on the prior item and touches biomass's CO_2 neutrality.
A straightforward analysis and comparison of biomass and fossil fuels was carried out using approximate formulas for the aforementioned fuels. Thus, based on the most abundant components in the subject fuel, coal can be represented by the approximate formula CH, oil by CH_2, natural gas by CH_4, and biomass by COH. Burning *coal* produces carbon dioxide from the carbon and water from the hydrogen. Both the hydrogen and the carbon are converted into energy, and one CO_2 is released into the atmosphere. Burning *oil* releases energy from both H atoms and from the C atom, and still one CO_2 is emitted. Compared to coal, more energy is released per unit of CO_2. When *natural gas* is burned, it releases energy from the four H atoms and from the carbon, and still only emits one CO_2. Therefore, in terms of energy output per unit CO_2 emitted, natural gas is the best fossil fuel.
Biomass has a similar formula to coal, but with an oxygen atom added. Oxygen is a ballast and reduces the energy obtained during combustion. When biomass is burned, energy is obtained from the H atom as well as some energy from the subsequent combustion of CO (which is less energy than produced from coal combustion), and one CO_2 is emitted into the atmosphere.
Hence, in terms of CO_2 emissions per energy produced, biomass is a worse fuel than coal, at least according to this argumentation. Nevertheless, because biomass breathes CO_2 (extracted from the atmosphere) and when it is burned, it emits same amount of carbon dioxide into the atmosphere this cycle is carbon neutral, as already stated in chapter 3.

- *Potentially harmful environmental consequences of irrational business practices*

When energy is produced from bio-residues or waste streams from other sectors (agriculture, paper and pulp production, forestry, households, etc.), the environmental impact is usually positive, depending on the type of bio-waste and what would otherwise be done with them. Unsustainable business practices can lead to deforestation and devastation of agricultural land over time. Deforestation to provide resources for biomass energy plants harms the natural environment and disrupts biodiversity. Forests are a natural absorber of CO_2, wood is a limited resource and emits CO_2 when burned. The removal of plants and organic material from the soil degrades soil quality, as compost and fertilization require biomass.

- *Risks associated with intensive farming*

Growing crops solely for bioenergy resources necessitates a greater use of water, and continuous irrigation of fast-growing crops can make the area more vulnerable to drought and soil depletion.
To mitigate these negative environmental impacts, grow biomass on already degraded land and soil to increase organic material content and reduce further soil degradation and erosion, with positive effects on biodiversity, especially if less intensive agricultural and autochthonous cultures are used.

- *Unprofitable for long-distance transport*

Biomass has a wide geographic distribution and a low energy density, which raises the cost of transportation and handling.

- *It requires more space*

Because of the low energy density of biomass, more space is required for both the combustion plant and biomass storage. This restricts the location where biomass plants can be built economically - they must be close to the fuel source to reduce transportation, storage, and handling costs. Large transfer warehouses are required for larger plants, as are smaller ones in the immediate vicinity of the plant, both with fire protection. This necessitates additional loading/unloading and biomass transportation by large trucks, which is a problem for plants in urban areas.

- *Other technical challenges*

- Different types of biomass have different combustion characteristics. The ash content in agricultural biomass is significantly higher than the ash content in wood. The alkaline content in the ash hinders the continuous operation of the biomass boiler due to ash deposit formation on the heating surfaces (fouling/slagging) [16], which is overcome by the correct choice of technology with lower combustion temperatures and appropriate ash blowing equipment.
- Biomass is a hygroscopic material. Humidity fluctuations and high humidity significantly complicate the combustion process. The problem is solved by storing biomass properly and on time in rooms with good ventilation and a dry floor.
- Biomass quality can fluctuate as a result of natural growth and/or artificial cultivation, or due to improper preparation and storage. It is critical to monitor and control the quality of the fed biomass to avoid potential complications in the plant.

- *Higher investment costs*

Despite the existence of a few international energy agencies, information on the investment costs of biomass plants is scarce due to the omission of cost data for specific technologies in order to avoid the disclosure of individual company data.

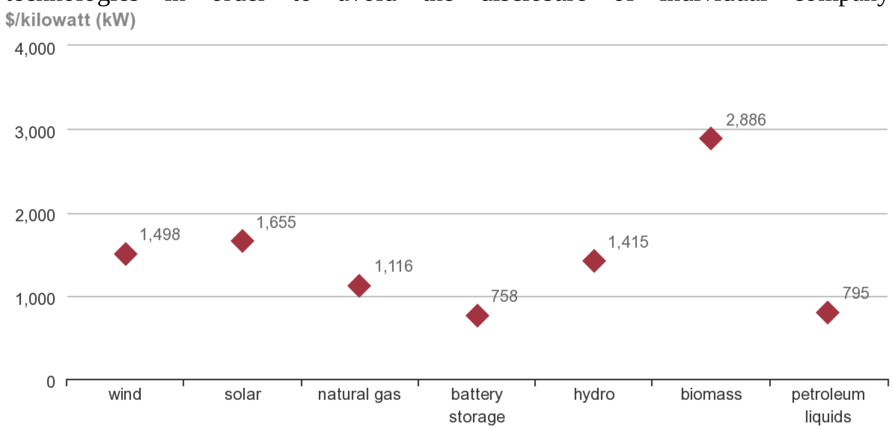


Figure 5. Depending on the energy source, the capacity-weighted average cost ($\$/kW_{el}$) [17]

Nevertheless, data on the cost of electricity produced based on the energy source is readily available. Fig. 5 depicts the average investment costs per kWel for various energy sources in the United States (government grants, tax benefits, and other incentives are not included). It should be noted in the presentation of biomass investments in the same picture that technologies for converting biomass into gas and liquid biofuels were also included in the cost estimate, which can justify such high investment prices. It is obvious that the investment in biomass plants for power generation is higher than in those using gas and oil derivatives, and thus subsidies are required to pay for it within a reasonable time frame.

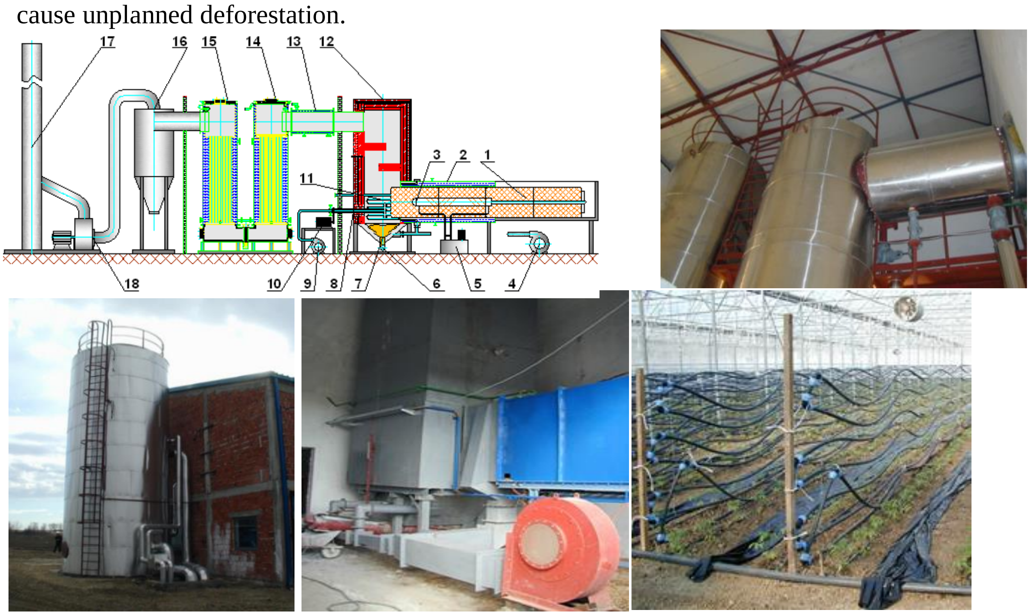
- *Natural gas and biomass comparison*

As the most competitive fuel to biomass is natural gas, and considering that 77% of energy in Serbian heating plants is obtained from it, it is interesting to compare the investment costs for these two energy sources. In the EU, the levelized cost of heating (LCOH) with biomass was, for 2018, 108-225€/MWh, while the costs for gas were 98€/MWh [18]. Several items will be further discussed to explain why the investment costs for biomass are higher.

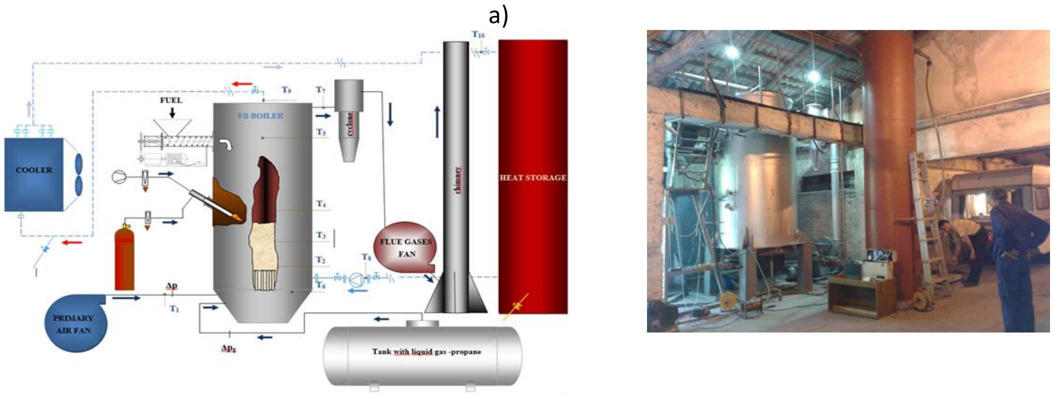
- In general, the price of a biomass boiler is higher than a natural gas boiler.
- A natural gas boiler is easier to regulate combustion, it is more compact, and it does not require much space for fuel storage.
- Regulating biomass boilers below 50% heat load is difficult, which can be overcome by building more boiler units and/or including heat storages, which makes the investment more expensive but provides greater security of supply with easier power regulation. The installation of a heat storage reduces the required power of the installed boilers and enables their operation without daily switching on and off during the heating season.
- Operating costs depend on the type of biomass used. In the case of bio-briquettes or pellets, they are more and more competitive with natural gas due to the increase in its price. In the case of wood chips or baled straw, they are much lower.
- Biomass quality can vary greatly, as was previously mentioned, whereas gas cannot.
- The government controls the price of natural gas, so there are no sudden oscillations, although the current situation, especially the one during the previous winter, belies this to some extent. On the other hand, there is no developed biomass market in Serbia, so the price and supply is unstable, and in order to overcome this, it is recommended to purchase in advance. This again implies a larger storage space.
- Biomass boilers must have equipment for purifying flue gases from particles and NO_x, desulfurization is generally not necessary. Natural gas boilers do not need PM removal equipment, but for the elimination of NO_x, if low NOx burners are not used.

5. COMBUSTION TECHNOLOGIES RECOMMENDED BY THE LABORATORY FOR THERMAL ENGINEERING AND ENERGY, INN VINČA

To summarize what has been said thus far, biomass is a good replacement/supplement for traditional fossil fuels. To achieve greater economic benefits and competitiveness with traditional fossil fuel technologies, biomass fuel application technologies must be improved while meeting three critical conditions: environmental protection, energy efficiency, and sustainable development. The first condition is largely met by the the choice of fuel itself, with the conversion technology requiring the lowest possible emission of harmful compounds (CO and NOx). The second condition implies that the energy consumption of the conversion process should be as low as possible to maximize the effective degree of conversion. This is accomplished by reducing the energy required to prepare the biomass for the conversion (combustion) process; thus, the least energy is required if the biomass is used in as close to its original form as possible. The final condition for sustainable development is met by using a portion of the biomass that represents the residue from primary agricultural production or of the process of rational forest management, so that energy production does not interfere with food production or cause unplanned deforestation.



a)



b)

Figure 6. a) Industrial 1.5 MW boiler of baled biomass, in PKB, exchangers, buffer, hydraulic bale feeder and 1 hectare of a greenhouse; b) Semi-industrial 500kW FB boiler

The aforementioned principles serve as the foundation for the Vinča Institute's Laboratory for Thermal Engineering and Energy (ITE), which has dedicated decades researching and developing technologies for burning biomass. Based on theoretical and practical knowledge, ITE advocates the application of technology for burning waste biomass (waste cereal grains, residues from food production, nut shells, fruit pits...) and wood chips in a fluidized bed and baled straw in boilers with cigarette combustion.

Based on research and acquired knowledge, a facility for cigarette combustion of baled agricultural biomass, power of 1.5 MW, with after-combustion in an ash fluidized bed has been developed. ITE also has a demonstration - industrial boiler, max power of 500kW, with fluidized bed combustion technology (FB), located within the Institute boiler room, where experimental combustion tests of different biomass fuels (paper sludge, corn kernels, hazelnut husks, etc.) have performed. Schemes and photos of both facilities are given in Fig. 6. ITE also has a number of experimental apparatus that can be used to study virtually all biomass combustion aspects in an efficient and controlled manner by varying different parameters. Expertise and competence in the field of biomass energy use, proven both in practice and in numerous scientific publications and technical solutions, gives us the right to give recommendations for more efficient use of this renewable fuel.

The recommendations of the European Institute of Energy [19] for the choice of combustion technology depending on the type of biomass used are given in tab. 2, and it can be seen that these two technologies are exactly recommended for the mentioned forms of biomass. Tab. 3 summarizes the primary benefits of these two technologies.

Table 2. Overview of biomass combustion technologies [19]

Combustion technology	Form of biomass					
	Firewood	Wood chips	Powder biomass	Pellets	Briquettes	Straw*
Open fire	0	-	-	-	0	-
Household ovens	+	-	-	-	+	-
Automatic burners	--	+	-	++	--	+
Combustion in batches	0	--	--	--	-	+
Inclinated grate	--	+	-	+	-	-
Travelling grate	--	++	-	++	-	+
Vibrationg grate	--	+	-	+	-	+
Furnace	--	+	-	+	--	-
Powder burners	--	--	+	--	--	-
Cigarette combustion	--	--	--	--	--	++
Fluidized bed**	--	++	++	++	--	0

* Baled straw, ** Added by authors of the article

Legend: (--) unapplicable, (-) not suitable, (0) possible, (+) suitable, (++) very suitable

The tab. 2 shows that no combustion technology is suitable for all the forms of biomass. Based on the explanations given so far, as well as the information in the table above, it is recommended to select biomass combustion technologies according to the "++" mark. Generally, for all types of biomass plants, frequent outages are not advisable;

the organization of the operation should be continuous, with as short and slower power oscillations as possible.

Table 3. Why exactly these combustion technologies are recommended?

Cigarette combustion	**Fluidized bed**
• Boiler of simple construction, • Easy to handle, • Application of biomass in the form collected in the fields, • Minimum own energy consumption, • Technology recommended by the EU Energy Institute as the best for baled biomass.	• The possibility of burning different types of biomass, reduced to granulation up to 35 mm • Less sensitive to variations in fuel quality, • Combustion temperature <900ºC, so there are no problems related to ash, with lower emissions of pollutants, primarily NOx, • High combustion efficiency - intense mixing of gases in the layer prevents the formation of CO and unburned hydrocarbons
• **These boilers can be manufactured by a domestic boiler manufacturer.**	

The assessment of investments for boilers with the mentioned biomass burning technologies (based on ITE's own experiences in their development and material prices in 2018) is given in tab. 4.

Table 4. Estimated investment cost for selected combustion technologies

Hot water boilers on	**baled harvest residues** with the application of **cigarette combustion**					
	Power	250 kW	500 kW	1 MW	3 MW	7 MW
	Cost (€)	110.000	140.000	200.000	310.000	480.000
	wood chips with the application of **fluidized bed** combustion					
	Cost (€)	70.000	100.000	150.000	250.000	400.000
Water heat storage	Volumen	50m^3	100m^3	200m^3	500m^3	1000m^3
	Cost (€)	15.000	30.000	60.000	100.000	180.000

6. POSSIBILITIES AND RECOMMENDATIONS FOR THE APPLICATION OF BIOMASS IN SERBIA

It was already demonstrated in Chapter 3 that biomass can be converted into energy in a variety of ways. Since the ITE laboratory has the most experience with direct combustion of biomass, focus are going to be on this type of conversion. Although biomass co-firing in modern coal power plants is one of the world's leading and most profitable ways of biomass energy utilization, the emphasis here will be on obtaining heat energy with the possibility of cogeneration. Biomass can thus be used in heating systems, cogeneration plants, to generate heat for growing plants and animals, industrial processing of agricultural products, and so on.

Biomass for heating and technological needs in agricultural production, processing, and storage

The Autonomous Province of Vojvodina (APV) is very interesting in terms of agricultural biomass application. It is dominated by agricultural production, and due to the terrain's configuration and the urbanization of all settlements, including rural ones, it is ideal for heating by biomass. The same applies to Posavina and Pomoravlje in central Serbia. In these areas, there is a dense natural gas supply network- gasification has been carried out. The aforementioned heating with biomass serves as an alternative to gasification. Gasification, however, does not rule out the possibility of using biomass for heating; in fact, these two energy sources can work best when combined. The quality and quantity of biomass can vary in unfavorable weather situations (dry or overly rainy years), so using gas can be very beneficial. However, because of the impending geopolitical crisis, we can anticipate further increases in the cost of all imported energy sources, particularly natural gas, making biomass an excellent gas substitute. With the exception of the increase in costs associated with the use of liquid fuels in the preparation of biomass, drastic price increases are not realistic when using biomass.

Heating by biomass requires that the areas be urbanized in order to build district heating plants in peripheral settlements on the outskirts of urban areas. Heating plants on the outskirts can use agricultural residue (waste biomass - not intended for food) as an energy raw material from the immediate surroundings. Biomass heating is only sustainable if it is collected in close proximity to the point of use, and the recommended distance ranges from 25 to 50 km (maximum distance for plants up to 2 MW) depending on the plant's capacity [20].

During the heating season, the average engaged power of heating plants in Serbia is 45-50% of total installed capacity. Looking at the entire year, this means that the heating plant's available power, which can be used for purposes other than heating, is greater than 75% of the installed capacity. This is essential for the construction of small industrial zones within the heating plants for the cultivation, processing, and storage of agricultural products, as well as other industrial/technological needs. At the current level of technological development, thermal energy can also be used in cooling systems for storing agricultural products. Based on the foregoing, it is possible to conclude that with proper agricultural production and processing of agricultural products, the biomass heating plant can operate throughout the year, resulting in a faster return on investment in such a biomass plant.

Similar assumptions apply to forest/woody biomass. Due to the greater dispersion of settlements in hilly and mountainous areas, it is recommended to use slightly smaller plants that are adapted for the processing of products available in those areas (forest fruits and berries, mushrooms, mini-dairies, wood processing, drying and extraction from medicinal plants, etc.). If such heating plants are built near larger settlements, they can be connected to the district heating system, if the heat supply network is not too dispersed. Here again, it is necessary to favor, from the standpoint of economic and energy efficiency, the use of wood chips versus pellets, if the thermal energy plants are of higher power (greater than 150 kW).

Cogeneration plants (CHP)

Dedicated biomass plants for combined heat & power (CHP), are typically of smaller size and lower electrical efficiency compared to coal plants, but in cogeneration mode the total efficiency may reach up to 90%. After the Republic of Serbia introduced preferential prices for RES-generated electricity in 2013, cogeneration plants became appealing to investors. When discussing CHP, it is critical to emphasize the use of the ORC (Organic Rankine Cycle), which is based on working with silicone oil vapors. These systems are ideal for smaller power plants ranging from 0.2-2 MW_{el}. This entails working with heat aggregates with a power range of 1-10 MW. The heat aggregates in these systems have the advantage of being low-pressure hot oil boilers that do not require highly skilled operators. The turbine component of the plant is imported from abroad in the form of a "black box" with connections for hot oil supply and drain and elements for connecting with transmission lines for the delivery of generated electricity. The energy from the turbine plant's output oil is then used to generate thermal energy for the operation of other technological units.

8. PROSPECTIVE CHANGES

The previous chapters attempted to examine both the positive and negative effects of biomass use critically. Natural gas is undoubtedly a more "elegant" heating solution, but it is imported, whereas biomass is burned in the fields or traditionally in low-efficiency wood stoves. Furthermore, as previously stated, the use of biomass provides numerous social and economic benefits, the most important of which is the economic development of local communities, particularly rural ones, which leads to the revitalization of villages and the re-industrialization of the economy in the sector of the production of thermal devices and equipment.

Therefore, national guidelines for using biomass as a renewable and domestic energy source must be established. Following the establishment of development directions, it is necessary to determine subsidies to support the development of its use. Many large agricultural combines and agricultural product processors, which are ideal users of biomass as an energy source, have been brought to their knees.

Subsidies to domestic manufacturers of thermotechnical devices and thermal energy equipment, as well as those who use them, must be clearly defined and, if possible, significantly higher than subsidies to foreign investors. Subsidies to foreign investors were and are necessary during the recovery of the domestic industry. In the short term, it was beneficial to our country, which was in a state of crisis due to bombing, sanctions, poor privatization, and high unemployment. In the long run, we must rely on the domestic economy as much as possible. Domestic production implies domestic intelligence and domestic development i.e. adequate education and employment of domestic professionals. Foreign companies that invest in new factories here, in the field of thermal energy, do not invest in our development. They organize development in their home countries, and here they use relatively cheap labor and an underdeveloped market, which is absolutely justified from their standpoint.

It is important to support local producers. So, the entire strategy for the development of biomass as an energy source must be geared toward favoring a PUBLIC/PRIVATE partnership that would ensure the formation of a larger number of companies large enough to survive on the market while also finding, primarily domestic, investors for their construction. Domestic thermotechnical equipment producers, no matter how small, are still capable of producing equipment for smaller thermotechnical facilities, whether it is the production of heat plants (primarily boilers) or equipment for growing and processing agricultural products.

9. CONCLUSION

The authors hope that this work can help in popularizing and organizing biomass applications for energy purposes. In addition, the authors argue that theories from practice can also help in affirming public-private partnerships as well as addressing possible donations and incentives in the direction that this work suggests.
Note: The authors reserve the right to present the views expressed in this paper on other occasions whenever possible.

Acknowledgement: *This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia; grant number 451-03-47/2023-01/200017.*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19^{th} – 21^{st} Oct 2023, Belgrade–Zemun, Serbia

DIMENSIONING AND ASSEMBLYING OF BRAZED ALUMINIUM HEAT EXCHANGER FOR NEEDS OF AGRICULTURAL PROCESS PLANTS

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Abstract (bold). *Heat exchangers used in agricultural processes are mainly manufactured by three technologies: brazed copper-brass, mechanically assembled aluminum and brazed aluminum. The appropriate choice depends on various criteria: price, weight, corrosion resistance, performance in a limited volume, required pressure drops, temperature resistance, reliability, etc. Brazed aluminum is increasingly popular due to several advantages, such as resistance to high pressure and temperatures. Aluminum heat exchangers can be exposed to external and internal corrosion in various environmental conditions. Corrosion has a negative impact on the mechanical integrity and thermal performance of heat exchangers. Therefore, specific operating design parameters, as well as mechanical design characteristics, are of great importance for consideration in construction. Proper selection and design can ensure the successful and safe operation of the heat exchanger and the plant itself. The HVAC industry is directed towards the search for the best solutions in order to increase the performance, energy efficiency and durability of the equipment while reducing the costs of their production. Aluminum pipes and other aluminum components are increasingly replacing copper pipes. In this paper, application, design, assembling process and operation considerations for brazed aluminum heat exchangers used for needs in agricultural processes have presented.*

Key words (bold): *HVAC, heat exchanger, aluminum, dimensioning, agriculture*

1. INTRODUCTION

Heat exchangers used in agricultural processes are mainly produced by three technologies: brazed copper-brass, mechanically assembled aluminum and brazed aluminum. The appropriate choice depends on various criteria: cost, weight, corrosion resistance, performance in limited volume, required pressure drops, temperature resistance, reliability, etc [1]. For years, aluminum (Al) and aluminum alloys have been used as heat exchanger tube materials due to their low density, good thermal conductivity, and satisfactory mechanical properties suitable for heat exchangers [2, 3]. As the pipe becomes thinner, corrosion resistance has a greater effect [4]. Brazed aluminum is increasingly popular due to several advantages, such as resistance to high pressure and temperatures, one of the reasons being fattening in order to reduce fuel consumption [1].

Brazed aluminum heat exchangers are designed and manufactured according to pressure equipment standards and need to meet safety requirements related to mechanical design, material, manufacturing, testing and inspection requirements of various standards [5,6]. Brazed aluminum heat exchangers are highly efficient, used for a variety of cryogenic and non-cryogenic heat transfer applications, including industrial gas production, petrochemical applications and agricultural processes. Considering that they have a high surface compactness and excellent heat transfer characteristics, they have an advantage over other traditional heat transfer technologies in the application of non-corrosive liquids and gases [7]. Research has shown that the rate of heat transfer in residential air conditioners is 50% higher than the rate of conventional heat exchangers [8].

Taking into consideration the fact that heat exchangers fabricated from aluminum much less represented in agricultural industry such as and problems related to their dimensioning have not been sufficiently explored, hence and the main goals of this paper is mechanical calculations of metal elements of one very specific construction of heat exchanger of which has been fabricated from SB-209-5083-0 material. Beside with the previously mentioned in this paper is also given and methodology of merging of elements of this apparatus with relevant brazing (welding) parameters.

2. STRENGTH CALCULATION OF THREE HEADER ALUMINUM HEAT EXCHANGER

Full calculation of the heat exchangers before starting its fabrication in the workshops usually consists three following necessary types of calculations: calculation of required thermal power (heat transfer), calculation of pressure drop (for needs of further adopting of pumps) and mechanical or strength calculation of metal elements.

After finishing calculation of required heat transfer and pressure drop and determining required design conditions it is starting phase of strength calculation of all metal elements [9-11]. In this paper, it will presented of dimensioning of aluminum heat exchanger, which is using in agricultural engineering. The required design conditions have shown in the Table 1.

For needs of performing strength, calculations and analysis of place installation it was adopted latest edition of ASME Section VIII Division 1 such as relevant standard for this calculation. Review of strength calculations of assembly elements of heat exchanger, which has shown on the picture 1, is in the next lines.

Header 1 thickness:

Minimum required thickness-t_m(according to the ASME Section VIII Division 1-UG-27(c))

$$t_m = \frac{p \cdot R}{S \cdot E - 0.6 \cdot p} + Co = \frac{51.0 \cdot 125}{801 \cdot 0.65 - 0.6 \cdot 51.0} + 0 = 13.01 \text{ mm} < \text{Ta} = 14.31 \text{ mm}$$

where
p=51 Kg/cm^{2}G, design pressure;
R=125 mm, inside radius of header;
S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;
E=0.65, joint efficiency;
Co=0, corrosion allowance;

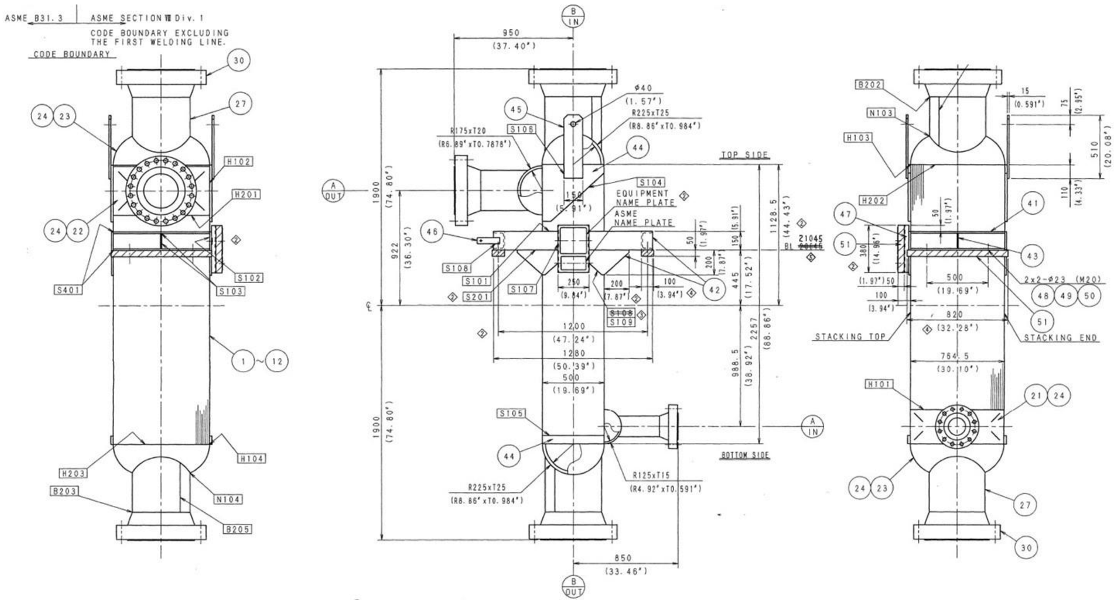
Header 2 thickness:
Minimum required thickness-t_m(according to the ASME Section VIII Division 1-UG-27(c))

$$t_m = \frac{p \cdot R}{S \cdot E - 0.6 \cdot p} + Co = \frac{51.0 \cdot 175}{801 \cdot 0.65 - 0.6 \cdot 51.0} + 0 = 18.22 \text{ mm}$$

where
p=51 Kg/cm^{2}G, design pressure;
R=175 mm, inside radius of header;
S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;
E=0.65, joint efficiency;
Co=0, corrosion allowance;

Table 1 Design conditions of brazed aluminum heat exchanger

Stream	-	(A1165)	(B1433)
Fluid	-	Liquified HC	Deethanizer reflux
Design pressure	Kgf/cm^{2}G	51	36.7
	psig	725	522
	barg	50	36
Design temperature	°C	-100÷65	-100÷65
	°F	-148÷149	-148÷149
Hydro test pressure	Kgf/cm^{2}G	66.3	47.8
	psig	942.5	678.6
	barg	65	46.8
Pneumatic test pressure	Kgf/cm^{2}G	-	-
	psig	-	-
	barg	-	-
Air leakage test pressure	Kgf/cm^{2}G	51	36.7
	psig	725	522
	barg	50	36



Picture 1 Construction and dimension of aluminum heat exchanger

Header 3 thickness:

Minimum required thickness-t_m(according to the ASME Section VIII Division 1-UG-27(c))

$$t_m = \frac{p \cdot R}{S \cdot E - 0.6 \cdot p} + Co = \frac{36.7 \cdot 225}{801 \cdot 0.65 - 0.6 \cdot 36.7} + 0 = 16.57 \text{ mm}$$

where

p=36.7 Kg/cm^{2}G, design pressure;

R=225 mm, inside radius of header;

S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;

E=0.65, joint efficiency;

Co=0, corrosion allowance;

Minimum required nozzle thickness (A-in)

(6) Minimum required thickness-tm(according to the ASME Section VIII Division 1-UG-27(c))

$$t_1 = \frac{p \cdot Ro}{S \cdot E + 0.4 \cdot p} + Co = \frac{51.0 \cdot 84.15}{752 \cdot 1.0 + 0.4 \cdot 51.0} + 0 = 5.56 \text{ mm}$$

where

p=51.0 Kg/cm^{2}G, design pressure;

R=84.15 mm, outside radius of pipe;

S=752 kg/cm^2, maximum allowable stress for material SB-209 5083-0;

E=1.0, joint efficiency;

Co=0, corrosion allowance;
(2) The smallest of the following:
(a) the thickness of the cylindrical shell (assuming E=1.0)

$$t_2 = \frac{p \cdot R}{S \cdot E - 0.6 \cdot p} + Co = \frac{51.0 \cdot 125}{801 \cdot 1.0 - 0.6 \cdot 51.0} + 0 = 8.28 \text{ mm}$$

where
p=51 Kg/cm^2G, design pressure;
R=125 mm, inside radius of header;
S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;
(b) the minimum thickness of standard wall pipe (STD)

$$t_3 = STD \cdot 0.875 + Co = 7.112 \cdot 0.875 + 0 = 6.23 \text{ mm}$$

The smallest thickness is 6.23 mm
(3) Minimum required thickness-t_m
t_m should be greater value of thicknesses calculated by (1) or (2)
t_m=6.23 mm<$t_n \cdot 0.875$=12.48 mm
where is t_n=14.27 mm-nominal thickness for this pipe;

Minimum required nozzle thickness (A-out)

(6) Minimum required thickness-tm(according to the ASME Section VIII Division 1-UG-27(c))

$$t_1 = \frac{p \cdot Ro}{S \cdot E + 0.4 \cdot p} + Co = \frac{51.0 \cdot 161.9}{752 \cdot 1.0 + 0.4 \cdot 51.0} + 0 = 10.69 \text{ mm}$$

where
p=51.0 Kg/cm^2G, design pressure;
R=161.9 mm, outside radius of pipe;
S=752 kg/cm^2, maximum allowable stress for material SB-209 5083-0;
E=1.0, joint efficiency;
Co=0, corrosion allowance;
(2) The smallest of the following:
(a) the thickness of the cylindrical shell (assuming E=1.0)

$$t_2 = \frac{p \cdot R}{S \cdot E - 0.6 \cdot p} + Co = \frac{51.0 \cdot 175}{801 \cdot 1.0 - 0.6 \cdot 51.0} + 0 = 11.59 \text{ mm}$$

where
p=51 Kg/cm^2G, design pressure;
R=175 mm, inside radius of header;
S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;
(b) the minimum thickness of standard wall pipe (STD)

$$t_3 = STD \cdot 0.875 + Co = 9.525 \cdot 0.875 + 0 = 8.34 \text{ mm}$$

The smallest thickness is 8.34 mm
(3) Minimum required thickness-t_m
t_m should be greater value of thicknesses calculated by (1) or (2)
t_m=10.69 mm<$t_n \cdot 0.875$=22.22 mm
where is t_n=25.40 mm-nominal thickness for this pipe;

Minimum required nozzles thickness (Bin and Bout)

(6) Minimum required thickness-tm(according to the ASME Section VIII Division 1-UG-27(c))

$$t_1 = \frac{p \cdot Ro}{S \cdot E + 0.4 \cdot p} + Co = \frac{36.7 \cdot 228.5}{801 \cdot 1.0 + 0.4 \cdot 36.7} + 0 = 10.29 \text{ mm}$$

where

p=36.7 Kg/cm^{2}G, design pressure;

R=228.5 mm, outside radius of pipe;

S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;

E=1.0, joint efficiency;

Co=0, corrosion allowance;

(2) The smallest of the following:

(a) the thickness of the cylindrical shell (assuming E=1.0)

$$t_2 = \frac{p \cdot R}{S \cdot E - 0.6 \cdot p} + Co = \frac{36.7 \cdot 225}{801 \cdot 1.0 - 0.6 \cdot 36.7} + 0 = 10.61 \text{ mm}$$

Where

p=36.7 Kg/cm^{2}G, design pressure;

R=225 mm, inside radius of header;

S=801 kg/cm^2, maximum allowable stress for material SB-209 5083-0;

(b) the minimum thickness of standard wall pipe (STD)

$$t_3 = STD \cdot 0.875 + Co = 9.525 \cdot 0.875 + 0 = 8.34 \text{ mm}$$

The smallest thickness is 8.34 mm

(3) Minimum required thickness-t_m

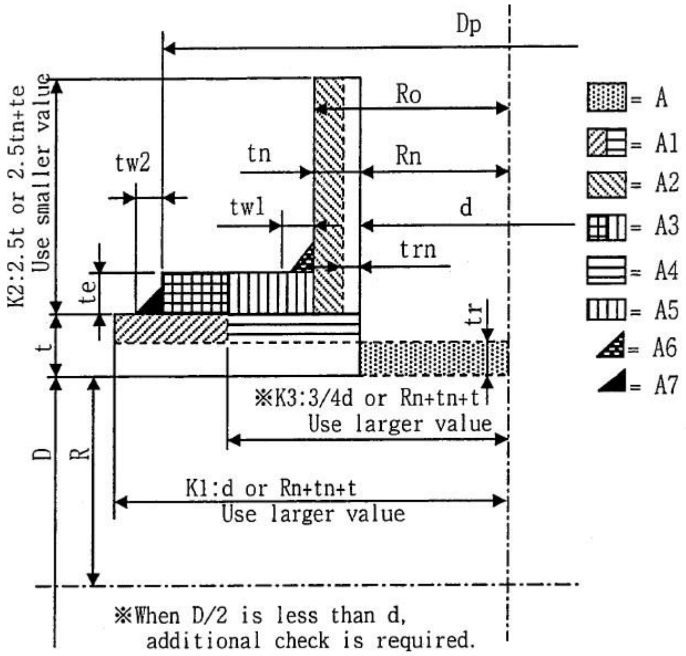
t_m should be greater value of thicknesses calculated by (1) or (2)

t_m=10.69 mm<t_n·0.875=17.50 mm

Where is t_n=20.00 mm-nominal thickness for this pipe;

Together with calculations for headers and nozzles, also calculations of nozzles reinforcement also should be performed especially in case heat exchanger, which are working in high-pressure environment. Taking into consideration that nowadays exist specialized software for this activities in this paper only will be presented nozzle Ain together with its appropriate markings [6, 10 - 12].

One of the most used software, which is using for calculation of pressure equipment elements, is ’’Bend-Tech-Header’’ which enables performing nozzle reinforcement calculations according to the relevant international standard related to pressure equipment. ’’Header software’’ also enables creating 3D-simulations of tube behaviour and bending simulations, which help the fabricator, visualize the bending process before running the part through the part through the machine. This helps to confirm the manufacturability of the part and the bend order [8].

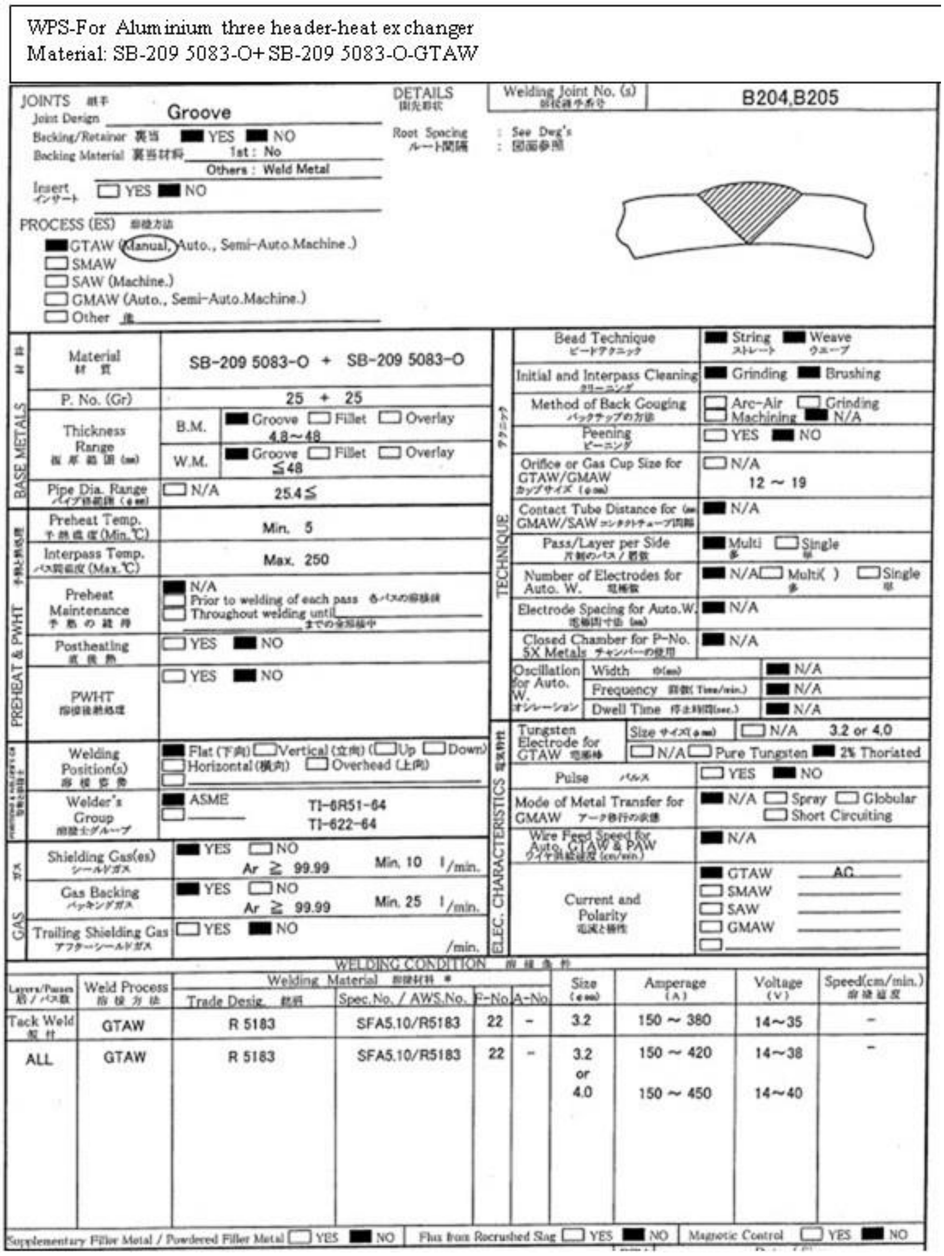


Picture 2 Markings of nozzle reinforcement dimensions

3. MERGING PROCESS OF ALUMINIUM HEAT EXCHANGER

In engineering practice, the working life of a certain apparatus includes the following stages: development, dimensioning and production of technical documentation, apparatus production, and functionality check of apparatus after production, installation of apparatus in a suitable complex system, functionality check after installation, maintenance, etc. After phase of dimensioning respectively creating heat transfer calculations, pressure drop and mechanical calculations, creating welding procedures specifications (WPS) are performing [14].

Creating of WPSs is of exceptional meaning for integrity of apparatus and safety of workers, which are doing maintenance of apparatus during its required working life. This phase is usually carried out in one of two possible ways, either a suitable WPSs are created which are checked and approved, or it is provided appropriate approved WPSs (or standardized WPS-SWPS) from renowned Welding houses. When is in question welding of specific materials (such as aluminium, titanium, magnesium, etc.) often is cheaper and more reliable buying of appropriate WPSs than preparing and approving of their own especially when fabrication companies does not have experienced Welding engineers especially trained for preparation specific WPSs and also when are requiring to performing of destructive examinations of welding samples for needs of qualifying these WPSs. For needs of fabrication, this apparatus appropriate approved WPSs have been provided with GTAW welding process with alternating current polarity.



WPS-For Aluminium three header-heat exchanger
Material: SB-209 5083-O+SB-209 5083-O-GTAW

JOINTS	DETAILS
Joint Design: Groove	Welding Joint No. (s): B204,B205
Backing/Retainer: ■ YES ■ NO	Root Spacing: See Dwg's
Backing Material: 1st: No; Others: Weld Metal	
Insert: □ YES ■ NO	
PROCESS (ES): ■ GTAW (Manual, Auto., Semi-Auto.Machine.) □ SMAW □ SAW (Machine.) □ GMAW (Auto., Semi-Auto.Machine.) □ Other	

BASE METALS	Material	SB-209 5083-O + SB-209 5083-O
	P. No. (Gr)	25 + 25
	Thickness Range (mm) B.M.	■ Groove □ Fillet □ Overlay 4.8~48
	Thickness Range (mm) W.M.	■ Groove □ Fillet □ Overlay ≦48
	Pipe Dia. Range	□ N/A 25.4≦
PREHEAT & PWHT	Preheat Temp. (Min.℃)	Min. 5
	Interpass Temp. (Max.℃)	Max. 250
	Preheat Maintenance	■ N/A □ Prior to welding of each pass □ Throughout welding until
	Postheating	□ YES ■ NO
	PWHT	□ YES ■ NO
	Welding Position(s)	■ Flat □ Vertical (□ Up □ Down) □ Horizontal □ Overhead □
	Welder's Group	■ ASME □ TI-6R51-64 TI-622-64
GAS	Shielding Gas(es)	■ YES □ NO Ar ≧ 99.99 Min. 10 l/min.
	Gas Backing	■ YES □ NO Ar ≧ 99.99 Min. 25 l/min.
	Trailing Shielding Gas	□ YES ■ NO /min.

TECHNIQUE	Bead Technique	■ String ■ Weave
	Initial and Interpass Cleaning	■ Grinding ■ Brushing
	Method of Back Gouging	□ Arc-Air □ Grinding □ Machining ■ N/A
	Peening	□ YES ■ NO
	Orifice or Gas Cup Size for GTAW/GMAW	□ N/A 12 ~ 19
	Contact Tube Distance for GMAW/SAW	■ N/A
	Pass/Layer per Side	■ Multi □ Single
	Number of Electrodes for Auto. W.	■ N/A □ Multi( ) □ Single
	Electrode Spacing for Auto.W.	■ N/A
	Closed Chamber for P-No. 5X Metals	■ N/A
	Oscillation for Auto. W. – Width	■ N/A
	Oscillation for Auto. W. – Frequency (Time/min.)	■ N/A
	Oscillation for Auto. W. – Dwell Time (sec.)	■ N/A
ELEC. CHARACTERISTICS	Tungsten Electrode for GTAW – Size	□ N/A 3.2 or 4.0
	Tungsten Electrode for GTAW	□ N/A □ Pure Tungsten ■ 2% Thoriated
	Pulse	□ YES ■ NO
	Mode of Metal Transfer for GMAW	■ N/A □ Spray □ Globular □ Short Circuiting
	Wire Feed Speed for Auto. GTAW & PAW	■ N/A
	Current and Polarity	■ GTAW AC □ SMAW □ SAW □ GMAW □

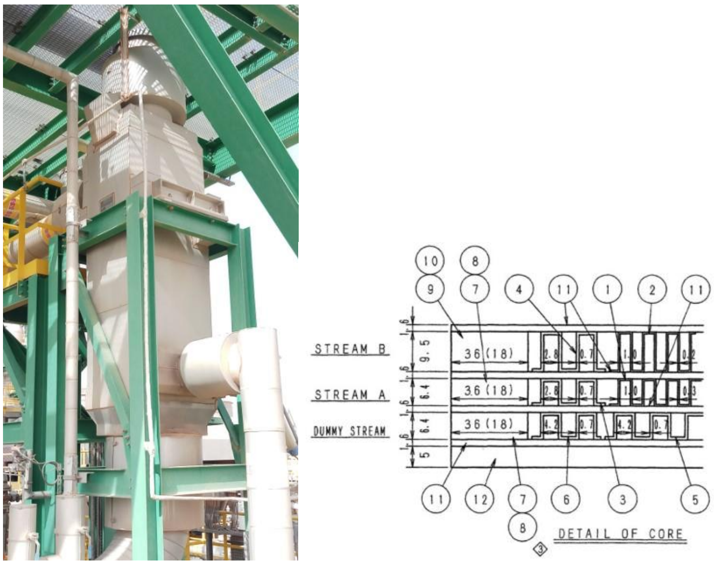
WELDING CONDITION

Layers/Passes	Weld Process	Welding Material: Trade Desig.	Welding Material: Spec.No. / AWS.No.	F-No	A-No	Size (mm)	Amperage (A)	Voltage (V)	Speed(cm/min.)
Tack Weld	GTAW	R 5183	SFA5.10/R5183	22	-	3.2	150 ~ 380	14~35	-
ALL	GTAW	R 5183	SFA5.10/R5183	22	-	3.2 or 4.0	150 ~ 420 150 ~ 450	14~38 14~40	-

Supplementary Filler Metal / Powdered Filler Metal □ YES ■ NO | Flux from Recrushed Slag □ YES ■ NO | Magnetic Control □ YES ■ NO

Picture 3 Welding procedure specification for aluminium heat exchanger

Here should be mentioned that alternating current has chosen because alternating current provides a cathodic cleaning (sputtering) that removes refractory oxides from the surface of weld joint, which is necessary during welding of aluminium, and magnesium. The cleaning action occurs during the portion of ac wave, when the electrode is positive with the respect to the work piece [15].



Picture 4 Aluminium heat exchanger after installation in plant and shape of internal core

After fabrication of heat exchanger, it were performed necessary non-destructive examinations of the weld joints. On that occasion for checking of surface indications penetrant tests were performed in range of 100% while for checking of volume indications radiography tests were performed in range of 20% for circumferential weld joints and in range of 100% for longitudinal weld joints [16]. Hydro tests of the working spaces have been performed whereby care it was taken regarding the space which is not pressure test in order to increasing pressure in not tested side in sense of avoiding its damaging during external pressure. After finishing all activities, heat exchanger was installed in the agricultural plant, name plate has been attached and insulation on the apparatus has been installed from exterior side (Picture 4). Also, proposed type of maintenance during estimated working life has been adopted according to the relevant international standards for pressure equipment.

4. CONCLUSION

The paper has shown phases of creating process equipment from defining designing conditions up to its installation. Mechanical calculations of specific type of aluminium heat exchanger, which has installed in agricultural process plant has presented which have conducted according to relevant ASME standards. Taking into consideration that selected material for heat exchanger is SB-209 5083-0 appropriate approved welding procedure specification has provided is given in chapter 3 and GTAW-welding process with alternating current has been used for welding activities. After fabrication process dye penetrant tests of weld joints in range of 100% performed for needs of examination of surface defects while for volume defects radiography has been used in range of 100% for longitudinal weld joints and in range 20% for circumferential weld joints. Hydro tests of both working spaces were performed on calculated test pressures and heat exchanger successfully put in service in agricultural plant.

ACKNOWLEDGEMENT

Acknowledgement: This research was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia through contracts Nos. 451-03-47/2023-01/200051, 451-03-47/2023-01/ 200213, 451-03-47/2023-01/200026 and 451-03-47/2023-01/200105.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

THE EFFECT OF PHASE-CHANGING MATERIAL THICKNESS ON LIGHT CONSTRUCTION BUILDING INDOOR TEMPERATURE

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INVITED PLENARY LECTURE

Abstract. *Due to the excessive use of air conditioners and heating systems, energy consumption by the builiding sector has been growing significantly in recent years, which leads to the accelerated depletion of conventional energy sources and to the fact that renewable energy sources are becoming more and more popular. Phase change materials are suitable for use in latent heat energy storage technology due to their high storage density and stable thermal properties.*

The thickness of phase change materials (PCMs) added to the thermal envelope of a lightweight building is investigated in this study. The simulations were run for 7 days in July, which was determined to be the hottest period of the summer based on the Meteonorm weather file, and when it is difficult to maintain thermal comfort without using a lot of energy. The thermal behavior of the building without PCM and with built-in PCM in the envelope of the building in one wall on the south side and on the ceiling, with different thicknesses of phase-changing material was simulated and the results obtained were analyzed with the aim of establishing which thickness of phase-changing material is optimal for installation in the envelope of the building.

Key words: *Building, PCM, Phase-change material, TRNSYS*

1. INTRODUCTION

A phase is the physical state of a substance, and on Earth matter can exist in solid, liquid, gas, and plasma states. Each type of matter has its own properties, such as specific heat, melting and boiling point.

Heat transfer consists of latent and sensible processes. Latent heat transfer is a phenomenon in which the phase change occurs without any change in the internal temperature. In sensible heat transfer, on the other hand, there is no phase change, but there is a change in the internal temperature.

Phase transition is a physical phenomenon used in applications involving the storage or release of thermal energy (see Fig. 1). The use of phase change materials (PCM) for thermal energy storage is a promising technology based on the principle of latent heat storage of thermal energy. During the charging and discharging process, PCM absorbs or releases significant amounts of energy at a certain temperature due to its high heat of fusion in the phase change temperature range [1] and behaves like a battery that can store and release thermal energy.

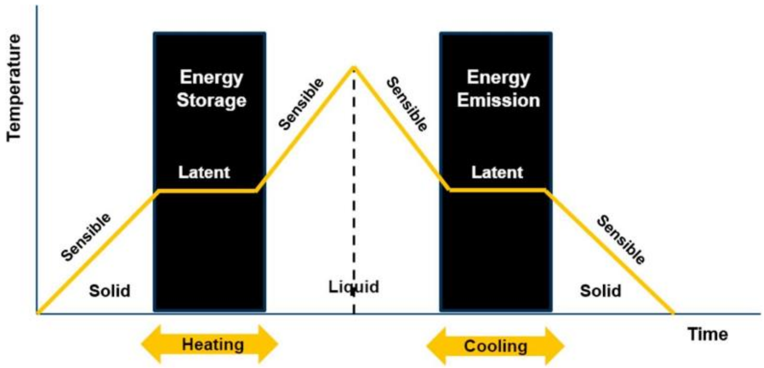

Fig. 1 Schematic diagram of the phase change transition of PCM [1]

The wide range of applications of phase-change materials is related to the temperature range in which the phase transition occurs. There are four basic application groups based on the temperature range. Low-temperature PCMs (-20°C to 5°C) are used in household refrigerators and commercially produced refrigerated goods to cool the products. Medium-low temperature ranges PCM (5°C to 40°C) are used for cooling in free cooling, solar absorption chillers, evaporative and radiant cooling systems, and air conditioning, as well as for passive heating and cooling of buildings. The medium temperature range (40 °C to 80 °C) is used for solar air heaters, solar stills, and solar domestic hot water heating, as well as for cooling electrical equipment. The high temperature range (80 to 200 °C) is used for solar thermal power generation, on-site waste heat recovery, and waste heat recovery for off-site heating purposes [1].

Building envelopes with phase change materials (PCMs) have gained popularity in recent years as an energy-saving option for buildings. This rapidly developing technology has shown that it can significantly improve the energy and thermal performance of buildings, making it an attractive building energy solution [2-4]. As a rapidly evolving technology, PCM has been incorporated into buildings that were still under development, taking into account a variety of factors, including the study of new PCM types, influential positions within the building envelope, optimal quantities, installation methods, and the best passive/active strategies that can be used effectively [5].

The primary purpose of installing PCMs is to increase the heat storage capacity of the building envelope and reduce both indoor temperature fluctuations and energy demand (see Fig. 2) [6]. The amount of latent heat required to cause a phase change in a material is much higher than its specific heat. Therefore, PCM effectively increases the thermal mass of the building material when the temperature rises above or below the PCM transition temperature [7]. PCMs can be broadly categorized according to the changes in their physical state. For building applications, especially for incorporation into walls and wall panels, only solid-liquid PCMs with a certain range of phase change temperatures are used [8]. These PCMs are classified by [9] into three categories: eutectic, inorganic, and organic. The operating temperature range and enthalpy of fusion are different for each group. The ideal properties of PCM for buildings should include: a suitable phase change temperature (18°C–30°C), good heat transfer capabilities, thermal performance stable over time, no overcooling or low undercooling, environmental friendliness, a small volume change during phase transition, and good economics [10,11,12].

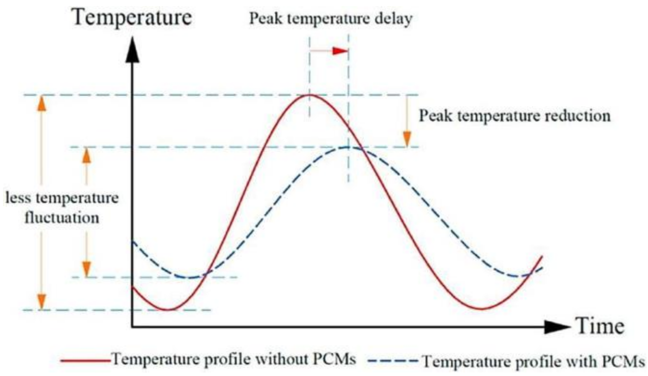

Fig. 2 Indoor temperature of a building with and without the use of PCM [6]

The world is experiencing a constant change in trends in the construction of buildings. The principles of solid construction are increasingly being abandoned in favor of the erection of lightweight building structures suitable for a variety of uses and for extreme weather conditions such as heavy rains, high winds and earthquakes. Lightweight container type objects, for example, can be easily disassembled, relocated, and adapted to a wide variety of needs thanks to their modular design. One of the main disadvantages of lightweight buildings is that they do not have a high thermal capacity, which leads to large fluctuations in indoor temperature with changing outdoor temperatures. The heat capacity of buildings made of lightweight materials can be increased by using phase-change materials (PCM) in the thermal envelope [7].

Recently, a large number of papers have been published on the use of PCM in buildings. For each climate, it is necessary to investigate which phase change material or combination of materials has the greatest effect on reducing energy consumption and payback time [13].

In a paper [14], researchers studied lightweight buildings integrated with phase change material (PCM) to improve the thermal performance of lightweight buildings. EnergyPlus software is used together with a building model validated by experimental data to investigate the improvement of indoor thermal climate with PCM in the five climate zones of China under typical weather conditions. The results show that PCM can effectively control the increase and fluctuation of indoor temperature. For most of the year in temperate regions, PCM can improve the indoor thermal conditions of light buildings.

The study [15] examined the use of bio phase change material (bio-PCM) as a thermal insulation material based on variations in thickness inside a composite wall. Even as the ambient air temperature drops, the PCM wall maintains its thermal inertia for longer periods of time. PCM-incorporated walls were found to be more thermally stable than non-PCM-incorporated walls. The addition of PCM reduces the intensity of temperature variation while also reducing the amplitude significantly. The thickness of bio-PCM can be increased to improve thermal comfort. This behavior suggests that bio-PCM walls can play an important role in maintaining human comfort temperatures in building walls.

The study [5] investigates the optimal thickness of a PCM layer-integrated composite roof under extreme outdoor temperatures. Three different thicknesses of PCM are installed in a residential roof combination in Iraq and compared with a reference roof without PCM. The thermal performance of each PCM layer thickness was evaluated using energy indicators based on room temperature, interior surface temperature, and average exterior surface temperature. Room maximum temperature reduction (RMTR), average temperature fluctuation reduction (ATFR), decrement factor (DF), and time lag (TL) are the indicators under consideration. The study concluded that a thicker PCM layer leads to better thermal performance, as expected. However, the effects of the heat transfer medium PCM and economic considerations should be taken into account when installing a large PCM thickness/quantity in real buildings.

The ability to maintain a certain temperature in buildings as part of thermal comfort, whether those buildings are used exclusively for the storage of goods or for the housing of people or animals, depends largely on the climatic conditions and the materials used for the construction of the thermal envelope. From an architectural point of view, lightweight containers have recently been increasingly used. These buildings have a number of advantages over traditionally built structures, including lower cost, ease of assembly and disassembly, ability to be placed in inaccessible terrain, lack of special permits for placement, and the ability to build a variety of structures for a variety of uses. The lack of such structures is primarily due to their low thermal capacity, which is a prerequisite for maintaining thermal comfort in them without consuming much energy. Phase change materials, as mentioned earlier, can be incorporated into the thermal envelope to increase the thermal capacity of buildings made of lightweight materials. The construction cost will undoubtedly increase due to the installation of phase change materials in the thermal envelope of the building. Therefore, in order to increase the thermal capacity of the building and be economically feasible at the same time, it is necessary to know the physical properties of PCM and the amount that needs to be installed in the walls of the building under certain climatic conditions. This paper deals with the influence of the thickness of PCM introduced into the envelope of the container-type object on the indoor air temperature.

2. Model and TRNSYS simulation

One of the very common objects of light construction that is used for various purposes is the container-type object shown in the fig. 3. This basic type of container was chosen for the analysis of the impact of the installation of different thicknesses of phase-changing material in the thermal envelope of the object with the aim of establishing the relationship between the internal air temperature in the object and the amount of phase-changing material embedded in the thermal envelope.

Fig. 3 Container for people accommodation

Google SketchUp software was used to create the geometric model of this object (Fig.4), which was required in order to simulate the object's thermal behavior. To enter the geometric data into the building model, TRNSYS3d for Google SketchUpTM was used as a plug-in. The thermal performance of the container with one thermal zone is modeled in Type56 modul of the TRNSYS software, a transient systems simulation environment that allows the user to create component-based models to represent energy systems (including localized weather, equipment, building structure, etc.) based on “in actuality” scenarios and then calculate various outputs based on the user's needs.

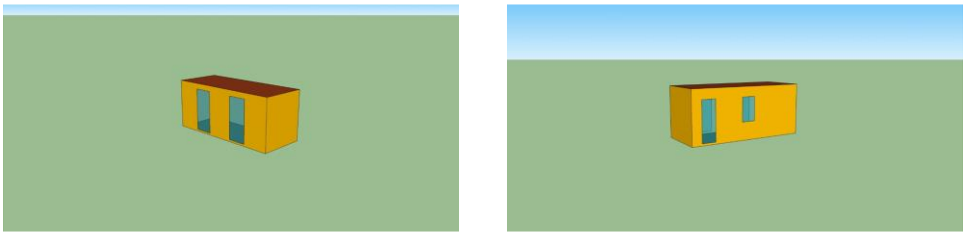

Fig. 4 SketchUp model of container

TRNSYS module Type1270 was used to simulate thermal behavior of a PCM. The phase change material is completely placed inside the envelope, implying that the PCM is not directly adjacent to the zone air. This module interacts with Type56 and models a PCM located anywhere along the thickness of a Type56 wall.

Phase change materials must satisfy a few fundamental requirements in order to be used in construction, including being widely accessible, inexpensive, and non-toxic. For this analysis, coconut oil with latent heats of solidification and melting of 107.34 J/g and 106.17 J/g, respectively, and a phase change temperature between 17.44 and 22.63 °C was used [16].

The density, thermal conductivity, and specific heat of all materials incorporated in the container shell are shown in table 1, and the composition of individual components of the thermal shell: wall, ceiling, and floor are shown in table 2, with layers order shown from the outdoor to the indoor direction. The phase change material is installed in the container's ceiling and south wall panels.

Table 1 Properties of envelope constituent materials

Material	Density (kg/m^3)	Thermal Conductivity (W/mK)	Specific heat (J/kgK)
Steel	7800	15	1800
Mineral Wool	80	0.05	900
PCM-Coconut oil	903	0.321	$2900^{sol.}/2100^{liq.}$
Polyurethane	40	0.036	2090
Cement chipboard	1250-1400	0.26	1150

Table 2 Wall, roof and floor layers

Layers	Wall	South Wall	Ceiling	Floor	Direction
Steel thickness (mm)	3	3	3	3	Outdoor
Mineral Wool thickness (mm)	60	60	100	-	
PCM-Coconut oil thickness (mm)	-	0-40	0-40	-	
Polyurethane thickness (mm)	-	-	-	50	↓
Steel thickness (mm)	-	-	-	3	
Cement chipboard thickness (mm)	-	-	-	20	
Steel thickness (mm)	3	3	3	-	Indoor

The simulations were run in the Simulation Studio (fig. 5) software from July 18 to July 25 (for the 4758th to 4926th hour observed since the start of the year), with a simulation step of 5 minutes. We used a weather file that contained data on external meteorological parameters for a typical meteorological year in Belgrade.

Simulations of the thermal behavior of the container without PCM and with various PCM thicknesses were performed by the Simulation Studio of the TRNSYS software package with the aim of analyzing the influence of the thickness of the phase-changing material on the container thermal behaviour by observing the internal air temperature.

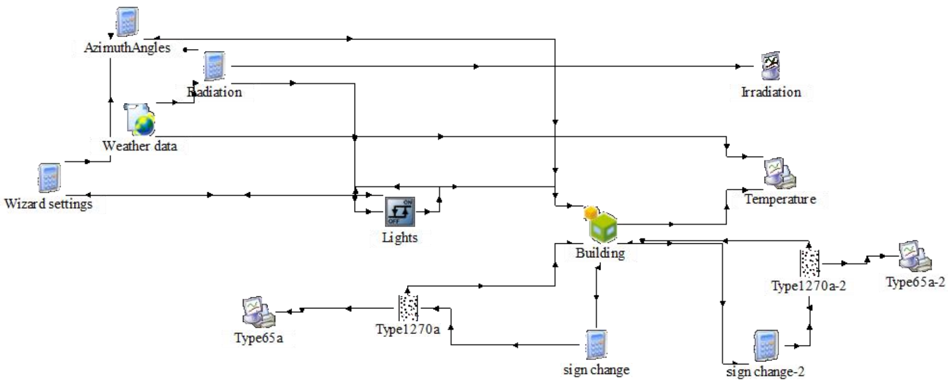

Figure 5 Component layout for a simulation studio

3. RESULTS AND DICUSSION

A simulation of the thermal behavior of the object in the hottest period of July was carried out according to the Meteonorm's weather file for Belgrade in the period from 4758-4926 hours observed since the beginning of the year, with the goal of analyzing the influence of the thickness of the phase-changing material embedded in the thermal envelope of the container, on the internal air temperature. For the phase change material, coconut oil with thermophysical properties suitable for use in the summer was chosen.

The thickness of the phase-changing material installed in the building's ceiling and the wall on the south side of the total area of 30.12m2 was varied in a total of 8 simulations of the container's thermal behavior, ranging from 0.002m to 0.04m. The outcomes of these simulations are shown in Figure 6. One temperature is represented by each curve. A red curve indicates the outside air temperature as reported by the Belgrade weather file. The internal air temperature of a container without a phase change material in its envelope is represented by the light yellow curve. The other curves represent the internal temperature of the air in the container in the following order: gray for a thickness of 0.002m, yellow for a thickness of 0.004m, light blue for a thickness of 0.008m, green for a thickness of 0.012m, purple for a thickness of 0.02m, and black for the largest observed thickness of 0.04m. The installation of phase-changing material significantly reduces the amplitude of the daily temperature change as well as the shift of the temperature peak.

It is clear that even very thin layers of phase-changing material embedded in the envelope can cause a sizable drop in internal air temperature. The internal temperature peak is reduced by about 10 degrees Celsius for the simulation's observed period.

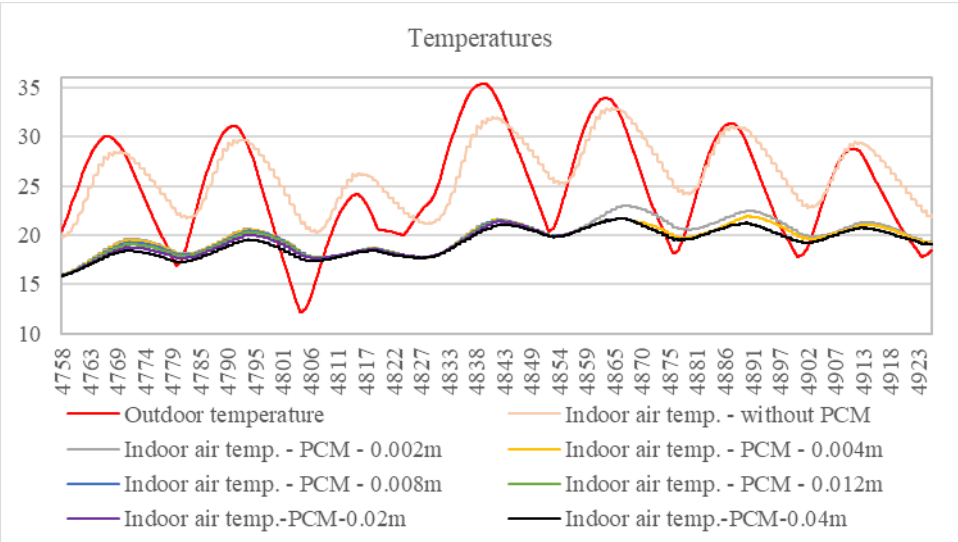

Fig. 6 Indoor and outdoor temperatures

Figure 7 depicts a more detailed view of the second sinusoidal temperature change's peak. Depending on the thickness of the embedded phase change material, the blue circles represent the maximum indoor air temperatures at a time point corresponding to 4794.08 hours from the start of a typical meteorological year. The temperature of the internal air in the container where the phase-changing material is not embedded in the shell is represented by the red circles. The temperature of the indoor air can be reduced by 8.83°C by installing a small thickness of PCM of 0.002m observed for the above-mentioned moment of time. Installing PCM with a thickness of 0.04m reduces the temperature by 9.94°C, so increasing the thickness of PCM from 0.002m to 0.04m reduces the temperature by 1.11°C.

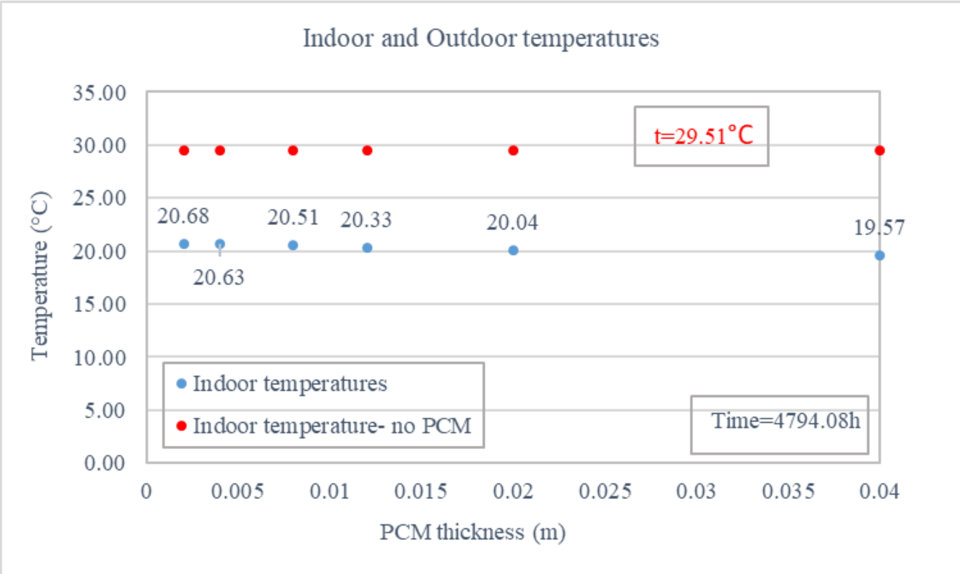

Fig. 7 The internal temperature change as a function of the PCM thickness

Figure 8 depicts a graphical representation of the increase in mass of PCM embedded in the thermal envelope of the container as the thickness increases. When the thickness of PCM material is increased from 0.002m to 0.04m, the mass of PCM increases from 54.4kg to 1087.9kg, or about 20 times, while the indoor air temperature is reduced by 1.11°C. This increase in mass could cause significant problems for container-type facilities in terms of construction and transportation, threatening their primary advantage over traditional construction.

Before installing PCM material, it is necessary to simulate the thermal behavior of the object with all available parameters in order to choose the best combination of PCM type, quantity, and position of the material to be installed for the ambient conditions of a specific geographic location. This is necessary because the need to increase the thermal capacity of light objects must be met in a way that does not endanger their other characteristics.

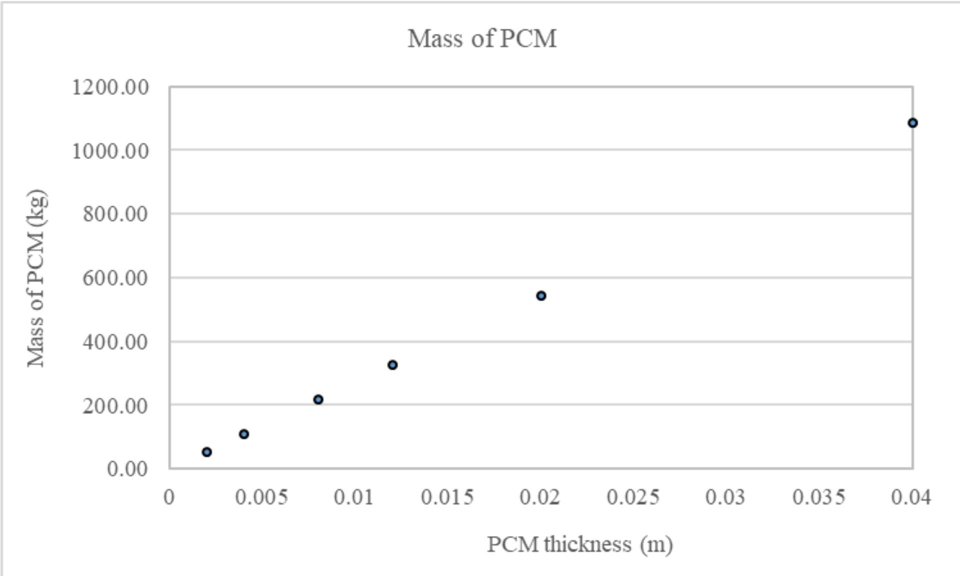

Fig. 8 The relationship between PCM mass and thickness

4. Conclusion

This study is based on a simulation of the thermal behavior of a lightweight, container-like object in which a phase-change material was added to the thermal envelope. According to the Meteonorm weather file for Belgrade, the simulation was conducted from July 18 to 25 during the hottest time of the year. Indoor air temperature was simulated for a container-type facility without PCM and a facility with PCM. Coconut oil was added to the sandwich wall panels on the south side of the building, as well as to the ceiling panels, as a phase-changing material, and the thickness of this material was varied from 0.002 to 0.04 meters.

The installation of phase-changing material can lower the internal air temperature and mitigate the sinusoidal daily distribution. Installation of the smallest and largest PCM thicknesses of 0.002 m and 0.04 m, respectively, decreased the indoor air temperature by 8.83 °C and 9.94 °C during the observation period. This increase in thickness resulted in a decrease in the indoor temperature by 1.11°C, but the total weight of the installed PCM increased from 54.4 kg to 1087.9 kg, which is a very negative consequence for lightweight buildings.

These results show that the internal temperatures of a building can be significantly reduced by installing PCM even at very low thicknesses, but an analysis of all the important parameters related to the thermophysical properties of PCM, the environmental conditions of the climate in which they are used, their cost, etc. must be carried out beforehand. A balance must be found between improving the thermal capacity, whose low values are one of the main disadvantages of container-type buildings, and modifying other properties resulting from the addition of PCM to their thermal envelope.

Acknowledgement: *This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia; grant number 451-03-47/2023-01/ 200017.*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

NEW TRENDS IN REFRIGERATION TECHNOLOGY IN SERBIA

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INVITED PLENARY LECTURE

Abstract: *The food and agriculture sector is constantly evolving, so in general refrigeration industry needs to follow these changes and to grow; however several directions of development currently stand out in the Serbian refrigeration market. The major direction in which refrigeration is developing is the use of natural refrigerants. Nevertheless, Freons (such as HFCs, HFOs, and their blends) still find an important place for a wide range of applications because of the familiarity in use and low prices. Whatever system is applied, the refrigeration industry in Serbia is witnessing several notable trends driven by environmental concerns, energy efficiency, and regulatory compliance. Although apparently different, these three concepts are strongly related to each other. The adoption of natural refrigerants, including carbon dioxide (CO2), ammonia (NH3), and hydrocarbons (such as propane R290, isobutane R600a, etc.), is gaining support (despite higher investment costs) due to their lower global warming potential (GWP) and zero ozone depletion potential (ODP), and good thermodynamic properties. Retrofitting and upgrading existing systems in an attempt to comply with legal and environmental frameworks is also a widespread tendency. Smart refrigeration systems, that incorporate remote monitoring and predictive maintenance, are used more and more to optimize performance. For sure, the cold chain industry must focus also on parameters optimization to ensure product quality and decrease waste. Compliance with the latest regulations and standards and aligning with new directives is an important aspect. Training and skill development programs need to be implemented to keep professionals up to date with new technologies and refrigerants.*

Key words: *refrigerants, cooling, ODP, GWP.*

1. INTRODUCTION

During the 1800s with the development of science, technique, and technology, the modern refrigeration systems that we know today were also developed. In that time when the modern concept of vapor refrigeration system was made only a limited number of substances were used as working matter. These included natural fluids such as ammonia, carbon dioxide, sulfur dioxide, methyl chloride, ethyl ether, and some others...

- The year 1748, the physician William Cullen succeeded in freezing the water using ethyl ether in an open process. The accidents occurred due to the vapors of ethyl ether released into the atmosphere by evaporating, because of the flammability/explosivity of this fluid.

- In 1823, Michael Faraday conducted experiments with the liquefaction of carbon dioxide (R744) and some other gasses.

- In 1842, Doctor John Gorrie built the first closed-cycle refrigeration system, with the purpose of air-conditioning the rooms with the patients. This system relied on the mechanical compression of refrigerant gases that were evaporated during the cooling process. In the year 1851 he obtained the patent for an ice-making machine.

- During the 1860s French engineer Charles Tellier devised the first industrial refrigeration machine using methyl ether. This system was primarily constructed to produce ice. However, in the time to come, it was used to develop refrigeration systems for food preservation using ammonia as the refrigerant, and this system worked with success in one chocolate factory in France.

- In 1875, Carl Von Linde made his first compression machine using methanol. Afterwards, he made his first compression system with ammonia.

- French monk Marcel Audiffren made the design of domestic refrigerators with sulfur-dioxide, and General Electric produced it in the year 1911 using the concept of Audiffren and named it after him…

- The greater production of domestic refrigerators started in the 1930s when the CFCs were discovered. These are Chlorofluorocarbons, compounds widely known as "Freons". Later on, HCFCs (Hydrochlorofluorocarbons) were introduced.

Concluding from the historical facts, highly flammable, explosive and toxic substances were used at that time for the purpose of refrigeration until freons came upon. And the systems with CO2 worked at very high pressures. At the time, freons were the game changer, because (not only) domestic refrigeration systems could be made human risk-free.

These natural fluids (sulfur dioxide, methyl chloride, ethyl ether, etc.) largely used were phased out when CFC and HCFC refrigerants were made. However, ammonia has never stopped being in use, because it is established as the main refrigerant in industrial systems. For around 50 years Freons were dominant in use in a large number of applications. During the 1970s and 80s, it was discovered that CFCs and HCFCs (used in refrigeration systems, so as blowing agents and solvents) contribute to the depletion of the ozone layer, because of atoms of chlorine in the chemical structure. ODP factor is the number that tells about the depletion potential of some substance (Freon CFC R-11 has maximum value of ODP equal to unity). Taking different actions and measures to manage these substances led to the establishment of the Montreal Protocol in 1987. Until now, it is the most successful environmental agreement. The phase-out of ozone-depleting substances introduced the use of alternatives to these substances, which were mainly HFC fluids. It is a group of freons called hydrofluorocarbons. Despite the development of HFCs, part of the industry has reverted to the use of hydrocarbons (HC) and carbon dioxide (R744) in certain applications. For example, in Germany R600a was widely used in refrigerators (Figure 1).

Although HFCs do not have the potential to damage the ozone layer (ODP=0), the widespread use of these refrigerants leads to the undesired impact on the environment popularly known as global warming. These fluids have a high global warming potential (GWP). The value of GWP factor shows a measure of how much energy would be absorbed by one kilogram of released substance in atmosphere during a period of time, relative to the one kilogram of carbon dioxide (CO2). The larger the GWP factor, the greater the influence on the global warming. The period usually used for determining GWP value is 100 years. So, the Global Warming Potential (GWP) is the factor used to compare the impact of different substances to the environment.

As an alternative to freons with high GWP values, some industries have started to use HFO fluids (unsaturated organic compounds called hydrofluoroolefins). For example, from 1st January 2017, the new “mobile“ air-conditioning units from some manufacturers use HFO-1234yf as a refrigerant with GWP = 4.

Figure 1. Hydrocarbons in domestic refrigeration appliances in Germany [1]

Global warming is the reason why the Kigali Amendment to the Montreal Protocol was adopted and it is expected to lead to phase down the usage of high GWP refrigerants. Acceptable refrigerants in the future will be the ones that have ODP=0 and (for now) GWP<150. Table 1 summarizes the applications for which these newest alternatives are most likely suitable (however it does not indicate where these refrigerants are actually used).

Table 1. Possibilities with alternative fluids in use [3]

Application / Refrigerant	Centralized plants	Chiller	Condensing units (remote)	VRV/VRF[1] systems	Splits/ Heat pumps (HP)	Integrals[2]
R744	🟢	🟢	🟢	🟡	🟡	🟡
R717	🔴	🟢	🔴	🔴	🔴	🟡
R600a	🔴	🟡	🔴	🔴	🟡	🟢
R290	🔴	🟢	🔴	🔴	🟡	🟢
R1270	🔴	🟢	🔴	🔴	🟡	🟢
R1234ze	🔴	🟢	🟡	🟡	🟢	🟢
R1234yf	🔴	🟢	🟡	🟡	🟢	🟢

[1] VRF/VRV –both acronyms VRV and VRF represent the systems with variable flow.
[2] Integrals - Self-contained refrigeration units (e.g. domestic refrigerators, cabinets, small package units, etc.).

Nowadays, we return to „the beginning of the refrigeration technology“, facing the same (safety) problems almost after 150 years.

Some of these new refrigerants with low GWP values are already widely used; some others are tested and gradually introduced into use. Their application is often limited due to flammability and toxicity. In the table 1, green designates that the systems are suitable for the refrigerant type indicated. Yellow indicates that these systems can and are used with the refrigerant type indicated, but there are restrictions because of the maximum charge or practical limit specified in (SRPS) EN378. Red means that the systems should not be used with the refrigerant type indicated.

2. REFRIGERATION FRAMEWORK IN SERBIA

The phase-out process is currently in progress and it includes a decrease in production and consumption of ozone-depleting substances (ODS). Since there is no production of ODSs in Serbia, only the servicing sector is in attention.

New refrigeration technologies in Serbia are more or less affected by existing (and future) legal acts, which leads us to the application of a limited number of refrigerants (mostly with small GWP values).

Environmental regulation in force contains the legal framework for the implementation of the Montreal Protocol and control of ozone-depleting substances (ODS). The most important regulations in Serbia are:

- Law on Air Protection („Official Gazette RS”, No. 36/09 and No. 10/13);
- Law on Environmental Protection („Official Gazette RS”, No. 135/04, 36/09, 72/09, 43/11 and 14/16);
- Decree on the treatment of substances that deplete the ozone layer, as well as on the conditions for issuing permits for the import and export of these substances („Official Gazette RS”, No. 114/2013 No. 23/2018);

This regulation prescribes the gradual reduction of consumption of ozone-depleting substances, conditions and manner of issuing permits for import and export of these substances, treatment of ozone-depleting substances as well as procedures for mandatory leak checks in stationary refrigeration and air conditioning equipment.

- Decree on the treatment of fluorinated greenhouse gases, as well as on the conditions for issuing permits for the import and export of these gases ("Official Gazette of RS", No. 120/2013);

This regulation prescribes more detailed conditions for issuing permits for the import and export of fluorinated greenhouse gases as well as products and equipment containing these gases, procedures for mandatory leak checks in stationary refrigeration and air conditioning equipment, etc.

- Amendment of the Decree on the treatment of substances that deplete the ozone layer, as well as on the conditions for issuing permits for the import and export of these substances („Official Gazette RS”, No. 23/2018) introduces ban on import of equipment containing or relying on ODS substances
- Decree on certification of persons performing certain activities related to ozone-depleting substances and certain fluorinated gases with a greenhouse effect ("Official Gazette of RS", No. 24/2016)

This regulation defines the minimum requirements and procedure for obtaining certificate A and certificate B for refrigeration and air conditioning service technicians who perform tasks such as installation, maintenance and servicing, leak testing, collection of ozone-depleting substances or fluorinated greenhouse gases and exclusion from the use of RAC equipment.

- Law on ratification of the Kigali Amendment ("Official Gazette of RS - International Agreements", No. 17/2021).

The above-mentioned legislation covers the following: quota system for import/export HCFCs, licensing system (licensing system is extended to include HFCs and HFCs – containing mixtures), mandatory reporting by importers/exporters, ban on import/placing on the market of products and equipment containing/relying on HCFCs, special requirements for labeling, handling of controlled substances and products/equipment containing them and national certification system.

3. Codes and Standards in use

The goal of the Kigali Amendment is to implement low-GWP fluids, as well as to accelerate innovation in sustainable RAC technologies. In general, one of the key issues for the implementation of the Kigali Amendment is the replacement existing high-GWP refrigerants with low-GWP refrigerants.

After the adoption of the Kigali Amendment to the Montreal Protocol, a significant trend can be observed towards the application of natural refrigerants and HFOs as alternatives with low global warming potential (GWP).

In Serbia, the main obstacles to the wider use of low GWP refrigerants (natural refrigerants such as HCs, CO2 or NH3) are safety issues (as already said, those refrigerants are flammable and/or toxic) and the lack of qualified personnel to work with. The problem with safety issues leads to the improvement of the knowledge base and the introduction of new standards that can cover the design, manufacturing of equipment, installation, maintenance, and commissioning/decommissioning of equipment that will work with these refrigerants.

At the international level, standards have been revised or are in the process of being revised to adapt to the new regulatory framework under the Kigali Amendment, especially for the use of natural refrigerants and HC as substitutes for HFC fluids.

Table 2. International and national standards for refrigerants [5]

Standard	Title	Level
ISO 817:2014[3]	Refrigerants — Designation and safety classification (last reviewed and confirmed in 2020 and therefore this version remains current)	International
ISO 17584:2022	Refrigerant properties	International
ANSI/ASHRAE 34-2019	Designation and Safety Classification of Refrigerants	National

[3] Serbian national standard SRPS M.E7.101:1970 - Refrigeration plants - Basic technical safety rules - Refrigerants and their classification by risk level, despite it was withdrawn on in 2012 still in occasional use.

The standards covering refrigerants are presented in Table 2, while the most important safety standards and product safety standards for refrigeration, air-conditioning and heat pumps (RACHP) are presented in Table 3.

Table 3. Safety standards for RAC systems [5]

Sector	Safety standards SPRS EN 378[4]				Product safety standards			
	SRPS EN 378-1	SRPS EN 378-2	SRPS EN 378-3	SRPS EN 378-4	IEC 60335 -2-11	IEC 60335 -2-24	IEC 60335 -2-40	IEC 60335 -2-89
Domestic appliances	√	√	√	√		√		
Commercial refrigeration	√	√	√	√				√
Industrial systems	√	√	√	√				
AC and HP air-to-air	√	√	√	√			√	
HP for hot water	√	√	√	√			√	
Chillers	√	√	√	√			√	

[4] SRPS EN 378 (parts 1 to 4) is Serbian standard identical with EN 378 and synchronized with ISO 5149:2014 (last reviewed and confirmed in 2020).

The main standard covering safety issues is SRPS EN 378 (i.e. ISO 5149) which is composed of four parts. European and national standard SRPS EN ISO 22712:2023 - Refrigerating systems and heat pumps - Competence of personnel (supersedes SRPS EN 13313:2012), as the name suggests, specifies the activities related to refrigeration systems and the necessary set of knowledge, skills, and abilities that one's need to properly perform the activities, and also defines procedures for assessing the competence of persons who perform these activities.

All refrigerants currently in use in Serbia (mainly HCFC R-22 in existing systems and a wide range of HFC refrigerants) already require qualified personnel to work with. The establishment of the training and national certification system is a very important step that should reduce leakage from existing systems (thus reducing the requirement for refrigerants for servicing purposes), and good maintenance should ensure the operation of the plant/system in the design parameters (therefore with the expected energy consumption). The next step is organizing more trainings and lectures that can cover the use of the wide range of applicable refrigerants with low GWP values.

Flammability and toxicity - risks that need to be taken care

Refrigerants are classified based on two general safety criteria: 1. Flammability, and 2. Toxicity, table 4. The classification is given with alpha-numerical symbols. The capital letter corresponds to the toxicity (in gradation) and the number to the flammability. Basically, this would mean that the letter ”A” stands for lower toxicity and the letter ”B” for higher toxicity. There are no refrigerants that are classified as non-toxic. The flammability classification can be marked as “1” depicting no flame propagation, lower flammability is marked with ”2L” and higher flammability with ”3”.

Table 4. Classification of refrigerants according to safety aspects (ISO 817)

Flammability / Toxicity	Lower Toxicity (A)	Higher Toxicity (B)
Higher Flammability	A3	B3
Flammability	A2	B2
Lower Flammability	A2L	B2L
No flame propagation	A1	B1

Combustion requires fuel, oxygen and an ignition source. Fire can occur naturally when these three elements are simultaneously present in appropriate proportions. Therefore, in order for the refrigerant to ignite, all three prerequisites must be met at the same time:

1. Refrigerant leakage from the system, then,

2. To create the mixture with air within the limits of flammability (oxygen is needed!). According to table 5, in principle, more than 1.5 %, but also less than 9 % of hydrocarbons (HC) per unit volume, as well as

3. An energy source (spark source) with a thermal power of 0.25 MJ, or at a temperature above 370°C.

Table 5. Safety aspects - flammability/explosivity limits [9]

Refrigerant	Explosivity limits in mixture with air, %vol.	Ignition temperature, °C
Propane (R290)	1,7 ÷ 9,5	470
n-butane (R600)	1,4 ÷ 9,3	370
Isobutane (R600a)	1,8 ÷ 8,5	460
Ammonia (R717)	15,5 ÷ 34,0	>400
R152a	3,7 ÷ 20,0	455
Propylene (R1270)	2 ÷ 11,1	455

So, if one of these three conditions does not exist, therefore no fire/explosion occurs. Combustion of all flammable refrigerants will occur if the refrigerant concentration in the air is between the lower and upper flammability limits and an ignition source is present.

- The lower flammability limit (Lower Flammability Limit - LFL) is the minimum concentration of refrigerant in the air that can lead to the spread of flames.
- Upper Flammability Limit (UFL) is the maximum concentration of refrigerant in the air that can lead to flame propagation.
- The auto-ignition temperature is the lowest temperature at which refrigerant will spontaneously ignite in a normal atmosphere without an external ignition source (flame or spark).

The service technician must organize and prepare the work area to avoid all potential (fire) hazards. Temporary flammable zones are areas where at least some refrigerant emissions are expected to occur during the operating procedures on the system.

Table 6 shows some important safety information for the most commonly used natural refrigerants and HFOs that can be found in SRPS EN 378 [4].

Table 6. Safety information for commonly used natural refrigerants and HFO

Refrigerant	Safety classification	LFL, kg/m^3	Ignition temperature, °C	PL[5], kg/m^3	ATEL /ODEL[6], kg/m^3
R744	A1	/	/	0,1	0,072
R717	B2L	0,116	630	0,00035	0,00022
R32	A2L	0,307	648	0,061	0,3
R1234ze	A2L	0,303	368	0,061	0,28
R1234yf	A2L	0,289	405	0,058	0,47
R600a	A3	0,043	460	0,011	0,059
R290	A3	0,038	470	0,008	0,09
R1270	A3	0,047	455	0,008	0,0017

[5] PL is a practical limit as specified in EN378-1. For refrigerants A1, it is the highest concentration in the occupied space that will not result in harmful effects. For flammable refrigerants, it is approximately 20% of the LFL.

[6] ATEL/ODL is Acute Toxicity Exposure Limit/Oxygen Deprivation Limit. It is the level above which there is a harmful effect resulting from single or multiple exposures in a short time interval (usually shorter than 24 h).

Charge limitation

Standard EN 378 provides the limitation of the refrigerant charge for RAC equipment for:

- Fluids that have toxicity as the main hazard, e.g. R717 and R744;
- Fluids that have flammability as the dominant hazard, e.g. A3 (i.e. HC) and A2L refrigerants.

The maximum charge amount depends on:

- Equipment location;
- Space classifications according to occupation;
- Type of system (e.g. direct or indirect).

4. Increased Use of New Refrigerants in Serbia

A large variety of low-GWP refrigerants could be found in the Serbian Market. There is a significant number of R600a and R290 systems belonging to the A3 safety group. R32 and R1234yf freons that are currently the most widely used are within A2L. The application of R744 is in expansion, but despite being A1 (as a large variety of HFCs such as R134a, R404A, R407C, etc.) it brings with it some other challenges as high pressure.

Hydrocarbons

Hydrocarbons (HC) are organic compounds used in the production of all synthetic refrigerants (including HFCs). Their impact on the environment is reflected in several numbers. First of all, the ODP factor (refers to the negative impact of fluids on the ozone layer) for all natural hydrocarbons is zero (ODPHC = 0), which means that there is no negative impact on the ozone layer. Furthermore, these compounds have a low global warming potential, which is reflected in the low values of their GWP factor (GWPHC < 8). These are colorless and odorless fluids, which are with lower toxicity and high flammability.

When used in refrigeration equipment, these fluids show good compatibility with compressor lubricating oils and good contact compatibility with materials, such as copper. This means that pipelines can be made of copper pipes and that hermetic compressors can (should) be used. Hydrocarbons are non-corrosive and have a relatively high coefficient of performance (COP) due to good thermodynamic characteristics. The discharge temperature is lower compared to certain synthetic fluids and ammonia. The compression ratios are lower compared to some synthetic refrigerants. Table 5 lists the lower and upper limits of flammability in their mixture with air, as well as the ignition temperature. Many safety experts consider the term lower flammability limit to be the same as the term lower explosive limit (LEL).

Carbon dioxide

Carbon dioxide is an inorganic refrigerant that belongs to group A1 of lower-toxicity and non-flammable fluids. Its code number is R744, and the chemical formula is CO2. The carbon dioxide is heavier than air, which means that it collects in the lower zones of the room, so it is easy to control it by exhausting it from the bottom of the plant room. Carbon dioxide is an odorless and tasteless gas, non-flammable and a natural substance - it is found in the environment.

An unfavorable fact related to carbon dioxide is that it has a low temperature and high pressure at the critical point, i.e. tcrit = 31°C and pcrit = 73.8 bar. It also has a relatively high triple point temperature of -56.6°C at a pressure of 5.2 bar. Because of that, it has a limited range of application for subcritical cycles, in a relatively narrow range of temperatures (from -56.6°C to +31°C). The evaporation temperature must be sufficiently higher than the triple point temperature to prevent the formation of dry ice.

Carbon dioxide is non-combustible, and in atmospheric conditions it is a stable substance. It is often used to extinguish fire. It is non-corrosive and compatible with most materials. It is an excellent medium for heat exchange (its vapor density is seven times higher than R134a at -10°C [6]). It has low vapor and liquid viscosity values, which leads to smaller pressure drops (smaller losses due to friction). Carbon dioxide has high values of the heat transfer coefficient, which allows operation with a lower temperature difference in the exchangers up to 2 K [7]. Its specific capacity is six times higher than that of the R404A fluid, so the size of the compressor and the pipelines in the refrigeration installation are smaller.

The value MAK (germ. "Maximale Arbeitsplatz Konzentration") represents the maximum concentration of a chemical substance (either it is a particle, vapor, or gas) in the workplace air. In general, this concentration doesn't have a known harmful effect on the employees health, nor it causes some discomfort (e.g. from the strong odour), even if an employee is repeatedly exposed for long periods, (e.g. 8 hours per day) [8]. The maximum allowed concentration of CO2, i.e. the value of the MAK parameter, is 5000 ml/m^3 (ppm). At certain, high enough concentrations in the air, CO2 can also lead to suffocation. Table 7 shows the danger to human health at high concentrations of carbon dioxide.

Table 7. CO_2 concentrations and impact on humans [7]

Concentration ppm	Comment
400	Concentration in atmosphere
5,000	**LTEL**
15,000	**STEL**
30,000	Can be tested
30,000	Discomfort, breathing difficulties, headache, dizziness, etc.
100,000	Loss of consciousness, death
300,000	Quick death

LTEL – long-term exposure limit (8 hours), STEL – short-term exposure limit (10 minutes)

Leadership in knowledge

Faculty of Mechanical Engineering, University of Belgrade is trying to follow the general refrigeration trends and state of the art in this industry. Therefore the development of the Refrigeration laboratory at the Faculty is one of the main goals. So far, new refrigeration plants have been introduced in the curriculum, such as propane air-to-water heat pump, cascade system with Freon R134a and CO_2, and transcritical booster system with CO_2 (figure 2).

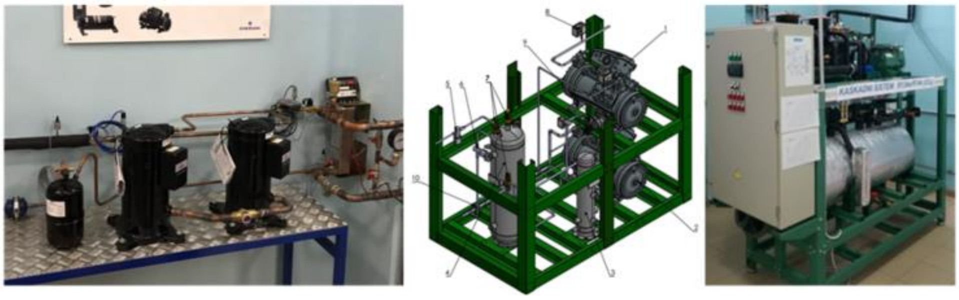

Figure 2 Faculty of Mechanical Engineering - Refrigeration Laboratory

4. CONCLUSION

As a result of the ongoing worldwide efforts to protect the climate, interest in natural refrigerants is on the rise. Natural refrigerants, in addition to positive environmental criteria, are also highly efficient - in fact, ammonia is considered the most efficient refrigerant of all - which accordingly reflects the plant's low energy consumption.

The performance of the RAC system also depends on the application of a certain system, design and maintenance of the system, and not only on the thermodynamic properties of the fluid used, so a more detailed analysis of a large number of factors is required.

An ideal refrigerant does not exist and it is unlikely that one will ever be created. The choice will therefore have to be reduced to certain substances from the group of refrigerants with a low GWP factor (such as R717, R744, HC, unsaturated freons - olefins - HFO and mixtures of these refrigerants and traditional refrigerants). Many new alternatives are being proposed, creating a challenge in finding the right one for each application.

From an economic point of view, natural refrigerants are available everywhere and are cheap. This is a significant factor for the initial plant charge (and investment cost), and this also has a positive effect on ongoing maintenance costs when leakage losses are taken into account.

In efficiency studies, refrigeration plants with natural refrigerants are often several steps ahead of their competitors. Reasons for this include lower costs associated with leakage, low maintenance costs, as well as lower energy consumption (which is especially important for large ammonia industrial plants). Add to this the relatively inexpensive disposal of natural refrigerants at the end of a facility's service life.

Evolution and technological innovation have helped to consider "natural refrigerants" as a safe and economically acceptable solution for application in many sectors. As a result of minimal environmental impacts and being more adequate in the perspective of sustainable technological development, refrigeration systems with natural refrigerants have begun to play an important (perhaps the only!) role as an alternative to existing refrigerants (mainly HFC) in many applications.

Based on the above mentioned, it is clear that the Republic of Serbia must get involved in solving this problem as soon as possible. The replacement of existing refrigerants is inevitable and obviously a real need. This replacement should be performed within a short "transitional" period. With full awareness of the fact that the implementation of an appropriate strategy has its price, it is still necessary that the future use of natural refrigerants (in terms of ecology, the most acceptable fluids) as soon as possible introduce and define by the appropriate national regulations.

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SETTING UP AND OPTIMIZATION OF NOVEL CLEANING SYSTEMS FOR SOLAR PANELS USED FOR IRRIGATION

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Abstract. *Thanks to developing technology, agriculture has required more energy in recent years. However, the energy cost has increased due to the ever-increasing demand and some geopolitical tensions. A renewable energy source such as solar is one of the alternatives. On the other hand, a decrease occurs in the efficiency of solar panels if the dust and dirt on the surface prevent sunlight from reaching the cells. Therefore, it is essential to constantly maintain and clean the solar panels. This research developed the cleaning method for solar panels used for irrigation purposes. To clean 80 panels with a length of 40 meters, 7 Pop-up type sprinklers were used. The transmitted water and rainwater to the panels were collected and returned through a 1000-liter water tank. The system was operated via a timer to optimize regular cleaning instructions. It was run for 5 min (sunrise), 10 min (sunrise), 2x5 min (sunrise and sunset), and 2x10 min (sunrise and sunset) in a day. As a result, a portable cleaning system was carried out with a low-cost and sustainable system.*

Key words: *Design, rainwater harvesting, pop-up sprinkler, photovoltaic, efficiency*

1. INTRODUCTION

In today's agriculture, electricity is widely used in many applications such as heating, cooling, lighting, and irrigation. Moreover, energy demand will continue to increase with new electricity consumers such as electric tractors or drones representing the future path in the coming years. However, current worldwide energy production (more than 85 percent) is based on energy from non-renewable sources. Therefore, Renewable energy sources are gaining widespread adoption as they offer a compelling alternative to conventional energy sources, which come with drawbacks like pollution, resource depletion, and contributions to global warming, especially in light of the global push for the Kyoto Accord [1].

Of all the renewable energy resources accessible, solar power reigns supreme as the most abundant and commonplace reserve on our planet. Solar energy is intercepted by the Earth at a pace that exceeds humanity's energy consumption by a factor of approximately

10,000 [2]. The sun offers a cost-effective energy source, enabling the existence of life on our planet [3]. The most common way of converting sunlight into electrical energy is by solar panel applications. Over the past decade, the manufacturing costs of solar panels have seen a significant reduction, rendering them not only affordable but frequently the most cost-effective option for generating electricity. These solar panels typically maintain a lifespan of around 30 years depending on the materials used in their production [2].

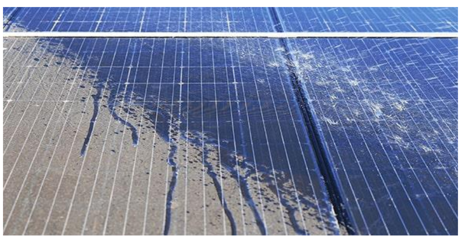
Due to its cleanliness, sustainability, durability, and reliability, solar energy has captured the interest of numerous researchers, scientists, and industries as a viable alternative [1]. Worldwide cumulative installed photovoltaic (PV) capacity in 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, and 2021 is 72, 101, 137, 175, 223, 295, 390, 483, 584, 710 and 843 MW [2]. The total cumulative installed PV capacity worldwide had reached approximately 1,185 GW. On the other hand, Turkey had 95.890 MW electric installed capacity in 2020 (22.53% from natural gas, 20.45% from coal, 32.31% from hydropower, 9.21% from wind, 1.68% from geothermal, 6.87% from other sources and 6.95% from solar energy). The 2019–2023 Strategic Plan of the Turkey Ministry of Energy and Natural Resources, aims to continue to promote the expansion of solar energy, and it is expected to reach a commission of 10 GW capacity [4].

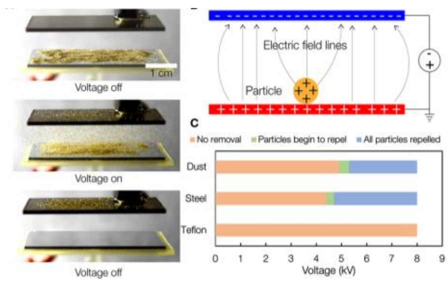
Despite its status as a free, clean, and sustainable energy source, solar power does present certain challenges [3]. The first approach as a strategy is to maximize the production efficiency of the existing solar power plants. However, it has been determined that the efficiency losses due to the dust and dirt factors in solar power plants are approximately 15% [5]. In order to prevent efficiency losses, various systems have been developed to clean the surface of solar panels [6-7].

2. COMPARISON OF CLEANING SYSTEMS

The accumulation of dust and stains can significantly reduce the efficiency of PV panels, underscoring the importance of regular cleaning. Numerous researchers are actively working on developing efficient cleaning techniques for PV panels to ensure their long-term effectiveness. Table 1 presents an overview of various PV panel cleaning systems.

Table 1 Types of PV panel cleaning systems [8]

Features	**Figures**
Rainfall, wind, and gravity are the sub-methods. The falls of rainwater on the tilted PV panels or a high-speed wind cleans the PV panel surface. Otherwise, during dry seasons, dust accumulation caused a daily decrease in PV performance of over 20%. However, less than 1 mm of rainfall effectively cleared the dust from the PV panels, allowing them to function optimally under standard operating conditions [10].	 Fig 1. Natural [9]

Sub-methods are brushing, washing, and blowing. A continuous water supply is provided with compressed air or water for better PV cleaning. It is high cost as it requires expert labor that will not cause scratches on the panel surface. A solitary natural rainfall event proved adequate to cleanse the panel to a degree that restored power output to within 1% of the manually cleaned panel [11].	 Fig 2. Manual
Mechanical, super hydrophobic aircraft, standing wave electric curtain, ultrasonic vibration, and super water jet are the sub-methods. Devices such as robots or engines are controlled through sensor systems, but they do require power and maintenance for their mechanical components. The robotic system successfully mitigated the impact of dust on the PV panel, resulting in increased power output compared to the weekly-cleaned controls [12].	 Fig 3. Automatic [12]
Sub-methods are superhydrophilic coating, superhydrophobic coating, and electrical dynamic screens. To enhance PV panel performance, research and development in nanotechnologies are crucial for creating both super hydrophilic and super hydrophobic thin films on the panel's glass surface. The super hydrophilic coating reduces dirt through a photocatalytic reaction, while the super hydrophobic coating causes water droplets to roll off, carrying away surface dirt. Additionally, an electrostatic method is employed to effectively remove dust, particularly lunar dust, by utilizing standing and traveling waves within the electric curtain [14].	 Fig 4. Preventive/Self Cleaning [13]

3. SETTING UP AND OPTIMIZATION OF NOVEL CLEANING SYSTEMS

The experiments were performed in the village of Balabanköy (41.0892 N ve 26,5482 E) of Uzunköprü/Edirne. The solar power plant is operated by Balabanköy Agricultural Development Cooperative and was established to meet the energy consumed in pumping water used for agricultural irrigation purposes. A photograph of the solar power plant is shown in Figure 5.

Fig 5. Solar power plant

The developed cleaning system consists of pump (1.5 hp, Einhell), water tank (1000 L) shown in Fig 6a, irrigation pipe (40m, Ø32) shown in Fig 6b, timer (Hunter Xcore) and filter (Hunter) shown in Fig 6c, sprinklers (7 pieces) shown in Fig 6d and wastewater collection line (40 m, 50x50) shown in Fig 6e. Preliminary experiment presented in Fig 6f. To optimize, the system will operate for one month. Each week various application times will apply such as 5 min (sunrise), 10 min (sunrise), 2x5 min (sunrise and sunset), and 2x10 min (sunrise and sunset) in a day.

a

b

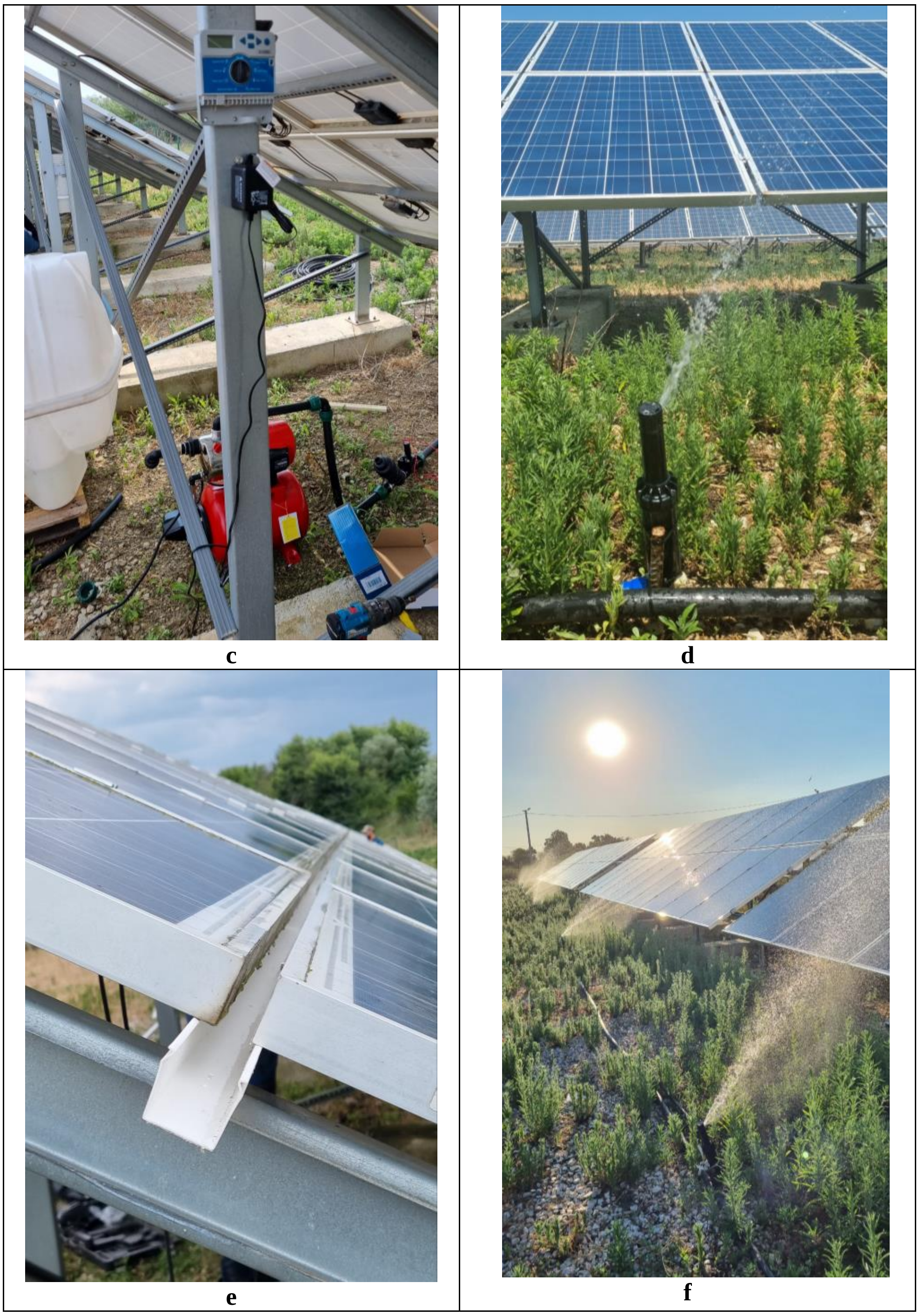


Fig 6. Components of the cleaning system and pre-trails.

4. CONCLUSION

While numerous methods have been explored to address soiling and various cleaning solutions have been studied, the literature indicates that selecting an appropriate cleaning mechanism should be contingent upon the specific environmental conditions of the installations. In this research, we developed an autonomous prototype cleaning system with a cost of $550. The installation cost can be significantly reduced by using parts such as irrigation pipes, sprinklers, and irrigation motors that farmers probably already have. Additionally, the novel cleaning system demands no costs for water with the help of rainwater harvesting and circular usage of water. The maintenance and operating cost (low electricity) can be considered negligible considering the promising benefits it offers.

Acknowledgment: *The paper is a part of the research done within the project FYL-2023-1474. The authors would like to thank the Bursa Uludag University Scientific Research Projects Coordination Unit.*

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FOOD PRODUCTION AND PROCESSING: REDUCING FOOD WASTE AND LOSS

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Abstract

With significant economic, social, and environmental implications, food waste and loss have become critical global challenges. This paper shows strategies to reduce food waste and loss in food production and processing stages to enhance food security and sustainability. Key factors contributing to food waste and loss are identified by a comprehensive review of relevant literature and theoretical background.

In the methodology, we have adopted a mixed-method approach, including case studies, surveys, and statistical data from food processing industries. Results reveal that food processing industries experience an average waste rate of approximately 15%, with variations from one sector to the other. Overproduction, inadequate inventory management, perishability, and packaging issues contribute to consequent wastage.

The discussion section highlights the importance of stakeholder engagement, technology adoption, and consumer awareness campaigns in combating food waste, and Policy implications include standardized waste management guidelines, investment in waste handling infrastructure, and incentives for technology adoption. Collaboration among governments, industries, and civil society is crucial for effective policy implementation.

By embracing emerging technologies such as data analytics, Internet of Things (IoT), and artificial intelligence (AI), the food industry can optimize inventory, supply chain logistics, and transportation, leading to waste reduction. What's more, consumer awareness campaigns can promote responsible consumption habits.

So, concerted efforts from all stakeholders are essential to mitigate food waste and loss effectively. By adopting sustainable practices and implementing suitable policies, the global community can create a more efficient and flexible food system, reducing environmental impact and promoting food security.

Keywords: *Food waste, Food production, Food processing, Food loss, Sustainability*

1 INTRODUCTION

Food waste and loss present critical challenges in the global food system, with significant economic, social, and environmental implications. As the world's population continues to grow and climate change applies increasing pressure on agricultural resources, solving food wastage becomes an urgent priority. When there is inefficient practices during food production and processing not only food security is jeopardized, but it also contribute to greenhouse gas emissions and wasteful depletion of natural resources.

Food waste encloses the discarding of edible food at different stages of the food supply chain, including production, distribution, processing, and consumption. It arises from factors such as overproduction, cosmetic imperfections, mishandling, spoilage, and consumer behavior. food loss, is the reduction in the quantity or quality of food during production and post-harvest activities, often caused by inadequate storage, transportation, and infrastructure, particularly in developing countries. This global issue results in the wastage of approximately one-third of all food produced annually, equivalent to around 1.3 billion tons, valued at nearly USD 1 trillion. Beyond the economic impact, food wastage exerts immense pressure on essential natural resources, such as water, land, and energy, and contributes to environmental problems like greenhouse gas emissions and deforestation.

A key step toward achieving sustainable development goals is actually minimizing food waste and loss. When wastage is reduced throughout the food supply chain, we can bolster food security, alleviate hunger, and maximize resource utilization. More to that, reducing food waste significantly aids in mitigating climate change, as the decomposition of wasted food in landfills produces methane, a potent greenhouse gas. This study explores innovative strategies and technological interventions to effectively tackle food waste and loss in food production and processing stages. By identifying some key contributing factors and evaluating the existing initiatives, this research aims to offer valuable insights to policymakers, industries, and stakeholders, facilitating the implementation of measures that promote a more sustainable and resilient food system. Through collective efforts, we can envision a future where food waste is minimized, and available resources are responsibly tackled to meet the global food demand.

2. LITERATURE REVIEW / THEORETICAL BACKGROUND

2.1 Definition of Food Waste and Loss

It is essential to establish a clear understanding of these concepts before examining the strategies to reduce food waste and loss. Food waste refers to the edible, or fit to be eaten portion of food thrown away at any point in the food supply chain, including production, post-harvest handling, processing, distribution, and consumption. It also encloses food that is fit for human consumption but is not consumed, often due to decay, overproduction, or expiration.

Food loss, on the other hand, happens during the early stages of the food supply chain, such as harvesting, storage, and transportation. It's the reduction in the quantity or quality of food that results from inefficiencies or deficient infrastructure, rendering the food unsuitable for human consumption. Food loss is particularly prevailing in developing countries, because of inadequate storage facilities and transportation methods.

2.2 Causes and Impacts of Food Waste and Loss

The literature review reveals various causes of food waste and loss, ranging from structural factors to individual behaviors. Ineffective agricultural practices, lack of proper storage and transportation infrastructure. More to that, supply chain complexities and communication gaps among stakeholders also lead to increased wastage.

The impacts of food waste and loss extend beyond economic losses and food shortage. Environmentally, food waste generates substantial greenhouse gas emissions due to decay in landfills. More to that, the nonessential use of resources, such as water, energy, and land, for producing wasted food further aggravates environmental degradation. Socially, food waste keeps alive global food insecurity, with millions of people suffering from hunger while substantial amounts of food are discarded.

The theoretical structure of this study is grounded in sustainability and circular economy principles. Stressing the need to optimize resource use, sustainability aims to minimize waste, promote efficiency, and preserve ecological balance. The circular economy paradigm adopts a holistic approach, stressing the reduction, reuse, and recycling of resources to create a circular process system.

Drawing from this theoretical basis, this research explores various strategies and interventions that align with viable practices to reduce food waste and loss. By identifying the challenges and opportunities within the food supply chains, the research objectives is to create awareness by promoting a more sustainable and flexible food system, at length contributing to a worldwide food security and environmental conservation.

3. METHODOLOGY

In order to investigate and propose effective strategies for reducing food waste and loss in food production and processing, a mixed-method approach was adopted, both quantitative and qualitative research methods. This section outlines the research design, data collection methods, and data analysis techniques employed in the study.

3.1 Research Design

The research design included a multi-phase approach, involving data collection and analysis from various sources. First of all, a comprehensive literature review was conducted to gather existing knowledge, insights, and best practices related to food waste and loss reduction in the food production and processing stages. It served as the foundation for identifying research gaps and guiding subsequent data collection.

Secondly, primary data was gathered through case studies and surveys conducted across diverse food processing industries. The selection of case study companies considered their size, location, and specialization to ensure representation of different segments within the food industry. Lastly, surveys were given to food processing companies, farmers, and stakeholders involved in various stages of the food supply chain.

3.2 Data Collection Methods

Case studies involved in-depth interviews with key personnel, including production managers, quality control officers, and supply chain managers, to comprehend the specific challenges and opportunities related to food waste and loss reduction. These interviews were covered by structured questionnaires to ensure consistency and comparison across different cases. The surveys had as goal, to capture quantitative data on the volume and types of food waste generated, the factors contributing to waste, and the existing waste reduction practices. The surveys were distributed electronically, and participants were assured of anonymity to encourage honest and accurate responses.

3.3 Data Analysis

We recorded, organized, and analyzed qualitative data from the interviews using thematic analysis. Common themes and patterns related to food waste and loss were identified to inform the development of strategies and recommendations. The case study findings were separated with the insights from the literature review to enhance the validity and reliability of the results.

We employed appropriate tools such as regression analysis and descriptive statistics to run quantitative survey data to statistical analysis. The quantitative discovery provided valuable insights into the extent of food waste and loss, as well as the factors influencing these losses within the food processing sector.

The combination of qualitative and quantitative data allowed for a comprehensive and deep understanding of the challenges and opportunities associated with food waste and loss reduction in food production and processing. The findings from this methodological approach serve as a basis for drawing up effective strategies and policies to address this critical issue and contribute to a more viable and efficient food system.

4. RESULTS

The analysis of data obtained from the mixed-method approach discloses critical insights to an extent and causes of food waste and loss in food production and processing. The results (Table 1) presented in this section give a comprehensive overview of the findings from both the qualitative case studies and the quantitative surveys.

The quantitative analysis of survey data indicates that food waste and loss occur at various stages of food production and processing. The data reveals that, on average, food processing industries experience approximately a waste rate of 15% of the total food processed. More to that, a significant portion of this waste is attributed to factors such as overproduction, insufficient inventory management, and product defects during processing.

The survey data also focuses on variations in waste generation across different food processing sectors. For example, the fruit and vegetable processing industry showed a higher percentage of waste due to perishability and handling challenges, while the cereal and grain processing sector reported substantial waste during packaging and transportation stages.

The in-depth case studies provided valuable qualitative insights into the root causes of food waste and loss within specific food processing companies. The analysis identified common themes and challenges, including the lack of systemized waste management practices, insufficient infrastructure for waste handling, and limited technological adoption for real-time monitoring and decision-making.

Moreover, the case studies as seen in table 1, revealed successful waste reduction strategies implemented by some companies, including process optimization, employee training, and collaborative partnerships with farmers and suppliers. These successful initiatives offer potential models for other food processing industries to emulate in their efforts to reduce food waste, this can be clearly seen in table 2.

Table 1: Quantitative Analysis of Food Waste in Food Processing Industries: The percentages represent the average waste rate reported by companies in each sector.

Food Processing Sector	Percentage of Waste	Major Causes of Waste
Fruit and Vegetable	18%	Perishability, Handling Challenges
Cereal and Grain	12%	Packaging, Transportation
Dairy	14%	Expiration, Inadequate Inventory Management
Meat and Poultry	16%	Processing Defects, Overproduction
Seafood	20%	Quality Control, Storage

This table shows the summary of the common themes identified from the qualitative analysis of case studies conducted in different food processing companies. The challenges reflect the major factors contributing to food waste and loss, while the successful strategies represent practices adopted by certain companies to effectively reduce waste.

Table 2: Common Themes in Food Waste and Loss - Case Study Analysis

Themes	Challenges	Successful Strategies
Lack of Standardized Waste Management	Inconsistent waste handling practices	Implementation of waste reduction protocols
Inadequate Infrastructure for Waste Handling	Insufficient waste storage and disposal facilities	Investment in advanced waste management technologies
Limited Technological Adoption	Absence of real-time monitoring systems	Integration of IoT and data analytics for waste reduction
Inefficient Inventory Management	Overstocking and stock outs	Optimization of inventory management processes

The analysis of both quantitative and qualitative data enlightens on the potential of latest technologies in minimizing food waste and loss. Implementing Internet of Things (IoT) devices and sensors in production facilities allowed for real-time monitoring of inventory and perishable goods, enabling more efficient management and reduced waste.

Data analytics and (AI) applications were also found to be instrumental in predicting demand patterns, maximizing production schedules, and improving supply chain logistics, ultimately bringing more effective waste reduction strategies.

Overall, the results from this study provide crucial insights into the current state of food waste and loss in food production and processing. The combination of quantitative and qualitative data increases the understanding of the complex challenges and opportunities for waste reduction in the food industry. These findings serve as a basis for formulating practicable strategies and policies to alleviate food waste and loss, promote sustainability, and contribute to a more resilient global food system.

5. DISCUSSION / POLICY IMPLICATIONS

This section examines the key insights obtained from the results and their implications for addressing food waste and loss in the food production and processing stages. It also explores potential policy measures and strategies that can be adopted to further waste reduction and create a more sustainable food system.

Based on the results from both the quantitative and qualitative analyses, several policy recommendations can be proposed to tackle food waste and loss in the food industry. These include:

a. Standardized Waste Management Guidelines

Governments and relevant authorities should develop and execute standardized waste management guidelines for the food processing sector. Such guidelines should focus on waste separation, composting, and recycling practices to reduce the environmental impact of food waste.

b. Investment in Infrastructure
Encouraging investment in waste handling infrastructure, including modern storage facilities and transportation systems, can help reduce food loss during transportation and distribution.

c. Technology Adoption Incentives
Governments can provide incentives or assistance to encourage food processing companies to adopt innovative technologies such as IoT devices, data analytics, and AI applications for better inventory management and waste reduction.

The discussion emphasizes the importance of collaboration and engagement among stakeholders to combat food waste and loss effectively. Governments, food processing companies, farmers, retailers, and consumers all play crucial roles in the food supply chain. Aligning their efforts, sharing best practices, and raising awareness can create a collective impact in reducing waste.

The study highlights the potential of emerging technologies in curbing food waste. So, fostering partnerships between technology providers and food processing industries can accelerate the adoption of these innovations. Table 3 highlights some of the technological solutions that can be employed to reduce food waste in the food processing industry. Each technology has a specific role in waste reduction and can collectively contribute to creating a more efficient and viable food supply chain.
It provides a concise summary of key technologies and their potential impact, making it easy for readers to understand the significance of technology in waste reduction efforts.

Table 3: Technology Solutions for Food Waste Reduction

Technology	**Description**	**Potential Impact**
Internet of Things (IoT)	Sensors and devices to monitor inventory in real-time	Minimizes overproduction and stockouts
Data Analytics	Utilizes data to predict demand patterns and optimize production schedules	Reduces excess inventory and waste during production
Artificial Intelligence (AI)	Enables smart decision-making for supply chain logistics	Improves transportation efficiency and minimizes spoilage
Block chain	Ensures traceability and transparency in the supply chain	Prevents food loss due to mismanagement and fraud
Smart Packaging	RFID and QR codes on packaging to track expiration dates	Extends shelf life and reduces premature discarding

Consumer behavior also have a major impact on food waste and loss. To address this issue, it's crucial to initiate public awareness campaigns to educate consumers about the impacts of food waste and put emphasis on responsible consumption practices, such as proper meal planning, correct storage, and utilizing food leftovers creatively.

Effective policy implementation demands strong collaboration between governments, private sectors, and civil society organizations. Policymakers should collaborate with stakeholders and seek their contributions during the formulation and implementation of waste reduction policies to ensure practicality and feasibility.

Providing economic supports for companies that successfully reduce food waste can be a powerful motivator. Tax benefits, grants, or certifications for businesses with efficient waste reduction practices can encourage wider adoption of sustainable measures.
This comprehensive discussion and policy recommendations provide actionable insights for policymakers, industries, and stakeholders to address food waste and loss effectively. By practicing these strategies and collaborating at different levels, the global community can collectively work towards achieving a more viable and resilient food system.

6. CONCLUSION:

In conclusion, addressing food waste and loss in food production and processing is vitally important for achieving a sustainable and flexible food system. This study has provided valuable insights into the extent and causes of food waste and loss in the food industry, as well as prospective strategies and policy implications for waste reduction.

The quantitative analysis revealed the significant percentage of food waste generated during food processing, with variations across different sectors. Meanwhile, the qualitative case studies shed light on the existing challenges faced by food processing companies and the successful strategies they employed to minimize waste.
The study highlights the importance of adopting a comprehensive approach that involves all stakeholders in the food supply chain. Governments, food processing industries, retailers, farmers, and consumers must collaborate to effectively implement waste reduction practices. Technology comes as a critical enabler in this endeavor, with IoT, data analytics, and AI promising interesting solutions for optimizing inventory, transportation, and supply chain logistics.
Policy recommendations stress the need for standardized waste management guidelines, investment in waste handling infrastructure, and motivations for technology adoption. Additionally, raising the awareness of consumers and promoting responsible consumption can contribute to a greater scale to waste reduction efforts.
By integrating these findings and policy implications, the global community can work towards a more sustainable and efficient food system. Alleviating food waste and loss not only enhances food security and resource utilization but also lessens greenhouse gas emissions and environmental degradation.
In conclusion, concrete efforts from all stakeholders are vital in achieving a more sustainable and waste-free future. By embracing innovative technologies, implementing vigorous policies, and encouraging, and promoting collaboration, we can collectively reduce food waste and loss and create a stronger food supply chain for generations to come.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

IMPLEMENTATION OF GIS TECHNOLOGIES FOR PLANNING THE VALORISATION OF AGRICULTURAL WASTE: THE TANGO-*CIRCULAR* PROJECT

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Abstract. *The volume of waste produced by agricultural activities is constantly rising, due to the continuous increase of crop and livestock production, aimed to cover the nutritional needs of the accreting population of the Planet. According to recent estimations, the total amount of waste produced in the whole EU by the agricultural sector during the period 2010-2016, has been around 18.4 billion tons, which represents an average of 2.6 billion tons/year. This number is slightly exceeding the amount of waste from all other sectors combined. This enormous mass of waste has a significant environmental impact, which needs suitable solutions to reduce the carbon footprint of agriculture, while increasing the economic income for farmers.*

A promising way to reduce agricultural waste, passes through the valorization of agricultural co-products, by-products and residues, as well as other non-organic materials - such as plastics, widely used in crop cultivation and animal production - after the end of their working life. In order to involve farmers to play an active role on this issue, contributing to transform what they currently consider as a "waste" into a new "resource", under the perspective of a circular economy and for a more sustainable agriculture, the Project TANGO-Circular has been financed by the EU Erasmus+ Programme. Aim of this Project is to train farmers and other agricultural *stakeholders to be involved in finding viable solutions to exploit unusable remains of crops or animal farms, so as to enhance their financial input, while simultaneously contribute to reducing the environmental impact of their agro-livestock activities.*

With the aim to plan the valorization of agricultural waste, under the TANGO-Circular Project, a Geographical Information System (GIS) has been implemented through an open-access software (Q-GIS). This GIS has been structured into a first part dedicated to the quantification of agricultural waste flows – both organic, coming from agro-industrial activities, and not-organic, such as plastics - and a second part, focused on the spatial distribution of these flows in the study area of the project partners. Through GIS, the areas with high density of agricultural waste have been pointed out, and the suitable location of potential collection centres has been proposed. The maps that have been produced, as well as the GIS database, are always updatable tools, useful also for monitoring and optimizing the sorting and collection of agricultural waste from the farms, their suitable treatments and transport to the collection centers or recycling stations.

The implemented GIS methodology has revealed very useful to support farmers and their associations, as well as all public bodies interested to govern the agricultural waste flows, to individuate possible solutions designed for the valorization of these flows, in the perspective of a circular economy. The sustainability and economic, territorial, environmental and social convenience of each form of valorization designed have been investigated, and criticalities associated with each phase of the process and consequent implementation of appropriate solutions to each problem have been addressed. Finally, further possible solutions, aimed at an increasingly better valorization of these flows, have been proposed as well.

Key words: *Sustainable agriculture, Circular economy, Agricultural waste, Farmers training, GIS technologies.*

1. INTRODUCTION

Renewable energy is a priority in the European society, due to reasons of energy security and climate mitigation. Member states are adapting to the EU Directive 2009/28/EC (Renewable Energy Directive) on the promotion of the use of energy from renewable sources, which defines, within the year 2020, the use of 20% of renewable energy. Renewable energy sources are, however, characterized by a high temporal and spatial variability, so they need to be carefully planned in order to safeguard a suitable supply in the energy system. Biomass plays, among different sources of renewable energy, a central role, since it can store energy feedstock for the required use, compared to other renewable energy sources. Considering different types of biomass residues and by-products, there are several processes that allow transforming biomass into high-energy fuels that are easily transportable. In recent years, the attention has been focused on biomass coming from agricultural co-products, by-products and wastes. Even if this kind of biomass has a limited energy potential, in the framework of a circular economy, its valorization can contribute to an energy-efficient conservation, to the economic and environmental sustainability of agricultural practices and to enhance the preservation of natural resources as well [1, 2]. Mostly in the case of Mediterranean countries, biomass production for energy currently looks primarily to its collection and disposal. Especially the incorporation in the energy system of by-products, co-products and waste from agriculture, forestry and agro-industry, should be carefully evaluated at regional level, so as to avoid unsustainable removal of organic matter from the soil and negative effects on natural ecosystems. Waste biomasses are often diffuse sources of energy, spread over large geographic areas, so they need to be collected and transported to a closer conversion plant. Biomass mapping, as a tool for measuring the amount of waste and by-products, helps to conceive the development of an economically sustainable reuse and recycling supply chain.

Geographical Information System (GIS) technologies are currently employed to optimize the flux of materials and goods. In case of waste management and final disposal localization, they have been proposed in different applications. GIS models have been even proposed to determine the minimum cost/distance efficient collection paths for transporting solid wastes to the final disposal option [3]. The applied models can be used as a decision support tool by municipal authorities, to organize an efficient management of the daily operations for transporting solid wastes and by-products.

The present paper is aimed at mapping agro-industrial waste, biomass and agricultural plastics, aspiring to offer a reference database for policy makers and investors, who need to evaluate a possible use of local biomass for bioenergy purposes, or to be processed in biorefineries. In this way, virtuous supply chains would ultimately start, in the full spirit of implementing the concept of circular economy, with integration between waste management and industrial policies. The relevant results here presented have been obtained in the framework of the Project "*Training A New Generation Of farmers and agricultural entrepreneurs to implement the concept of Circular economy in agriculture* – TANGO-*Circular*", financed by the Erasmus+ Programme [4], A part of this Project is indeed focused on the planning the valorization of agricultural waste through the implementation of GIS technologies. A specifically targeted research has been carried out, in order to define a GIS methodology for mapping the agricultural wastes, since they require, at the end of their lifetime, a suitable management system for the collection, treatment and valorization. The produced maps and the GIS database will be always updatable tools, useful for monitoring and optimizing the collection of agricultural waste from the farms and their transport to collection centers/ recycling stations.

2. MATERIALS AND METHODS

The annual local availability of waste of agro-industrial origin have been estimated in all Countries participating into the TANGO-*Circular* Project, *i.e.*: France, Greece, Italy, Portugal and Spain. According to an appropriate planning hierarchy, agricultural and agro-food co-products, by-products and wastes should be primarily employed to re-balance soil fertility, then valorized as new secondary raw materials used in the same agricultural sector or in different industrial chains (*e.g.*, cosmetics, nutraceuticals, *etc*.). Only at the end of this process, they could be finally conveyed to energy production through co-generation. Estimating the quantities that can be obtained annually is not simple and often subject to great uncertainty. The methodology that has been here applied refers to survey criteria already extensively and suitably expanded and updated by different authors. Among the many variables that affect the actual annual amount of agricultural residual biomass available, there are climatic factors, agricultural crop productivity, the amount of residues actually produced, the amount that can actually be used and the amount already used for other purposes.

The applied methodology estimates the theoretical potential, which represents the maximum amount of biomass potentially available in an area. From the exploitation of agro-food products, the following different types of biomass may be derived:

- Residual biomass from forestry waste;
- Traditional food crops, cereal straw (*e.g.*: wheat, rice, barley, oats) and pruning of fruit tree (*e.g.*: grapes, olives, apple, peach);
- Livestock (*e.g.*: cattle, pigs, sheep and goats) manure;
- Remaining processes of transformation from the agro-food industries (*e.g.*: olive mills, wineries, cheese factories, wheat mills);
- Organic fraction of urban waste

as well as not-organic materials, like:

- Agricultural plastic waste.

At the level of spatial definition, the data used to calculate the quantities of by-products have been estimated at NUTS3 level.

The data obtained were thus collected and collated into a database referred to geographical space (geo-database). This particular database has been then appropriately processed and manipulated with specialized a GIS (Geographic Information System) software. The result of this processing made it possible to graphically assess the geographic distribution of agricultural residual biomass and develop thematic maps.

The analyses performed allowed the calculation of the potential availability of the different types of biomass of interest.

2.1 Forest residues

Biomass residues from forestry are currently restricted to tree parts, which are traditionally or, due to technical and environmental restrictions, not completely harvested (crown material such as twigs and branches, stumps and roots). Moreover, a variable amount of branch material is also produced. For ease of calculation, average values were considered for estimating the amount of residual forest biomass resulting from plant management operations of "European Forest Type". The estimation of the potential biomass arising from managing operations of forested areas has been estimated (in m^3 ha^{-1} $year^{-1}$) based on data and information arising from the Land Use Categories (Code 3: Forest and Seminatural Area – 3.1 Forest) or considering the forest area (expressed in ha). The estimation of the potential biomass arising from managing operations of forested areas has been estimated based on data (expressed in hectares) of forest areas in different countries reported in National Statistic Institutes. Where these data were not present, they were obtained from spatial analysis conducted in GIS, to extrapolate the necessary data. Regarding the level of detail, in some Countries it was not possible to consider NUTS3, so data elaboration was conducted at NUTS2 level. Then, the land surfaces were multiplied by the annual increase in biomass (0.5 cubic meter) that is an average value [5]. Finally, the results were expressed in tons of forest residues.

2.2 Cereal straw and pruning of tree

Many agricultural crops that are currently cultivated produce an important source of biomass as by-product, the *straw*. After harvesting the crop, a large quantity of straw, estimated to have a larger volume than the crop itself, is available in the form of waste. Considering the amount of the total cereal residues harvested has to be left on the field as organic fertilizer and the losses of straw during the harvesting process, the gross calculated quantity of by-products can be roughly reduced by up to 50% [5, 6].

To understand the spatial variability of different crops, the data derived from the agricultural census in each country or data arising from Corine Land Cover (Code 2: *Agricultural Area* – 2.1 *Arable land*) have been used to calculate the spatial availability of straw in the different Countries.

Table 1: Overview of residue yield estimation for all crops

CROP	RESIDUE YIELD (t/ha)
Wheat	3.627
Barley	4.216
Rye	5.625
Oats	3.76
Maize	7.84
Other cereals	3.6

From pruning operation in Mediterranean fruit plantations, it is possible to obtain large quantities of ligneous biomass. Currently, these residues are destroyed by crushing them into the soil or by in-field burning (a practice forbidden by law in many countries). But, such residues, also having other potential industrial uses, can be used as a source of energy, if they are properly collected and valorized for energy purposes. To be used as energy source, they need a transformation by physical or chemical processes into liquid, solid or gaseous biofuels [7-9]. However, at the moment, there are some technical problems during harvesting, that do not allow using such residues as biomass for energy purposes. In case of tree crops, an average of 2.20 t/ha of dry biomass has been estimated, while a specific analysis has been conducted for olive grove (2.16 t/ha) and vineyards (2.15 t/ha), which are the most diffused tree production in the study area (Mediterranean Europe). Also in this case, the data derived from the agricultural census in each country or data arising from Corine Land Cover (Code 2: *Agricultural Area* – 2.2 *Permanent crops* – 2.2.1 *Vineyards*; 2.2.2 *Fruits tree and berry plantations*; 2.2.3 *Olive groves*) have been used to calculate the spatial availability of straw in different Country

2.3 Livestock manure

Using manure for energy production after an anaerobic digestion process, it is possible to avoid negative environmental effects. Converting manure to energy at the farm scale (or small cooperatives) allows to avoid transport of high-moisture content feedstock. In the different study area, considering the currently existing livestock units and the total amount of livestock manure, and assuming as the typical manure production rate per animal per year (Table 2) the values reported in [10], the total manure production has been estimated into tons of dry matter per year.

Table 2: Estimates of dry matter from manure

LIVESTOCK (UNITS)	MANURE PRODUCTION RATE (t d.m./head)	RECOVERABLE (%)
Cattle	1.69	25
Pigs	0.21	85
Sheep & Goats	0.28	10
Poultry	0.01	85

2.4 Remaining processes of transformation from the agro-food industries (*e.g.*, olive mills, wineries, cheese factories, wheat mills)

Concerning the agro-food industry, significant quantities of biomass residues would contribute to the calculation of the energy potential or can be reused in other sectors, mainly as exhausted pomace arising from the olive oil industry and exhausted marc from the alcoholic grapevine/wine industry. The main by-products of the olive oil mill consist in vegetation water and pomace. Exhausted olive pomace is the waste generated from the drying and subsequent extraction of residual oil from the olive pomace. The reuse of vinification residues could anyway find a second life in different areas, *e.g.*: as a substrate for the growth of plants (pomace); these materials, after having contributed to the restoration of the level of organic matter in the soil, could be effectively exploited in different ways, *e.g.*, as added-value components in other industrial sectors (nutraceutical, cosmetic, *etc.*), or in the building sector - as a natural additive - that could be incorporated into clay bricks to increase their mechanical and thermal performance [11].

Assuming an average quantity of by-product (40%), the annual amount of virgin pomace has been calculated, 55% of this quantity being of exhausted pomace, which is reusable. Similarly, the amount of exhausted marc to be reused has been determined considering the annual production of grapes, and the percentage of the total amount of exhausted marc considered in this case is 4.6% of the production of wine grapes.

2.5 Organic fraction of urban waste.

The organic fraction of municipal solid waste (OFMSW), or bio-waste, is composed mainly of food rejects (animal or green waste), depending on the region and custom considered. Considering the population in the different study area and the amount of organic waste per inhabitant equal to 121 kg/year [12], the total amount of municipal organic waste has been calculated at spatial level. Data were expressed in tons.

2.6 Agricultural plastic waste

The use of plastics is an integral part of many agricultural production processes. The applications of plastic material are extremely extensive and beneficial to agricultural production, which is why their use is constantly expanding. For agricultural plastic waste, there is still no integrated management system, and only a fraction of agricultural plastic waste is recycled throughout Europe. There is therefore a lot of agricultural plastic waste ending up in landfills, uncontrolled or not, and scattered in the fields, or incinerated in an uncontrolled way. It is therefore necessary to establish an Integrated Management System, in which the managed quantities of Agricultural Plastic Waste (APW) will be monitored and certified [13]. For each study area, data about the quantities of agricultural plastic waste have been considered for the estimation of quantities at spatial level or, starting from data about the greenhouse cultivation or intensive crop, the quantities of plastic waste have been estimated [14-15].

In Italy data were calculated considering coefficient and crop surface [13]; in the other countries, where data on the amount of plastic used in agriculture was not reported, the value was estimated from data reported in Portugal (Table 3), assuming similar growing conditions in the Mediterranean basin. All data were expressed in tons.

Table 3: Use of plastic material in crop production

Crop	Plastic used (Kg/ha)***
Crops for industry	14,86
Horticutural crops	20,04
Tomato	7,67
Forage	111,16
Pomegranate	0,91
Blueberries	0,02
Citrus Fruit	3,59
Almond	297,12
Nut	7,07
Vineyard	18,30
Grape	773,58
Olive grove*	1272,36

All spatial tasks have been performed using an open-source software (Q-GIS v.3.10), able to calculate the spatial distribution of the agricultural by-products considered. Through the use of GIS data in the form of vector, the information has been integrated to calculate values for the whole spatial area with a geographic reference.

3. RESULTS

The use of GIS for data analysis and processing has the great advantage for visualizing the result in a quick and timely manner, considering the peculiar feature of the GIS systems, that is, the geo-referencing of data. Therefore, by visualizing the maps produced (Fig. 1-6), for different countries and for different types of by-products, it is so possible to have a clear picture of the availability of waste produced in the each study area, presented at NUTS3 level. Only when this level of detail was not available, they have been reported at the regional level (NUTS 2).

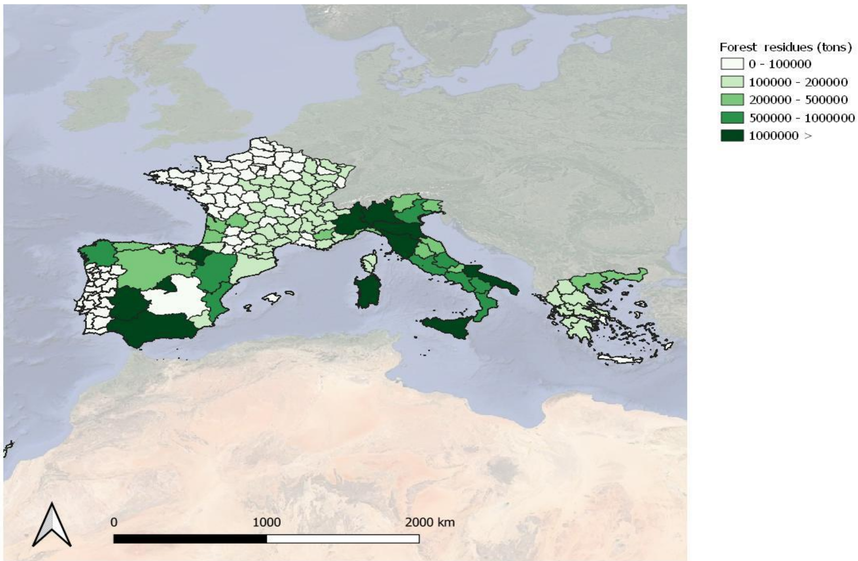

Figure 1: estimation of forest residues in Project Countries

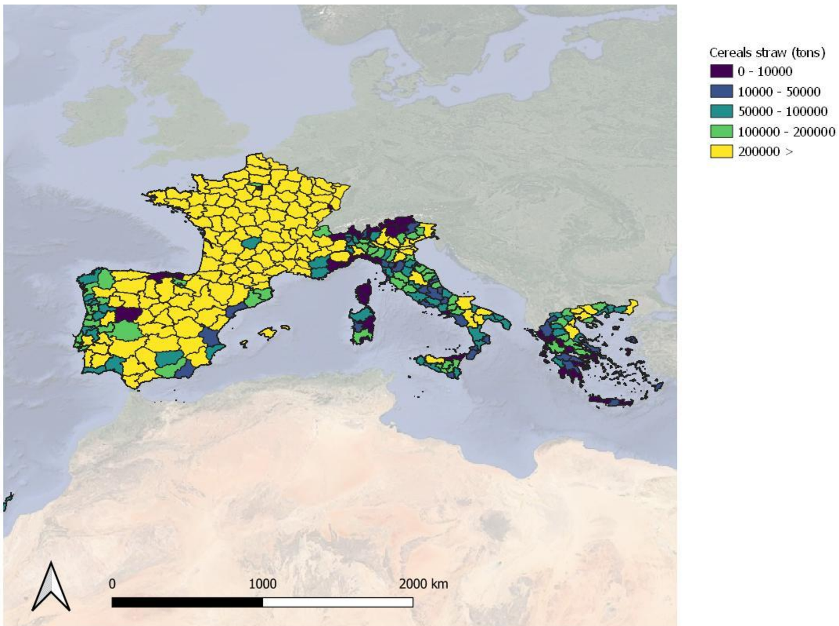

Figure 2: estimation of cereal straw in Project Countries

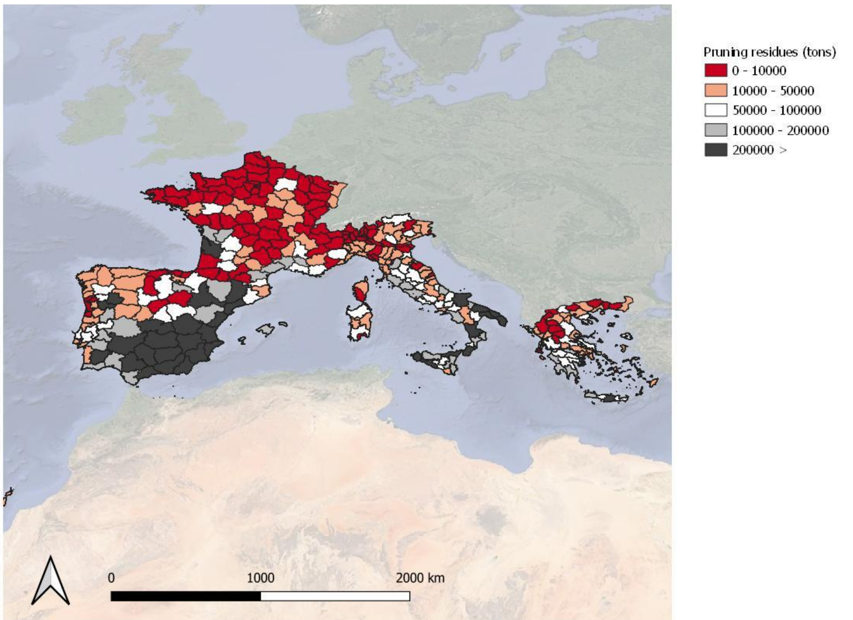

Figure 3: estimation of pruning residues in Project Countries

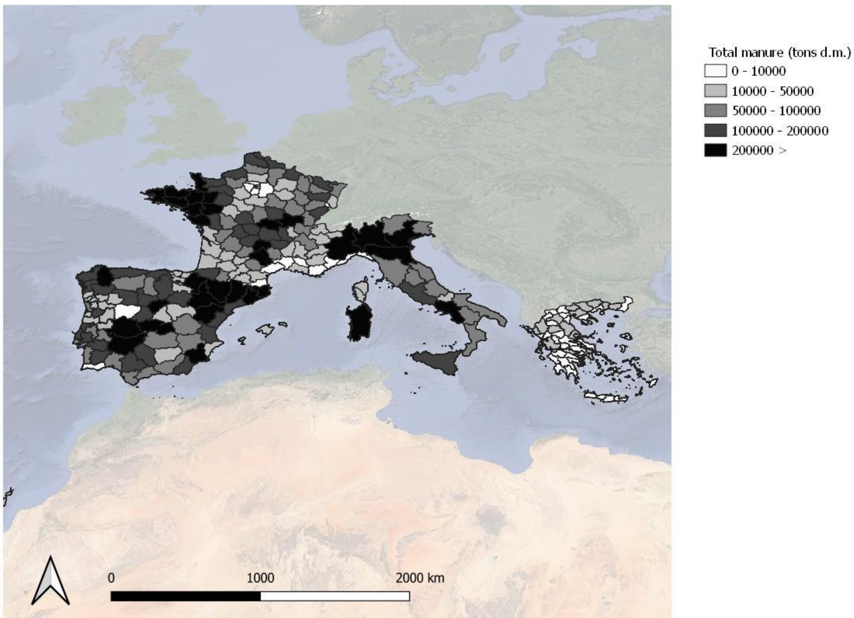

Figure 4: estimation of total manure in Project Countries

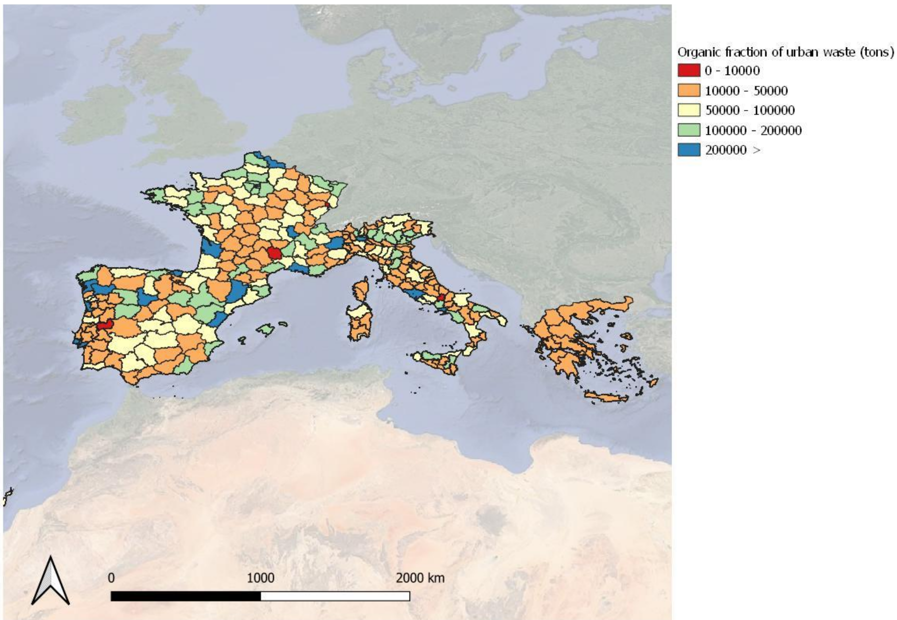

Figure 5: estimation of the organic fraction of urban waste in Project Countries

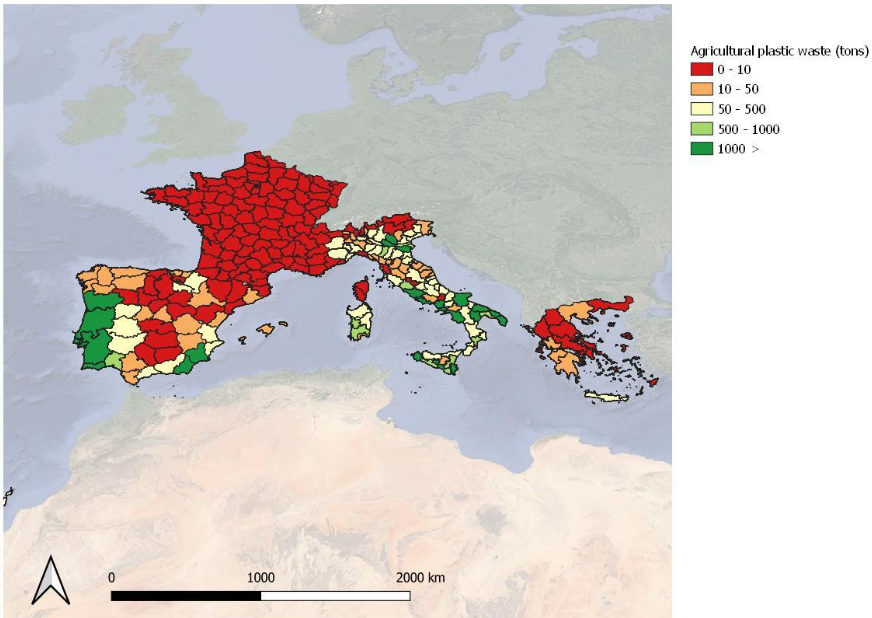

Figure 6: estimation of agricultural plastic waste in Project Countries

4. DISCUSSION AND CONCLUSIONS

From the GIS implemented at a European scale to analyze the agricultural waste production as well as collection and disposal of agricultural by-products in the Countries participating into the Project, it is possible to examine the data introduced in the database, relating to the area in consideration, by querying the system.

The proposed GIS methodology may be improved including an analysis of the road network, in order to optimize the localization of the recycling centres, the optimal distances from them to the principal areas subject to intensive use of agricultural waste and the useful time and the average speed to cover these distances. Also, data regarding the distribution along different seasons of the year could be introduced in this GIS, in order to best fit the material flow towards the recycling centres.

So, this implemented GIS tool enables to localize the main agricultural areas characterized by intensive production with biomass/plastic material; to analyse the specific type of biomass/plastic material in each zone; to study the stream of agricultural waste from the farms to collection areas, in order to optimize the flow of material in the framework of a Circular Economy approach. To achieve this objective, the collaboration of various players is fundamental: from legislators to producers, from environmental protection agencies to the infrastructures for the management of materials, from the personnel responsible for collection and disposal to the citizen and, mostly, from farmers, whose pro-active involvement in sorting, collecting and managing agricultural waste is crucial to reduce the environmental footprint of agriculture, so contributing to implement an eco-sustainable living model.

Acknowledgement: *The paper is a part of the research done within the TANGO-Circular Project, co-funded by the Erasmus+ Program of the European Union (Project: 101055970 — TANGO-Circular — ERASMUS-EDU-2021-PI-ALL-INNO).*

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USING SURPLUS FRUIT AND VEGETABLES TO PRODUCE A JUICE - A VIRTUOUS EXAMPLE OF FOOD WASTE RECOVERY IN THE PROJECT S.K.I.P.E.

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Abstract (bold). *Worldwide, 1.3 billion tons of food are currently wasted and this represents a major problem for the planet, as it produces negative impacts from a social, economic and environmental point of view. We can distinguish two types of issues: food losses and food waste. Food losses are determined upstream of the agri-food chain, especially in the sowing, harvesting, storage and, generally, in the first stage of the agrifood chain. Food waste are the losses that occur in the second stage of the supply chain, related to the industrial transformation, distribution and final consumption. The causes of this waste are to be found at all levels of the food supply chain, in particular, three macro areas have been identified where the most waste occurs: a) production stage, b) distribution stage, and c) consumption stage.*

The present work aims at carrying out experimental trials aimed at defining a line for processing surplus fruits and vegetables (edible food that cannot be sold for aesthetic or dimensional defects, and therefore destined to be wasted) into juices, in order to produce a more stable food with a longer shelf life, and to reduce the impact of food waste. The activity was developed using apples, fennel, rocket leaves and carrots. Fruit and vegetable products were, firstly, characterized for the following parameters: size, firmness (N), sugar content (°Brix), external and internal color according to the CIELab system, dry matter (%), juice content (%), pH, titratable acidity of juice (% citric acid). All products were used for the juice production and two different blends were chosen (based on some preliminary trials, not reported in this paper), packed in glass jars and pasteurized with different time/temperature combinations. Physical and chemical evaluation was carried out for the two blends, and the kinetic model of destruction was calculated for vitamin C. Results were used to design a processing line for the production of juice and for the cost estimation of the line.

Key words (bold): *Food chain, postharvest loss, thermal treatment, kinetic destruction model, processing line.*

INTRODUCTION

Two types of food waste are generally recognized: food losses and food waste:

• FOOD LOSSES: these are the losses that occur upstream of the agri-food chain, especially during the sowing, harvesting, storage and initial agricultural processing phases.

• FOOD WASTE: these are the losses that occur in industrial transformation, distribution and final consumption. Therefore, the losses that occur in the last link of the supply chain.

The agri-food industry produces enormous quantities of waste, which must be disposed of appropriately. In Italy, approximately 135 thousand tonnes of waste are produced every year from the processing of industrial tomatoes (peels, seeds), 1.5 million tonnes from wine grapes (peels, seeds, stems) and 2.2 million tonnes from rice. of tons of straw, 0.3 million tons of husk (the covering that encloses the grain) and 0.1 million tons of chaff (residue obtained from whitening rice). These wastes are the weak point of the agri-food supply chain and could largely be transformed from a company cost (for disposal) into a resource.

The FAO has estimated that approximately 1.3 billion tonnes per year of edible parts of food intended for human consumption are discarded and wasted worldwide (Gustavsson et al., 2011). Of all waste generated globally each year, more than 88 million tonnes are generated in the European Union (data for EU-28 countries in 2012) (Stenmarck et al., 2016), and it is estimated that this value will continue to grow up to 40% in the following years.

As regards plant products, in developing countries the greatest generation of FVW (fruit and vegetable waste) occurs during the harvesting and processing phases, while the consumption phase produces just 10% of the FVW (Gustavsson et al., 2011). Poor storage and processing facilities and lack of infrastructure are among the main causes of this situation. However, in industrialized countries, fruit and vegetable losses are greater during the harvesting and consumption phases of FSC than in the processing phase (Capone et al., 2014; Girotto et al., 2015) . In this case, the generation of FVW is closely related to the demanding food quality standards set by retailers and requested by consumers. For example, in the United States, approximately 45 million tons per year of fresh vegetables, fruits, milk and grain products are wasted. In India, annual FVW production reaches 5.6 million tonnes. The central distribution market of a city like Barcelona (Spain) is capable of generating around 90 tonnes of FVW per day (Kosseva, 2009).

Laufenberg et al. (2003) collected data on FVW generated by food processing industries. Some exceptional wastes are sugar beet pulp, apple pomace, tomatoes, grapes and olives, stone shells, potato pulp and peels and citrus and pineapple peels. Other recent studies have attempted to estimate the environmental, financial, and social impacts of FLW, including impacts on nutrition and job losses (Blakeney, 2019).

On the basis of the previous considerations, this paper intends to carry out an experimental analysis aimed at defining a line for the transformation of vegetable products into juices, with the aim of processing raw materials excluded from sale, for aesthetic or caliber reasons, and therefore destined to be wasted. The experimental thesis is based on the international cooperation project S.K.I.P.E. (Sharing Knowledge to Increase Postharvest Efficiency), and in particular on Work Package 3 - Optimization of the fruit and vegetable supply chain and reduction of waste.

MATERIALS AND METHODS

For evaluation of juice properties, the products were homogenized with a laboratory blender (Moulinex, Madrid, Spain), and the homogenate was used for subsequent tests. Soluble solid content (SSC) was measured with a digital refractometer (Atago, Japan). Titratable acidity (TA) was determined by titration with 0.1N NaOH to pH 7.8 (OIV-MA-AS313-01, 2009) and expressed as grams of citric acid per kg of product (7). pH and TA were determined for each homogenate in 5 g aliquots diluted in 50 mL deionized water. TA analysis was conducted with a T50 automatic titrator (Mettler Toledo).

The vitamin C content in juice sample was determined by titrating an unknown aliquot against the prepared iodine solution (Lugol solution). A 20 ml aliquot of the sample solution was taken in a pipette and transferred into a 250 ml conical flask. About 150 ml of water and 1 ml 0.5% starch indicator solution were added to the solution. The sample was titrated with 0.005 mol L^{-1} iodine solution taken in a 50 ml burette. The endpoint of the titration was identified as the first permanent trace of a dark blue-black colour due to the starch-iodine complex. Five replicates of the titration with further aliquots of sample solution were repeated.

Color was evaluated with a colorimeter (Minolta CR 400ChromaMeter, Minolta Corp., Japan). The color parameters, L* (brightness) corresponding to the black-white scale (where 0 is black and 100 is white), a* (red tendency), b* (yellow tendency), were recorded using the CIELAB colorimetric system.

A Sauter 250N dynamometer with a 6-mm tip was used for firmness, as reported by Delwar Hossain et al. (2020).

Statistical analysis

Data were analyzed using MatlabTM software (Matlab R2016a, The MathWorks Inc., Natick, MA, USA). Two-way analysis of variance (ANOVA) was performed to determine whether there were significant differences ($\alpha = 0.05$) between treatments. In particular, the effect of time and heat treatments was studied. Specifically, Tukey's post hoc was used, which involved graphing the results through box plots. The box plot is a statistical graph used to represent quantitative variables and is useful for figuring out whether the distribution is symmetric or skewed, comparing the shape of multiple distributions, and quickly and accurately identifying outliers and outliers.

Extraction

Juice extractors operate by a motor mechanism that pushes an auger. It presses the fruit or vegetable parts inserted into the mouth of the cold juice extractor and separates the juice from the waste parts. In order for this process to take place without altering the properties̀ nutrients contained in the vegetables, it needs to be done at a low RPM and at low temperatures. An IMETEC model “Succovivo” extractor was used for the extraction tests.

Based on preliminary tests (not shown in this paper), the following two blends were formulated, differing in the percentage of rocket, which can affect, due to its bitterness, the intensity of the flavor of the juices.

Table 1 composition of the two blands formulated with the identified products.

Raw fruits/vegetables	Blend1 (%)	Blend2 (%)
Carrots	35	35
Apple	24	26
Fennel	35	35
Rocket	6	3

Thermal treatment

After the production of juice extracts for the two blends, glass jars (300 ml volume) were filled and the thermal treatments were carried out, as described below.

- 60°C/30 minutes, also known as low pasteurization;
- 80°C/3 minutes;
- 90°C/1 minute.

Five jars were prepared per treatment. A sensor, manufactured by Pico Technology (Sesto San Giovanni -MI), equipped with thermocouples was used to monitor the temperature of the treatments. Therefore, an additional jar with a cap containing a thermocouple was added to monitor its internal temperature. A second thermocouple, on the other hand, was inserted into the water to get an account of the correct process temperature.

The heat treatment tests were carried out putting the jars in a 15L vat, heated by means of a hotplate.

The total phenol content of the juice samples was determined by the Folin-Ciocalteu reagent method, using gallic acid as the standard for the calibration curve. Folin-Ciocalteu was used as the oxidizing agent. Three replicates were performed for each sample.

Once the treatment was finished, the jars were cooled and subsequently subjected to the analytical assessment.

Kinetics of thermal destruction of vitamin C

Kinetic models are often used for rapid assessment of food quality. Kinetic modeling can also be used to predict the influence of various treatments on critical quality parameters.

Knowledge of degradation kinetics, including reaction order, rate constant, and activation energy, is very important for predicting the loss of food quality during storage and especially thermal treatments (Patras et al., 2010).

Reaction rate is defined as the change in the concentration of a substance as a function of time, according to the general relationship:

$$\pm \frac{dC}{dt} = kC^n$$

where C is the concentration of the substance, t is the time, k is the rate constant and n is the order of the reaction.

Vitamin C loss is a reaction that follows first-order kinetics. If n = 1, the relationship between C concentration and time t is logarithmic:

$$\frac{dC}{dt} = -kC$$

the negative sign indicates that it is a reduction, that is, the concentration C decreases as time t increases, separating the variables:

$$\frac{dC}{dt} = -kdt$$

integrating between 0 and t and C0 and C:

$$C = C_0 \exp(-kt)$$

Turning to logarithms:

$$lnC = lnC_0 - kt$$

Thus, the latter equation allows us to calculate the concentration of vitamin C that results from applying a certain temperature for a time t, the initial concentration C0 and the value of the rate constant k being known. More often the above equation is expressed with decimal logarithms:

$$log \frac{C}{C_0} = \frac{k}{2{,}303} t$$

and by posing:

$$\frac{2{,}303}{k} = D$$

$$log\ \frac{C_0}{C} = \frac{t}{D}$$

this equation represents a straight line in a graph log C = f (t). It can be written in fact:

$$log\ C = log\ C_0 - \frac{t}{D}$$

In the above equation log C0 is the ordinate at the origin and -1/D is the angular coefficient, the constant D is the size of a time and is called the decimal reduction time, since it represents the time required to reduce the concentration of vitamin C to 1/10 of its value. It is evident, in fact, that when C0 is equal to 10 C, log C0/C is equal to 1, therefore D = t.

RESULTS

Results of juice extraction

The results for the tests carried out after juice extraction are shown in Table 1.

A good and common technological practice that is widely used is blanching, next to pasteurization, the main treatment that can guarantee both microbiological safety for the production of vegetable preserves and the chemical and physical stability of the product as it deactivates enzymes of the polyphenol oxidase class among the main culprits of oxidative browning phenomena.

For the carrot, two blanches were carried out at equal temperature (85°) but with different times, fixed at 5 and 10 minutes. In contrast, considering the characteristics of rocket the blanching time is 3 minutes. This quick blanching was performed only on the vegetables, so the apple was not blanched.

Table 2 Chemical and physical properties detected on the extracted juices for each fruit and vegetable product.

Fruits/vegetables	Colour			DM	SSC	pH	TA
	L*	a*	b*	(%)	(%)		(g citric acid/kg)
Carrot	35,57	14,93	24,33	16,64	9,30	6,13	0,89
Rocket	29,75	10,82	15,92	18,17	5,70	5,56	2,19
Apple	36,08	13,52	24,06	21,02	13,90	3,61	3,30
Fennel	32,58	8,00	17,49	10,17	5,20	5,84	1,26

The following table, on the other hand, shows the same properties with reference to the juices extracted from the products subjected to the blanching treatment.

Table 3 Chemical and physical properties detected on the extracted juices, after blanching of fruit and vegetable product

Fruits/vegetables	Colour			DM	SSC	pH	TA
	L*	a*	b*	(%)	(%)		(g citric acid/kg)
Carrot (85°C-5 min)	35,77	14,01	21,67	11,77	8,2	6,11	1,14
Carrot (85°C-10 min)	36,95	15,47	23,64	13,15	9,2	5,92	1,31
Rocket (85°C-3 min)	36,52	8,41	23,89	25,37	3	6,15	0,51
Fennel (95°c-3min)	39,94	7,25	22,07	11,9	5,6	5,55	0,833

Vitamin C content

Experimental data processing was performed as a function of time and temperature, consequently, empirical models of reaction kinetics were developed, a first-order reaction for vitamin C as already anticipated in Materials and Methods.

Graphs 1 and 2 show that the applied models can adequately describe the loss of vitamin C in the two blends at the different heat treatment temperatures:

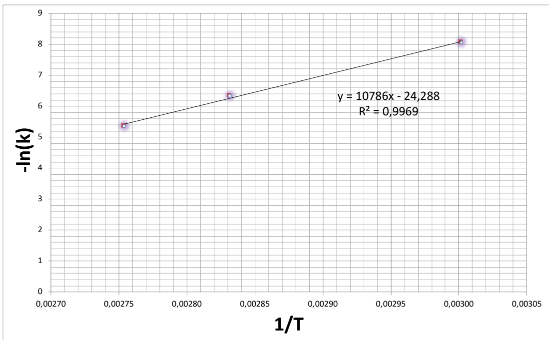

Fig. 1 Variation of vitamin C content in blend 1 at different heat treatment temperatures following first-order kinetics.

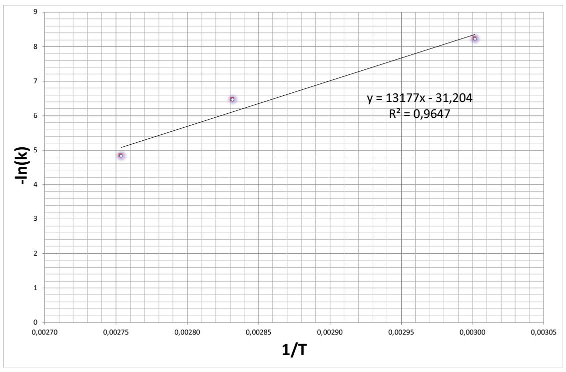

Fig. 2 Variation of vitamin C content in blend 2 at different heat treatment temperatures following first-order kinetics.

The dependence of the rate of vitamin C degradation on temperature was determined using the Arrhenius equation:

$$k = k_0 \exp[-\frac{E_a}{RT}]$$

where k is the rate constant, k0 is the pre-exponential factor, Ea is the activation energy (kcal mol-1), R is the gas constant (1.987 kcal mol-1 K-1) and T is the absolute temperature expressed in K (Kelvin).
The data used to make Arrhenius plots for blends 1 and 2 are shown in Table 3 and Table 4, respectively:

Table 4 Data used for the creation of the Arrhenius plots.

T(K)	T°C	k	1/T	-lnK
333,16	60	0,0003	0,0030	8,058
353,16	80	0,0018	0,0028	6,337
363,16	90	0,0047	0,0028	5,352

Table 5 Data used for the creation of the Arrhenius plots.

T(K)	T°C	k	1/T	-lnK
333,16	60	0,0003	0,0030	8,233
353,16	80	0,0016	0,0028	6,468
363,16	90	0,0080	0,0028	4,832

CONCLUSIONS

Given the growing interest of consumers in issues such as food waste, the search for plant products (with low environmental impact and high nutritional value) and a healthy lifestyle that adapts to frenetic rhythms, the development of such juice can be thought of in a “One Health approach”. The One Health holistic vision, i.e. a healthcare model based on the integration of different disciplines, is ancient and at the same time current. It is based on the recognition that human health, animal health and ecosystem health are inextricably linked. The pursuit of these objectives in our product translates into the use of processing waste in the formulation of the extract and therefore into the benefits that its consumption brings to health and the environment.
In this paper, the criteria for defining a processing line for juice production were analysed.

This work has made it possible to re-evaluate the raw materials excluded from sale for aesthetic or size reasons, and therefore destined to be wasted. The experimental work is based on the International Cooperation project S.K.I.P.E. (Sharing Knowledge to Increase Postharvest Efficiency), and in particular on Work Package 3 - Optimization of the fruit and vegetable supply chain and reduction of waste.
Main results show that there are juices, smoothies and extracts made up of various plant matrices on the market, but none present the raw materials used in this work. On the basis of the knowledge acquired, the unit operations considered fundamental for the transformation of vegetable products were identified and the first experimental tests were carried out on the basis of two blends formulated at lab scale.

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Soil tillage and agroecosystem protection

ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

MAINTENANCE OF UNMANNED AERIAL VEHICLES (UAVs) IN AGRICULTURE

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Abstract: *In recent years, unmanned aerial vehicles (UAVs) have rapidly gained popularity in various industries, including agriculture, due to their wide application in agricultural production. The UAV is most often used for recording conditions in the field, monitoring the condition of crops, targeted application of chemical agents, yield assessment, etc. The efficient and reliable operation of UAVs applied in agricultural production depends to a large extent on the maintenance system. We divide UAV maintenance into two groups: maintenance before and after takeoff and maintenance due to unplanned situations. Both maintenance groups are crucial for preserving the working condition of the UAV with the aim of efficient operational work and extending the service life of the UAV itself. In this paper is shown the importance of regular UAV inspections, the importance of following the manufacturer's instructions, and the maintenance of key UAV components that require attention during regular maintenance. In addition to UAVs that are used for recording fields (terrain and crops), this paper also analyzes the maintenance of UAVs that are used for chemical protection of crops. By applying a timely and appropriate UAV maintenance strategy, we can expect maximum efficiency, reliability and safety of the UAV during their exploitation, as well as a longer working life - longer exploitation of the UAV.*

Keywords: *unmanned aerial vehicle (UAV), regular maintenance, crop condition, chemical protection, maintenance strategy, reliability.*

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1. INTRODUCTION

Unmanned aerial vehicles (UAVs) have become increasingly relevant in the field of agriculture due to their numerous application possibilities and advantages. These modern technical systems equipped with advanced technologies offer new ways to monitor and manage agricultural activities, improving the efficiency and productivity of agricultural production.

The use of UAVs in agriculture implies the use of advanced sensors and digital images that allow agricultural producers to obtain a clear picture of the condition of crops. Information obtained by using UAV, at the right time about the conditions in the field itself, is an important tool for implementing adequate agrotechnical measures, all with the goal of effective influence on increasing the realized yield [10]. Also, by comparing UAV reconnaissance techniques with other methods, it can be concluded that UAVs provide much cheaper, more up-to-date and more realistic data on crop condition. Due to their advantages, UAVs represent the best solution for monitoring the condition of crops on areas from 50 to 500 ha. [9]

The intensive development of software solutions and applications that are used both for their management and for the processing and use of the obtained data contributes to the wide application of UAVs to a large extent. Depending on its purpose, the UAV has different hardware and software equipment [7].

UAVs have the ability to, with adequate equipment, primarily multispectral cameras, create high-resolution digital field maps very quickly. To collect real information from the field, the precision of the UAV during the entire data collection process is important.

As UAVs continue to create changes in the agricultural industry, their role in increasing productivity and efficiency becomes increasingly important. However, in order to ensure the uninterrupted operation of these systems, it is necessary to establish adequate maintenance practices. [19] The goal of this paper is to present the importance and procedures of technical maintenance of individual components and systems that are used in modern UAVs.

The paper presents a review of existing domestic and foreign literature, UAV manufacturer's instructions, as well as the author's experience. The review was done to summarize and reveal the current solutions and ways of maintaining different types of UAVs, which are used for different purposes.

2. DIVISIONS OF UAVs

The division of UAVs can be done according to different criteria. According to the Directorate of Civil Aviation of the Republic of Serbia [1], based on the maximum take-off mass, UAVs are classified into IV categories:

I. unmanned aerial vehicles with a maximum take-off mass of 0.25 to 0.9 kg.
II. unmanned aerial vehicles with a maximum take-off mass of 0.9 kg to 4 kg (not including 4 kg).
III. unmanned aerial vehicles whose maximum take-off weight is from 4 kg to 25 kg (not including 25 kg).
IV. unmanned aerial vehicles whose maximum take-off weight is from 25 kg to 150 kg

UAVs of all categories have a limited range of 500 m, a maximum flight height of 100 m, and no speed limit. These restrictions are prescribed by the regulations, whereby there is a possibility of approval from the Directorate if it is necessary to fly at higher altitudes or at a greater distance.

UAVs can also be divided according to different construction characteristics into:

I. Unmanned aerial vehicles with a single propeller
II. Unmanned aerial vehicles with multiple propellers (becopter, tricopter, quadcopter, octocopter, hexacopter).

Fig. 1 Bicopter [14]

Fig. 2 Tricopter [15]

Fig. 3 Quadcopter [16]

Fig. 4 Hexacopter [17]

Fig. 5 Octocopter [18]

3. TECHNICAL MAINTENANCE OF UAVs

Technical maintenance of UAVs is crucial to ensure their optimal performance, accuracy and longevity of application. UAV technical maintenance can be divided into two groups: planned and unplanned maintenance. Scheduled maintenance is performed before take-off and after landing, while unscheduled maintenance is that which is performed due to unexpected and unplanned situations, such as breakdowns.

3.1. Pre-takeoff and post-landing maintenance

Planned maintenance is a set of measures that include a visual inspection, before take-off and after landing, where it is necessary to pay attention to the elements that are most exposed to damage during the flight. In most cases, damage occurs if the UAV does not have elements to rely on during landing, but instead lands directly on the ground. During such landings, damage to UAV propellers occurs to the greatest extent. For this reason, it is necessary to pay extra attention to this group of elements and replace them in order to complete the mission without any problems. During the visual inspection, it is necessary to pay attention to electrical lines that may be mechanically damaged.

As the battery is one of the main components, it is necessary to check whether the battery is charged before each take-off. According to the manufacturer's instructions, the batteries are charged up to 100%. Batteries must never be left completely discharged, because in this way the batteries lose their functionality. Before each flight, it is necessary to take into account the weather conditions on the ground [3,4,11]. Research has proven that air temperature (extremely high and low values), wind speed and precipitation negatively affect UAV durability, maneuverability, aerodynamics and navigation sensors. [4,6]. Therefore, small-sized UAVs are not capable of flying in difficult weather conditions such as strong winds. Some of the manufacturers clearly emphasize the limits of wind strength within which it is possible to fly [12].

It is necessary that the operator during the mission itself takes into account all the changes that occur and reacts accordingly. It primarily refers to the possible existence of obstacles (eg trees), monitoring of weather conditions, sound and visual effects that give signals about the state of the battery or a malfunction. It is also the operator's duty to follow legal regulations and follow the rules related to no-fly zones (near borders, airports, military facilities...).

After completing the mission, it is necessary to repeat the process as at the beginning and perform a detailed inspection of the UAV and make sure that no damage has occurred. Batteries on UAVs that will not be used for a while must be charged at least to 70%, because even if they are not used, their charge capacity decreases over time.

The recommendation of the manufacturers themselves [5] is that, in addition to regular inspections before take-off, some subsequent checks should also be carried out, every 10 hours of flight or after longer storage of the UAV. Scheduled maintenance at authorized service centers varies depending on the manufacturer, but is usually done after every 100 hours of flight. If the UAV is often used in bad weather conditions, such services need to be performed more often. Maintenance in service centers is a condition for extending the warranty against some major defects.

3.2. Unplanned UAV maintenance

Unplanned maintenance[8] implies noticing damage in time and taking certain steps in order to repair the damage as quickly as possible. Diagnostics and identification of the fault itself on the UAV can be a long process, especially when there are frequent changes to the computer part of the UAV itself. Based on that, as well as based on the location where the maintenance is performed, the same authors provide an overview of the division of unplanned maintenance. The division itself implies maintenance in the field, maintenance in the workshop and in the service. Thus, the primary repair site is the field where the flight mission is performed, where it is possible to perform minor repairs and replacement of parts. It is also possible to eliminate minor operational program errors that do not require more time. The same malfunctions and errors, if they require more time, can be done in the operator's workshop. While maintenance in authorized service centers implies repairs of components that cannot be repaired by the operator, and are necessary for the operation of software systems. An entire team of experts works on the removal of demanding repairs in authorized service centers, while minor repairs in the field can be performed by one operator.

The most common reasons for unplanned maintenance are engine failures, failure of control components during flight or loss of UAV connection. In those cases, the operator can no longer control the UAV, and that is when the UAV falls and is damaged. Also, damage to the UAV occurs due to non-functioning sensors for avoiding objects. The main goal of installing these sensors in modern UAVs is to reduce the possibility of damage and autonomy [24]. These sensors allow UAVs to detect in time and avoid obstacles during the flight, so they are considered as a very important component of UAVs. This type of failure leads to situations that can pose a great danger to living beings and objects in the immediate environment. Reducing the risk of UAV malfunctions requires a combination of preventive measures, proper maintenance, and the responsibility of the person operating the UAV.

Some of the steps to minimize the chance of causing malfunctions are:

- Regular maintenance: which includes routine visual checks (previously explained) and taking care of the cleanliness of the UAV. Moisture, dust or other small impurities can cause damage to components or sensors [20].
- Updating the software according to the manufacturer's instructions to ensure that there are the latest applications with the correction of potential errors.
- UAV calibration which is a procedure in which it is ensured that the sensors are accurate and work properly [21]. This is very important to do when flying in new locations. This enables the improvement of flight stability, performance and safety of the UAV
- Checking the strength of the GPS signal. A strong GPS signal improves flight stability and enables real-time tracking [22].
- Use of quality batteries and proper battery charging.
- Monitoring of weather conditions because strong wind, rain or extreme temperatures put stress on the UAV components which directly affects the performance of the UAV during flight.

By following these UAV maintenance guidelines and performing routine maintenance, the likelihood of UAV malfunctions can be significantly reduced. This also ensures a longer operational life of the UAV [23].

4. MAINTENANCE OF UAVs USED FOR CHEMICAL PROTECTION OF PLANTS

Today's conditions of agricultural production require increasing control over the use of pesticides, so chemical protection by means of UAVs is therefore increasingly applied. By having adequate sensors and cameras, UAVs have the ability to detect various weeds, diseases and insects and thus apply variable chemical protection. In this way, the use of pesticides in quantities greater than necessary is prevented, thereby increasing the success of the controlled use of pesticides [13]. The maintenance of these UAVs does not involve major differences compared to the maintenance of UAVs for field imaging, the maintenance of which was previously explained.

Before flying, there are a number of factors that must be analyzed because their influence on the effective use of chemical protection is very significant. Some of those factors are related to climatic parameters such as: air temperature, air humidity, wind speed and wind direction. The effectiveness of the use of chemical protection also depends on another group of factors, which include: speed and height of application of chemical protection. Indicators of the quality of chemical protection, i.e. drift, droplet size, droplet distribution, determine the height and speed of movement of the UAV during the performance of chemical protection.

What is done within the scope of the visual inspection itself refers to certain elements. It is checked if something interferes with the operation of the propeller or the engine. The UAV battery level as well as the remote control, which must be fully charged, are also checked, followed by a check of all other elements. If it happens that an element is not in good condition or is broken, it is replaced in order to complete the mission without causing damage.

Special attention is paid to the system for the application of chemical agents. Before the actual chemical treatment, it is necessary to do a trial test where there will be no working fluid but only clean water. In this way, the operation of nozzles, pumps and sprayer hoses is initially checked. The manufacturers of these types of UAV [2] also warn about the frequent problems of the system for the application of chemical agents, and provide a series of recommendations that must be followed. One of the measures that can be applied is the avoidance of powdery chemical agents that can lead to clogging of the nozzles and the use of filtered water for preparing the working fluid.

After the finished treatment, when the tank is empty, it is necessary to fill the tank with clean water and take off in order to wash the tank and other components such as nozzles to prevent damage to the system and other processes that may be caused by the chemicals that were applied during the chemical treatments. The operator must wear adequate equipment, which will protect him from the possible harmful effects of the chemical agent.

5. CONCLUSION

In order for UAVs to be used adequately, it is necessary to service and prepare them for each flight in the prescribed manner and according to the manufacturer's instructions. Carelessness of the operator can lead to more serious consequences, from those that are material to those that can lead to injury to the operator as well as living beings and objects in the immediate environment. By implementing a comprehensive maintenance strategy, UAV operators can ensure the continuous and efficient operation of their UAVs. Planned maintenance plays a vital role in preventing unforeseen failures and optimizing the performance of UAVs applied in agricultural production. Regular inspections and routine servicing help identify and address potential problems before they escalate. It also saves money in the long run because early detection of minor defects avoids complete repairs that require more money. This proactive approach ensures that UAVs remain technically sound and adequately perform the technological operations for which they were designed

In the future, drone maintenance is expected to be highly automated, with advanced artificial intelligence systems. With which diagnostics will be carried out in real time as well as predictive maintenance, in order to ensure optimal performance and safety.

Acknowledgement: Paper is a part of research financed by the Ministry of Science, Technological Development and Innovation Development of the Republic of Serbia and agreed in decision no. 451-03-47/2023-01/200009 from 03.02.2023.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

TECHNICAL INSPECTION OF PESTICIDE APPLICATION EQUIPMENT IN EU

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Abstract: *According to the European Directive 2009/128/ EC, each pesticide application equipment (PAE) must have a valid technical inspection label. Each member state must harmonize its legislation with the EU, and the accession countries must start preparing for this work. A new standard has been created for the technical testing procedure: EN ISO 16122. It consists of five parts: 1 – Agricultural and forestry machinery: testing of sprayers in use, part 1: In general; 2 – Field boom sprayers; 3 – Air assisted sprayers for bush and tree crops; 4 – Fixed and semi-mobile sprayers; 5 – Aerial spray systems. Most EU countries have introduced technical inspection of boom sprayers and air-assisted sprayers, fixed and semi-mobile sprayers, while inspection of hand sprayers and knapsack sprayers on hand, battery and motor drive as well as knapsack motor orchard sprayers, is not required yet. In this paper ISO 16122 standard will be explained, as well as inspection procedure and the necessary equipment to perform the test. In the past years of application of the said standard, shortcomings have been identified and an improved version has been created, according to which the inspections perform a technical inspection. Therefore, this paper presents the latest progress and prospects of mentioned standard. A brief overview of the situation of mandatory technical inspection in the member states is also given. At the end of the paper, future trends of technical inspection for all machines applying pesticides are described: Fogging equipment, seed treatment equipment and different types of granular or powder applicators.*

Key words: *air assisted sprayers, ISO 16122, pesticide application equipment (PAE), sprayers, technical inspection*

1. INTRODUCTION

According to the European Commission Directive 2009/128/ EC, called the Sustainable Use Directive (SUD), all Member States (and future EU accession countries) should transpose this Directive into their national legislation. This directive consists of several parts related to agricultural engineering and other parts of general agriculture. The main principles are (European Directive: 2009/128/ EC) strategies for the reduction and optimization of plant protection products (PPPs); reduction of the impact of PPPs on human health; reduction of the impact on the environment; integrated pest management; mandatory training of all professional users; and technical inspection of pesticide application equipment (PAE). Each member/acceding country should implement an action plan for technical inspection of PAEs according to the standard EN ISO 16122 (https://www.iso.org/standard/56721.html), which prescribes the testing procedure as well as the required equipment. With the transposition of the Directive into the legislation of the Member States, the initial results of the technical correctness of PAE were poor. Banaj et al. (2012) and Wehnam, H.J (2023) found that the main cause of technical irregularities was defective pressure gauges and nozzles (up to 60%). Defective pressure gauges often had incorrect scales and sizes, and defective nozzles were usually associated with wear and clogging of the outlet. Even a minor deviation from the recommended operating pressure can lead to the emergence of diseases, weeds, and pests, along with unnecessary contamination of the agroecosystem and increased production inputs. This is due to improper application of pesticides, which translates into excessive or inappropriate use.

In the fifth technical inspection cycle in Belgium's Flanders region from 2008 to 2010, as reported by Declercq et al. (2012), only 9.7% (152) out of the 1557 evaluated orchard sprayers did not pass the technical inspection. In Spain, 11,639 machines were inspected between 2015 and 2016 (5,291 field sprayers, 5,761 orchard sprayers, 677 seed treatment machines, and others, accounting for 39.6%, 39.4%, and 20.2%, respectively). As per the findings from a study conducted by Solanelles F., et al. (2018), the most common problems observed in the reviewed sprayers included safety issues (24%), faulty liquid tanks (7%), pressure gauge malfunctions (28%), problems with the philtre system (13%), issues with the nozzles (13%), and various other flaws (15%). The analysis further revealed that 40% of these machines did not pass the technical examination due to these issues. The new standard ISO 16122 (2015) for technical monitoring of crop protection machinery is discussed in this article, along with ideas for technical monitoring of all machinery and equipment using PPPs.

2. EUROPEAN NORM *EN ISO 16122*

As mentioned in the introduction, the main standard for the technical testing procedure is *EN ISO 16122*, which is based on the old standard *EN 13790*. The new standard consists of five parts, which will be explained in further paper.

2.1. General part - *EN ISO 16122:1*

This standard requires that all sprayers for arable and orchard crops, as well as fixed and semi-mobile sprayers, undergo the required technical test. Hand-held, battery-operated or motor-operated sprayers, as well as motor-operated backpack sprayers used in orcharding, are presently excluded from the technical testing process due to the consideration of health and environmental risk assessments for both people and animals. In order to be included in the special register (in Croatia: Plant Protection System: FIS - Figure 1), the owners of these machines must register them and all other similar machines and equipment with an approved testing organization.

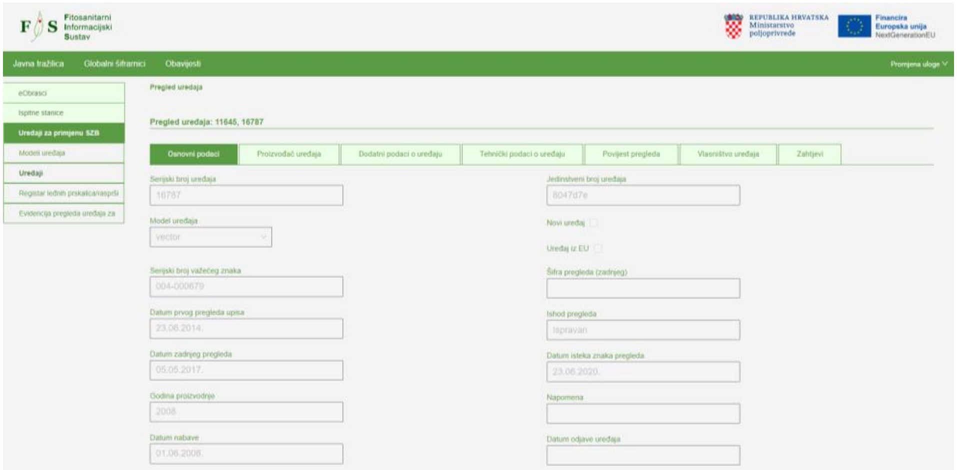

Figure 1 Croatian search engine at Plant Protection System interface

The inspection process, the tools required to verify performance, and the software used to collect all important data are described in the standard ISO 16122:1. This program prints a technical inspection report, two copies of which are sent - to the technical station and to the owner of the sprayer. This standard requires that a preview be made before starting the inspection to minimize the time lost during the inspection. This approach eliminates discrepancies, which, in certain instances, can prolong the duration of the technical inspection. Furthermore, it ensures that all machinery and equipment within the European Union adhere to a standardized inspection and test report requirement.

Figure 2 shows the structure of the technical testing software created by the University of Zaragoza (Gil E., et al. 2018) in accordance with the updated standard EN 16122.

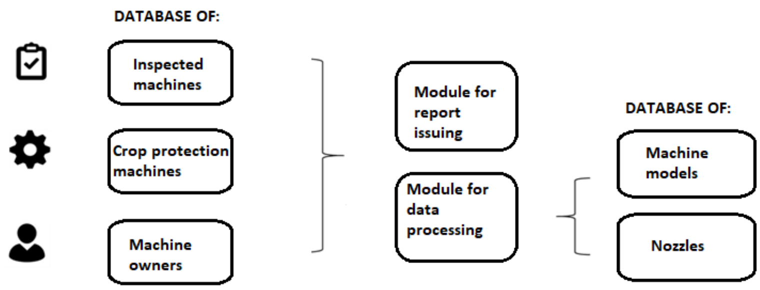

Figure 2 Software structure for technical inspection of plant protection machines
Source: Gil et al. (2018.)

2.2. Technical inspection of boom sprayers - *EN ISO 16122:2*

Under this standard, various components and aspects of the field sprayer are subjected to testing. This includes the field sprayer drive and rotating parts, PTO rotation, pressure gauge, pump, mixer, tank, control and regulation system, pipes and elastic lines, filtration, spray boom with nozzles, nozzle flow, sprayed liquid distribution, pressure drop, and so on. A specific testing technique is recommended for each of the aforementioned parts. It is precisely specified which components of the sprayer are tested and what accuracy levels the test instrument must meet. Each measuring device must be provided with a current designation and calibration certificate, and a declaration of tolerances is required for each tested component of the sprayer. Based on the nominal flow rate, a permissible deviation of 15% is allowed for the nozzle flow rate. With the exception of the final two nozzles intended for specific tasks at the end of the spray boom, a tolerance of 5% is applied to the average value that nozzles at the same pressure can achieve if the manufacturer of the nozzles is not known. Pressure gauges installed on field sprayers must have a minimum diameter of 63 mm and should provide a measuring accuracy of up to 0.2 bar within a test range of 0 to 2 bar. If needed, the measuring accuracy can be enhanced by 10% by using a broader test range. The measuring scales of the pressure gauges must be easy to read and matched to the working pressures used. Deviations of up to 10% from the nominal capacity specified by the manufacturer are permitted without any adverse effects. Figure 3 shows the technical test of spray booms with horizontal surface distribution of the liquid.

Figure 3 Surface distribution check with spray scanner

2.3. Technical inspection for air assisted sprayers for bush and tree crops - EN 16122:3

The accuracy of the orchard sprayer differs from the accuracy of the field sprayer due to differences in design. Vertical liquid distribution is one of the main differences. Since the control method with a vertical liquid collector is still in the trial stage, the control is done visually according to the above standard. There are two ways to adjust the nozzle flow: on the machine itself (Figure 3) or on the inspection table. In all scenarios, the flow rate specified by the manufacturer at a particular operating pressure is permitted to vary by +/- 10% of the allowed nozzle flow variation. Additionally, the pressure drop over the nozzle should not exceed 15% of the operational pressure indicated by the pressure gauge. An important characteristic of orchard sprayers is the radial or axial fan, which must include protection for its moving parts, be controllable for on/off functions, and have blades that are not broken. Figure 4 shows technical inspection of nozzle floe check for air assisted sprayer.

Figure 4 Nozzle flow check for air assisted sprayer

2.4. Technical inspection of fixed and semi-mobile sprayers - EN 16122:4

In the context of technical monitoring, the need has recently arisen to evaluate specific devices that use pesticides in particular circumstances. This type of equipment used in greenhouses includes stationary and semi-mobile sprayers. These devices come in a variety of designs and have not yet been standardized. Some of these devices have two basic systems: mobile parts with equipment for application of pesticides (hand applicator, vertical or horizontal boom) and fixed parts with spray tank and pump. Except for some modifications and additional tests, the technical testing process is similar to that of field sprayers. These additional tests concern the components of the sprayer and the tightness of the tank at the maximum allowable pressure specified by the manufacturer. If these systems are equipped with hand sprayers and not with booms, a pressure gauge must be installed according to the recommended pressures. In this case, the minimum size of the manometer is 40 mm, while for field sprayers it is 63 mm. The deviation from the applied dose for pesticides or fertilizers must not exceed 10% when administered directly into this system. Of course, uncontrolled leakage or dripping cannot occur in these systems. Figure 5 shows semi-mobile pesticide application equipment for greenhouses (image via https://medari.by).

Figure 5 Semi - mobile devices for pesticide application in greenhouses

3. FUTURE TRENDS FOR TECHNICAL INSPCTIONS

3.1. Applicators for powder pesticides and mineral fertilizers

Technical testing of application equipment for microgranules and fertilizer pellets is not yet provided for in *European Standard 16122*. These devices can apply mineral fertilizers, pelletized fertilizers, powder insecticides and herbicides. The overall condition, measurement systems, piping, supports and pneumatic system of these devices should be examined first. The deviations of the measured application values from the average value should not exceed 10%. These machines also include spreaders for mineral fertilizers. When inspecting mineral fertilizer spreaders, the key aspects to assess involve the specified maximum operating range and the uniformity of fertilizer application between the left and right sides, which should not deviate by more than +/-15%. These machines should undergo a technical check every six years. The testing procedure for mineral fertilizer spreaders, conducted using test boxes, is illustrated in Figure 6.

Figure 6 Mineral fertilizer spreader testing with test boxes

3.2. Fogging devices

According to the European directive, all types of equipment used to apply pesticides must be technically tested. Equipment for fogging, greenhouse use, and other unique indoor or outdoor applications are included in this. A guideline for conducting the technical inspection has been prepared, taking into account the specifics of the design and application of these machines (the topic was presented at SPISE 2016 - Standardized method for testing spraying equipment in Europe). A general condition check, an inspection of the liquid tank, filtration, fans, measurement equipment, and air compressor are all included in the technical inspection. The condition of cables, connectors, leaky power system, switches and control panel must be checked, since most of this equipment is powered by electricity. The flow rates of the individual nozzles must be listed in a table on the unit in order to calculate the required application rate. A safety net should be attached to the fan and the nozzle flow rate must be within +/- 10% of the nominal flow rate. There must be a table on the unit with the flow rate of the various nozzles prescribed by the manufacturer in order to determine the required application dose.

3.3. Devices for seed treatment

Establishing a procedure for testing proper use is difficult because of the variety of designs of seed processing equipment. There are industrial units with a capacity of more than 30 t h^{-1} as well as units for laboratory use (samples of up to 50 g). There are also stationary and mobile units. Figures 7 and 8 show different seed processing devices.

Source: https://www.cimbria.com

Figure 7 Stationary unit

Source: https://www.agrotrend.hu

Figure 8 Mobile unit

To ensure consistent and standardized technical testing of seed processing equipment across the entire European Union, it is essential to establish uniform standards and provide training programs for testing laboratory personnel. In addition, the time limits within which the tests must be carried out should be specified. At the EU level, the equipment for technical testing of these devices must also be defined and adapted. At the 6th SPISE Symposium in Barcelona, the procedure for accurate and safe testing of seed processing equipment was presented (Kole, J. 2016). The inspection must confirm the accuracy of the measurement devices employed, the safety and tightness of the equipment, and the appropriateness of the pesticide dosage. Since a pesticide is used in the test, the worker verifying the accuracy of the seed treatment equipment must rigorously adhere to wearing personal protection equipment. The seed storage tank should have the capability to operate continuously for one hour, with an automatic seed flow stoppage feature when the machine is turned off. Additionally, it should allow for the measurement of seed quantity, possess a dust extraction port with sufficient capacity, and be connectable to an outdoor unit.

4. CONCLUSION

After considering everything that has been said in this article, it is clear that the implementation of European Standard 16122 (2015) has greatly enhanced the process for technical inspection of all crop protection equipment. However, in order to reduce pollution and increase environmental protection, it is necessary to check that all equipment used to apply chemical agents in agriculture is functioning properly. The crop protection system should also be checked out and include handheld sprayers, backpack sprayers, battery- or motor-operated sprayers, and backpack sprayers for orchards. Misting equipment, seed treatment equipment, liquid and solid fertilizer application equipment, and various granular and powder pesticide application equipment are all included in this category of gear. Therefore, it is necessary to supplement and amend the European standard EN 16122 when a new technical control procedure is adopted at EU level.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

TRACE ELEMENTS ENVIRONMENTAL RISK OF SOYA STRAW ASHES WHEN USED AS A SOIL FERTILIZER

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Abstract: *Biomass is widely recognized as one of the most promising renewable energy sources in the world. Ash is a byproduct of biomass combustion that is produced in significant quantities. The environment could be overburdened and negatively affected by ash accumulation and its random return to the soil. Prior to utilizing ash as a fertilizer, it is important to determine trace element content and estimate the environmental risk using a variety of ecological indices. Among investigated trace elements, manganese has the highest concentrations in both ashes, while contents of cobalt in ash from the combustion chamber (CCB) and cadmium in cyclone ash (CB) are the lowest. CCB and CB ashes contain substantially lower concentrations than the maximum European limits for ash utilization in forestry and agriculture for most harmful trace elements. Based on the crustal enrichment factor, molybdenum displays the highest enrichment (CCB), while manganese and chromium (CB), as well as cobalt (CCB), show moderate enrichment. The modified potential risk index (MRI) is used to demonstrate the possible impact of these ashes to the environment. MRI value for CB is substantially higher than for CCB, indicating its considerable risk to the environment.*

Key words *soya straw ash, trace elements, metal pollution index, modified potential risk index, environmental risk*

1. INTRODUCTION

The proportion of renewable energy in the world's total energy consumption is increasing due to the energy crisis and concerns about CO_2 emission. Biomass is the most promising renewable energy source and electricity production from biomass is currently gaining considerable interest. More than 60% of biomass potential in Serbia has an agricultural origin [1]. The growing use of biomass during the previous decade produced large quantities of bottom and fly ashes [2]. The physicochemical properties of ashes depend on the biomass used and combustion conditions. Fly ashes have smaller particle sizes than bottom ashes, but their heavy metal and other pollutant concentrations are generally greater, resulting in higher toxicity of fly ashes when compared to bottom ashes [3].

Due to the significant concentration of macro elements (Ca, K, Na and P) in ash in relatively soluble forms, it is commonly used as a fertilizer. Recycling ash into the forest or agricultural soil can maintain the original level of nutrients and acid buffering capacity (high pH values), which are altered by intensive logging and harvesting [4]. On the other hand, recirculating ashes onto soil may also result in undesired releases of hazardous substances. Heavy metals such as Cd, Hg, Pb, Cr, Ni and As harm the environment, even at very low concentrations [5]. In some European countries, such as Denmark, Finland, Sweden, Austria and Germany, ash utilization on forest and agricultural soil is regulated [6]. For these reasons, it is necessary to determine ash composition prior to its sustainable application [3].

Many indices have been introduced to evaluate the metal soil contamination and ecological risk [7]. Some indicators, such as the metal pollution index (MPI), refer to the overall metal risk in ashes or sediments based on their content. Other indicators, such as crustal enrichment factor (CEF) and geoaccumulation index (I_{geo}), denote the enrichment of each investigated trace element in soil/ash compared to its background concentration to point out the impact of anthropogenic activities on surface soil content [8]. Multiple element indices, such as the modified potential ecological risk index (MRI), are used to assess possible ecological risks of ashes/sediments [9,10]. Therefore, the limitations of the single element indices are overcome.

It was highlighted that despite the low trace elements content in biomass ash, they have significant technological and ecological impacts during sustainable utilization of ash. An essential condition for the maintainable use of ashes in agriculture is the assessment of possible environmental impacts. Only a few studies have been conducted on environmental risk assessment regarding the ashes produced by biomass combustion [4,5,11].

The aim of this paper was to determine trace elements (Cd, Co, Cr, Cu, Mn, Mo, Ni, Pb, Zn, As and Hg) in the bottom and fly ashes that originate from the cigar burner biomass combustion system located in Agricultural Corporation PKB and to estimate the environmental risk of using ash as a soil fertilizer.

2. MATERIALS AND METHODS

2.1. Sample collection and storage

Bottom ash (CCB) and fly ash (CB) were sampled from the combustion chamber and the cyclone of a plant in Agricultural Corporation PKB in which cigar burner combustion technology of baled straw has been applied for heating greenhouses. Ash samples were homogenized and stored in a dark place in the laboratory at a temperature below 15°C.

2.2. Sample preparation and determination of trace elements

Sample preparation was done by a MILESTONE Ethos Easy Advanced Microwave Digestion System following a previously described procedure [12]. ICP/OES spectrometer ICAP 7400 DUO Thermo Fisher Scientific was used for trace elements determination. Multi-element standard solution IV (Merck, 1000 mg/L) was used for calibration.

2.3. Data analysis

2.3.1. Metal pollution index (MPI)

MPI represents the geometric mean of all trace elements concentrations found in ashes of soybean straw [5] and is calculated by Eq. (1):

$$MPI = \left(C_1 \cdot C_2 \cdot C_3 \cdots C_k\right)^{1/k} \quad (1)$$

C_1, C_2,… and C_k is the concentration of the first, second, …and k-th metal.

2.3.2. Crustal enrichment factor (CEF)

CEF is used as an indicator to specify the degree to which each trace element in ash is enriched relative to its content in the crustal core. To reduce the alterations among diverse samples, CEF values are estimated concerning a reference element (Fe in this paper) that is stable, immobile, and unaffected by anthropogenic influence [11]. $CEF_{Fe,i}$ is calculated according to Eq. (2):

$$CEF_{Fe,i} = \frac{(C_i / C_{Fe})_{ash}}{(C_i / C_{Fe})_{crustal\ core}} \quad (2)$$

C_i is the individual trace element concentration, and C_{Fe} is the iron concentration for ash samples and crustal core.

2.3.3. Geoaccumulation index (I_{geo})

I_{geo} is a numerical representation of the level of human-induced contamination of each trace element [8]. It is calculated as follows:

$$I_{geo} = \log_2 \frac{C_i}{1.5 \cdot B_n} \quad (3)$$

C_i is a particular trace element concentration in the ash sample, B_n is the geochemical trace elements background concentration [13], and factor 1.5 is added to account for variations in elemental composition that occur naturally in the environment.

2.3.4. Modified potential ecological risk index (MRI)

MRI is used to assess the extent of heavy metal pollution and its potential ecological harm [9]. It is calculated using the following formula:

$$MRI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} T_{fi} \cdot CEF_{Fe,i} \quad (4)$$

E_r^i is a potential ecological risk index; T_{fi} represents the toxic response [14] and $CEF_{Fe,i}$ is previously explained.

3. Results and discussion

3.1. Trace elements

The overall concentrations of the investigated trace elements in the ashes generated by soya straw combustion are 322.0 mg/kg and 472.5 mg/kg for CCB and CB, respectively. The concentrations of trace elements in this paper are lower than those in the literature [11,15]. The distributions of investigated trace elements in bottom and fly ashes are presented in Fig. 1. No ash contained As and Hg, nor was Cd detected in CCB. Manganese is the most abundant in both ashes. Zinc has a larger ratio than other trace elements in both ashes, while portions of Co in CCB and Cd in CB are the lowest.

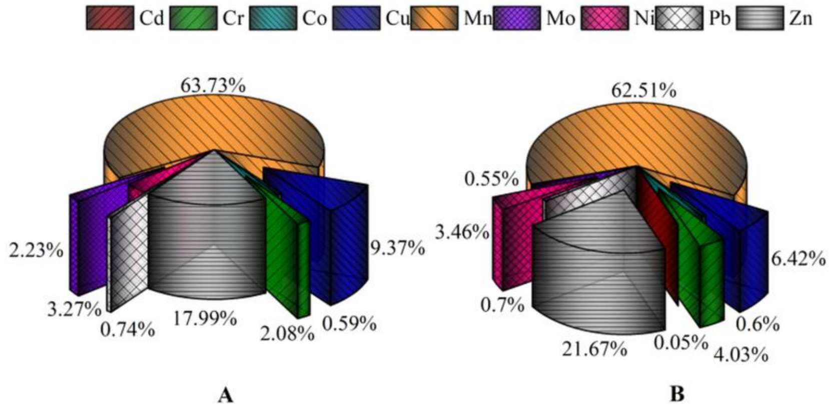

Fig. 1 Trace elements distributions in bottom ash (A) and fly ash (B)

Table 1 shows trace elements legislation limits in ashes for their utilization as a fertilizer in forestry and agriculture for some European countries [16], as well as the concentrations of these elements in investigated ash samples. Since trace elements concentrations in CCB and CB ashes are much lower than allowed according to Sweden, Denmark, and Finland regulations [16], they could be used as fertilizer.

Table 1 Trace elements concentrations in bottom ash (CCB) and fly ash (CB); European regulative limits for ash utilization in forestry and agriculture (all in mg/kg) [16]

Element	CCB	CB	Denmark	Finland	Sweden
As	< 2.50	< 2.50	/	25	30
Cd	< 0.15	0.24	15	1.5	30
Cr	6.70	19.06	100	300	100
Cu	30.16	30.34	/	600	400
Ni	10.53	16.34	60	100	70
Pb	2.40	3.31	120	100	300
Zn	57.92	102.40	/	1500	7000

3.2. Evaluation of investigated trace elements pollution

The metal pollution index is a helpful tool for monitoring metal pollution levels in different contaminated media [5]. MPI values are 9.09 and 8.05 for CCB and CB, respectively, while these values for wood pellet range from 1.5 - 8.4 [5,11]. Since the MPI for CCB is higher than reported in the literature, it could promote heavy metals accumulation in the soil if ash is used as a fertilizer for a prolonged period.

The crustal enrichment factors are used to estimate the impact of ash addition on soils and determine the degree of metal contamination. The CEF_{Fe} values for all investigated trace elements fluctuate between 1.12 and 50.09 (Fig. 2).

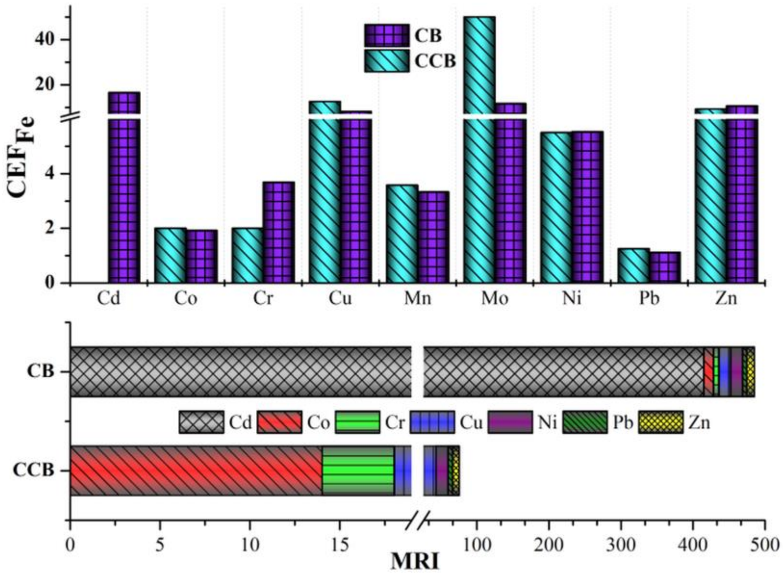

Fig. 2 Crustal enrichment factor CEF_{Fe} of investigated trace elements and modified potential ecological risk index (MRI) of bottom ash (CCB) and fly ash (CB)

Different trace elements are divided into five classes based on CEF values (Table 2). Among investigated trace elements, Mo (CCB) shows the highest enrichment, while Pb for both ashes and Co (CB) have no enrichment. Cu, Ni and Zn enrichments for both ashes, along with Cd and Mo for CCB, are significant, while Mn (CB), Cr and Co for CCB exhibit moderate enrichments.

Table 2 Trace element classification according to values of crustal enrichment factor (CEF) [11], modified potential ecological risk index (MRI) [9] and geoaccumulation index (I_{geo}) [8]

CEF	Enrichment degree	MRI	Risk degree	I_{geo}	Pollution degree
< 2	no enrichment	< 150	low risk	≤ 0	unpolluted
2-5	moderate	150 - 300	moderate risk	0 – 1	unpolluted to moderately polluted
5-20	significant	300 - 600	considerable risk	1 - 2	moderately polluted
20-40	high	≥ 600	very high risk	2 - 3	moderately to strongly polluted
≥ 40	very high			3 - 4	strongly polluted
				4 - 5	strongly to extremely polluted
				≥ 5	extremely polluted

The geoaccumulation index evaluates the pollution level of trace elements in the different matrices. According to I_{geo} values, trace elements can be categorized from unpolluted to extremely polluted (Table 2) [8]. Fig. 3 shows I_{geo} values of trace elements for CCB and CB ashes. Except for Mo, all trace elements have values of $I_{geo} \leq 0$, implying no environmental contamination. I_{geo} for Mo in the CB (2.26) is higher than in the CCB (0.79), indicating varying degrees of pollution from moderately to strongly and unpolluted to moderately, respectively.

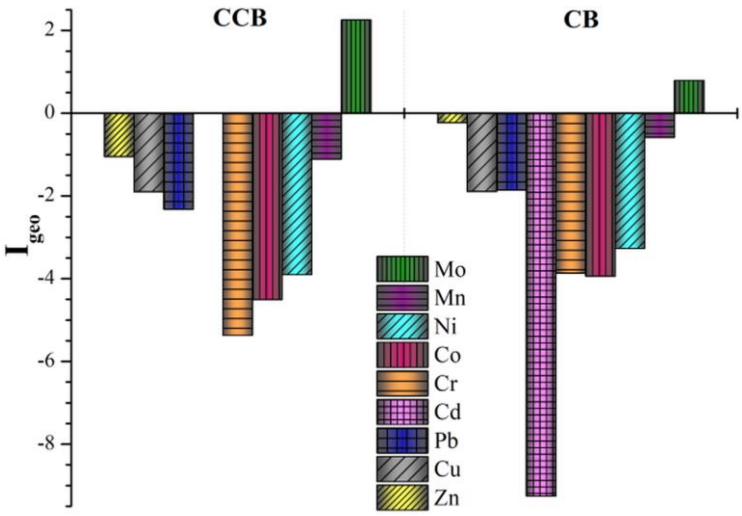

Fig. 3 Geoaccumulation indices of investigated trace elements (I_{geo}) from bottom ash (CCB) and fly ash (CB)

The modified potential ecological risk index determines the level of heavy metal pollution and the possible environmental impact of ashes. MRI values for CCB (75.37) and CB (485.14) are presented in Fig. 2. It is evident that CB has a significantly higher MRI value than CCB, indicating its considerable risk to the environment.

4. CONCLUSION

The concentrations of environmentally relevant trace elements (As, Cd, Cr, Cu, Ni, Pb and Zn) in bottom and fly ashes from the cigar burner combustion system at Agricultural Corporation PKB have been determined. Their content is higher in CB than in CCB but far lower than the limits given by the European legislation, implying that both ashes can be utilized as soil fertilizers. Hg and As are below detection limits in both ashes, as well as Cd in CCB. Various ecological indices have been calculated to estimate the potential environmental risk of ashes. MRI values indicate a considerable risk to the environment for CB and a low risk degree for CCB. MPI and MRI values show that long-term use of ashes as soil fertilizer could lead to soil contamination, so periodically monitoring trace element content in the soil is essential.

Acknowledgement*: This work was supported by the Ministry of Science, Technological Development and Innovation of Republic of Serbia; grant number 451-03-47/2023-01/200017.*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

UTILIZATION OF SOME AGROTECHNICAL MEASURES IN SERBIA COMPARED WITH THOSE IN THE FORMER YUGOSLAV REPUBLICS AND SURROUNDING COUNTRIES OVER A PERIOD OF THREE DECADES

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Abstract: *Numerous changes occurred in the countries that constitute the former Yugoslavia between 1990 and 2020. This research examines trends in agriculture in these and neighboring countries throughout the chosen time period. The need for food increased, while production risks grew due to climate change, which reduced the yields of many crops. Agrotechnical measures such as the use of artificial fertilizers and pesticides were essential since agricultural production was connected with expensive investments and the primary objective of each agricultural producer was to maximize output. Agrotechnical measures in the aforementioned countries are associated with agricultural soil portions, rural population share, economic aspects, and predicted environmental effects.*

Key words *agricultural soil, rural population, fertilizers use, pesticides, economic parameters, environmental impact*

1. INTRODUCTION

Currently, the global population is around 8.04 billion people, with a 0.88% annual growth rate and a median age of 30.5 years [1]. Global population growth is directly related to increased food demand [2-4]. In 2012, the United Nations Food and Agriculture Organization (FAO) projected that by 2050, food output would be required to grow by 60% [5]. Besides from worldwide population expansion, global food production and security are influenced by a variety of other factors, including arable land availability, water resources and quality, and climate change [6]. The ratio of arable land to population in developing countries decreased by up to 55% between 1960 and 2000. Furthermore, it is anticipated that half of the existing arable land will be unsuitable by 2050 due to a variety of factors (erosion, floods, etc.) [6]. Consequently, despite enormous growth in food production and availability, food insecurity remains unacceptably high.

Agrotechnical measures used by man to promote the growth and development of crops can have a major impact on the spread of harmful organisms [7]. Chemical plant protection treatments can be considerably lowered, and in some cases completely omitted by implementing suitable agrotechnical measures to improve agricultural production. The treatment of arable soil, erosion prevention, control of weeds, vegetation, pests, plant diseases, utilization and disposal of crop residues, maintenance of soil organic matter, and favorable soil structure are some examples of commonly used agrotechnical measures. Different agrochemicals such as synthetic fertilizers, growth promoters, hormones, a wide range of pesticides can be utilized [8].

This article provides an overview of several socioeconomic factors that influence agricultural output, as well as a comparison of some agrotechnical measures over a three-decade period. The time frame under consideration (1990-2020) was chosen since there was a lot of instability in the region surrounding Serbia; new countries originated from the former Yugoslavia, and have different statuses relating to EU membership.

2. COMPARISON OF AGROTECHNICAL MEASURES IN SELECTED COUNTRIES

2.1. Study area

The countries that arose from the former Yugoslavia did not achieve independence simultaneously [9]. Slovenia, Croatia, and North Macedonia were established in 1991, while Bosnia and Herzegovina and the Federal Republic of Yugoslavia were formed in 1992. The Federal Republic of Yugoslavia was renamed to Serbia and Montenegro in 2003, and thereafter became independent countries in 2006.

The world population in 1990 was 5.32 billion, with an annual growth rate of 1.8% and a median age of 23 years, whereas corresponding data for 2020 were 7.84 billion, 0.98%, and 29.7 years, respectively [1]. Simultaneously, the population of Europe in 1990 was 721.50 million, with a median age of 33.6 years and a yearly change of 0.39%, while the same figures for 2020 were 746.23 million, 41.5 years, and 0%, accordingly [10].

Table 1 lists countries chosen to be studied in this research, along with their abbreviations, as well as information about EU membership [11], overall country area, and population [12]. Selected countries can be classified into two categories: EU members (8 countries) and non-members/EU candidates (5 countries). Three countries joined EU before 2000, while other 5 countries became EU members after that year.

Table 1. Information on selected countries (abbreviations of country names, EU membership details, areas and population in cut-off years)

Country	Abbreviation	EU membership status in 2020	Area (km^2)	Population (million)	
				1990	2020
Albania	AL	candidate	27400	3.30	2.87
Austria	AU	1995	82409	7.68	8.91
Bosnia and Herzegovina	BH	*	51000	4.49	3.27
Bulgaria	BU	2007	108560	8.77	6.98
Croatia	CR	2013	55960	4.87	4.10
Greece	GR	1981	128900	10.30	10.51
Hungary	HU	2004	90530	10.38	9.75
Italy	IT	1958	294140	56.76	59.50
Montenegro	MN	candidate	13450	0.62	0.63
North Macedonia	NM	candidate	25220	2.04	2.11
Romania	RO	2007	230170	22.84	19.44
Serbia	SE	candidate	87460	7.99	7.36
Slovenia	SL	2004	20140	1.99	2.12

* BH became an EU candidate in 2022

The selected countries' total area equals 11.94% of the European surface. The areas of the eight EU countries and five non-EU countries account for 9.93% and 2.01% of the total European area. The ex-Yugoslav countries account for 2.49% of the total European area. Italy has the greatest land area among listed countries. For specified years, the population of selected countries was 19.69% (1990) and 18.43% (2020) of the overall population of Europe.

2.2. Overview of agricultural data

Figure 1 gives an overview of the arable soil portion, rural population share and percent of employment in agriculture for all selected countries as the function of time for the chosen period (1990-2020).

The average arable soil percentage for all 13 countries has been 44.8% for selected period. Greece, Hungary, and Romania have the greatest proportion of arable soil (Fig. 1A) and at the end of this period the arable soil percentage decreased by 35.6% (GR), 22.4% (HU), and 8.5% (RO) in relation to 1990. The decrease is the greatest in Montenegro (49.0%) and Croatia (36.6%). In contrast, Slovenia and Albania experienced increases of 8.9% and 3.9% during the same period. Bosnia and Herzegovina, Serbia, and North Macedonia have had minimal changes in the arable soil portion. The proportion of arable land (Table 2) ranges from 19.6% in Montenegro (2020) to 71.3% in Greece (1990).

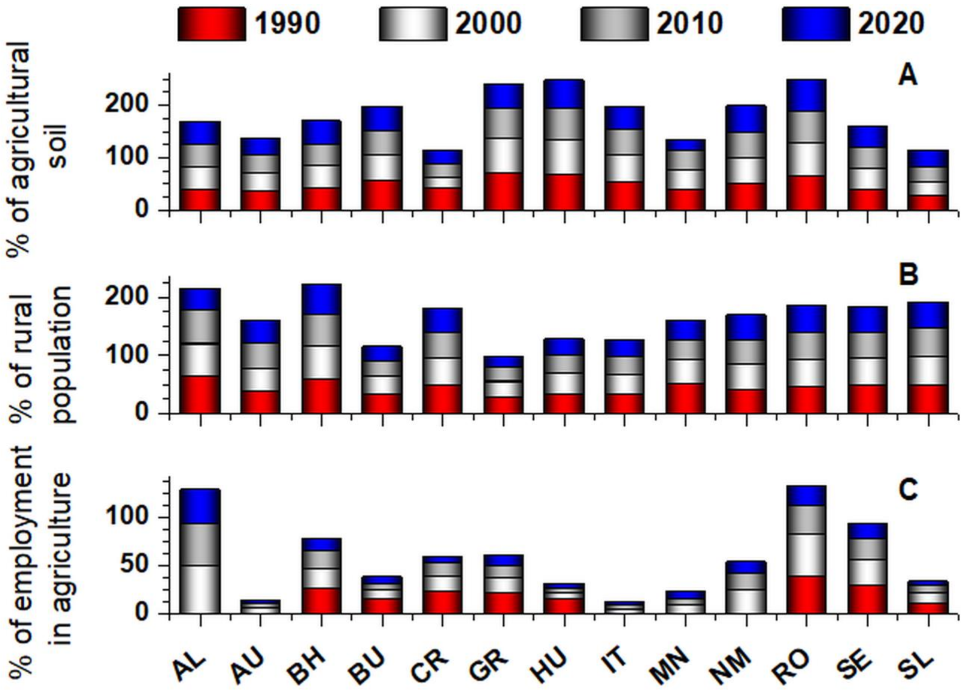

Fig. 1 Time dependence of arable soil portion (A), rural population share (B) and agricultural employment (C) for selected countries (Table 1)

Over a 30-year period, the rural population share ranged from 20.2% in Greece (2020) to 63.5% in Albania (1990), as shown in Figure 1B, with an average value of 41.2%. Albania (39.7%) and Montenegro (35.9%) had the highest reductions in rural population share in 2020 compared to 1990. Except for Romania and North Macedonia, where the rural population share remained constant, and Austria, where it raised, the rural population share decreased for all other selected countries.

The percentage of agricultural employment (Figure 1C) ranges from 3.8% in Italy (2010) to 50.0% in Albania (2000) with an average of 16.2%. The employment portion decrease at the end of the analyzed period ranged from 23.6% to 70.5% comparing to initial state in 1990.

The importance of agriculture in economy of some country is measured as the value contributed by agricultural sector (forestry, hunting, fishing, crop cultivation, and livestock production) as a percentage of GDP [13]. Figure 2 highlights the contribution of agriculture to the global GDP of each of the selected countries, and also the consumption of fertilizers and pesticides. The highest share of agricultural activity in overall GDP of each selected country was noticed for Albania, Romania and North Macedonia (Figure

2A). The range of agricultural GDP share was from 1.2% (Austria) to 22.1% (Albania). The decrease in GDP share of agriculture for 30-year period was from 3.4% to 80.4%, and it was the highest for Romania.

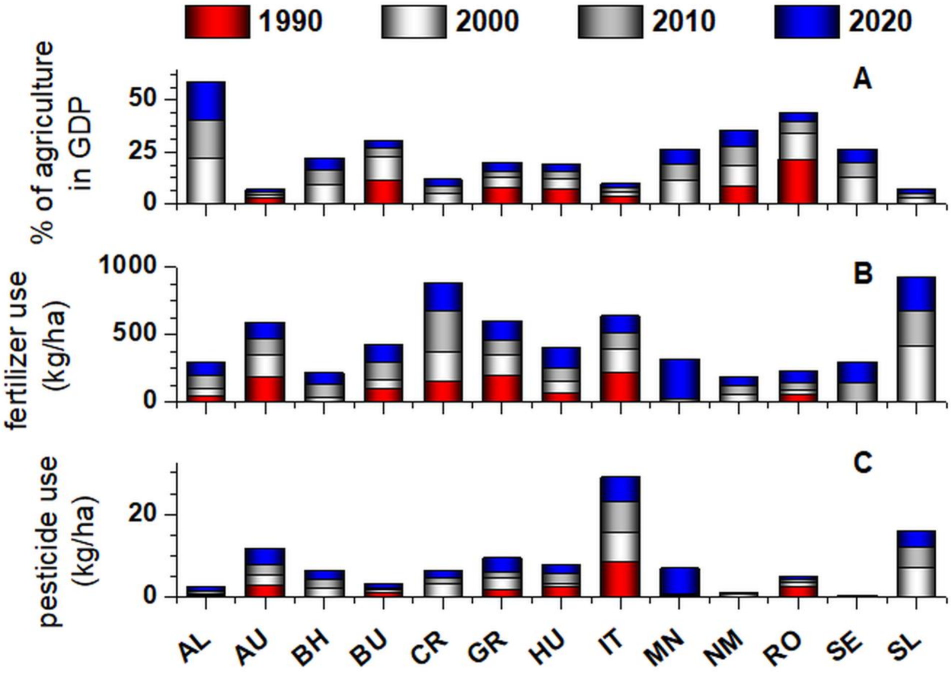

Fig. 2 Time dependence of agriculture's contribution to global GDP (A), fertilizer use (B), and pesticide use (C) for selected countries (Table 1)

Fertilizer use was from 16.7 kg/ha for Montenegro in 2010 to 409 kg/ha for Slovenia in 2000. Mainly, fertilizer use (Figure 2B) became more intensive except in the case of Austria, Greece, Italy and Slovenia, which are all the EU members.

Average pesticide use for 30-year period was 2.4 kg/ha (from 0.2 kg/ha for Albania in 1990 to 8.4 kg/ha for Italy in 1990). The highest increase in utilized pesticide amount is noticed for Montenegro and Albania (Figure 2C) which are candidates for EU members.

2.3. Data statistics

2.3.1. Pearson correlation

Pearson analysis allows finding out whether or not there is a linear correlation between two variables. The analysis of collected data was done for datasets denoted as D1-D6 (Table 3). Following variables were analyzed for six datasets: arable soil portion

(SP), rural population share (RP), agricultural portion in overall GDP (GDP_{ag}), percent of employment in agriculture (EM), fertilizer use (FU) and pesticide use (PU).

Table 2. Time dependence of minimal, maximal and average values for selected parameters in 13 European countries

Year	1990	2000	2010	2020
Agricultural soil portion (%)				
Min	SL (28.0)	CR (21.2)	CR (23.9)	MN (19.6)
Max	GR (71.3)	HU (65.4)	RO (60.0)	RO (59.0)
Average	48.95	45.23	43.85	41.13
Rural population share (%)				
Min	GR (28.5)	GR (27.0)	GR (23.2)	GR (20.2)
Max	AL (63.5)	BH (56.9)	AL (57.3)	BH (50.8)
Average	44.38	42.48	40.67	37.24
Employment in agriculture (%)				
Min	SL (11.2)	IT (5.2)	IT (3.8)	AU (3.8)
Max	RO (39.0)	AL (50.0)	AL (43.6)	AL (35.6)
Average	22.84	18.68	15.10	10.89
Agriculture's contribution to global GDP (%)				
Min	AU (2.4)	AU (1.7)	AU (1.4)	AU (1.2)
Max	RO (21.4)	AL (22.1)	AL (18.2)	AL (18.7)
Average	8.78	8.49	5.84	5.35
Fertilizer use (kg/ha)				
Min	AL (47.1)	BH (32.1)	MN (16.7)	NM (67.3)
Max	IT (219.0)	SL (409.0)	CR (304.0)	MN (299.0)
Average	126.93	129.77	123.97	148.62
Pesticide use (kg/ha)				
Min	AL (0.2)	MN (0.3)	NM (0.2)	NM (0.2)
Max	IT (8.4)	SL (7.2)	IT (7.4)	MN (6.2)
Average	2.73	2.20	2.08	2.74

2.3.2. Correlations between selected agricultural parameters

Data for all 13 countries, ex-Yugoslav republics were compared, and correlations between some of the selected parameters were tested. Table 3 contains correlations between variables which are statistically significant (p-value up to 0.05 or 0.01).

Table 3. Pearson correlation coefficients for different datasets (D1 – 13 selected countries; D2 - all EU member countries; D3 - EU members before 2000; D4 - EU members after 2000; D5 - non-EU members; D6 - ex-Yugoslav republics)

	D1	D2	D3	D4	D5	D6
SP-RP	-0.346*	-0.440*	-0.675*	/	/	/
SP-GDP_{ag}	/	0.503**	0.872**	0.512*	/	0.639**
RP-EM	0.538**	0.369*	/	0.485*	0.569*	0.496*
RP-GDP_{ag}	0.397**	/	-0.600*	/	/	/
EM-GDP_{ag}	0.841**	0.773**	0.963**	0.732**	0.889**	0.604**
FU-PU	0.619**	0.487**	/	0.766**	0.895**	0.826**

Correlation significant at level: **0.01 and *0.05

Pearson correlation coefficients vary depending on the dataset and variable pair analyzed. For three of the investigated datasets (D1-D3), there is a negative correlation between SP and RP. The strongest correlation between SP and RP is found in countries that were EU members before 2000. Correlation between SP and GDP_{ag} is not detected in datasets D1 and D5, and it is strongest for countries that were EU members before to 2000. Between RP and EM, correlation values are similar for all datasets, with the exception of D3, which has no correlation. There are correlations among RP and GDPag for just two datasets (all countries and for countries that were EU members before 2000), however their signs are opposite. All datasets exhibit positive EM and GDPag correlations and have high Pearson correlation coefficients. Correlations between fertilizer and pesticide usage have been observed in all datasets except D3, and they are greatest within non-EU member countries.

3. ENVIRONMENTAL ISSUES

The agricultural production systems should be considered in accordance with other natural ecosystems, *i.e.* it is importantant to take into account factors such as soil and water quality, nutrient cycling, soil structure and fertility, and biodiversity conservation.

Different fertilizers use in EU member countries is strictly regulated [14,15]. There is a trend to promote organic production which includes minimal, but necessary changes in quality of arable land. Average fertilizer consumption for all countries in selected period was around 133 kg/ha. In some of countries chosen for this study, fertilizer consumption in 2020 increased double (AL), around 30% (BU, CR) or around 60% (RO) comparing to 1990 (Figure 2B). At the beginning of study period, all these countries were not EU members. On the contrary, for countries which were already EU members (AU and GR) the consumption decreased around 35% and 26%, respectively.

The application of pesticides (insecticides, herbicides, fungicides) may cause contamination of the soil, surface and underground waters, food and the air, which may have an impact on human health [8]. To manage the entire chain of the pesticide market and use, the consumption of pesticides is strictly regulated in a number of countries [16,17]. Pesticide sales in the majority of EU countries decreased between 2011 and 2021 as a result of actions taken to mitigate environmental risk. In Italy, Romania, and Slovenia pesticide sales reduced by 29.1%, 26.8%, and 18.7%, respectively [18]. Among selected EU members, Austria's sales increased by 67.9%.

4. CONCLUSION

An evaluation of socioeconomic parameters influencing agricultural output and a comparison of conducted agrotechnical measures in 13 European countries with different EU membership statuses, during the period from 1990 to 2020, was done. A preliminary analysis was conducted based on the available data to detect some regularity in the relationship between the implemented measures and factors such as agricultural soil portions, rural population share, percent of employment in agriculture, and economic aspects. Countries with better economic status don’t implement agricultural measures more intensively without taking into account the potential consequences of their use. In these countries, legislation is much more implemented.

Acknowledgement: This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia; grant number 451-03-47/2023-01/200017.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

THE IMPACT OF PARTICULATE EMISSIONS ORIGINATED FROM AGRICULTURAL ACTIVITIES

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Abstract: *One of the most prevalent health and environmental problems, particularly in developing countries, is air pollution. It can lead to diabetes, lung cancer, cardiovascular and other diseases. Particle emission comes from a wide range of both natural and antropogenic sources. Particle emissions in agriculture originate from a number of activities, including tillage, planting, applying fertilizers and pesticides, harvesting, and controlled burning of plant residues in fields. Burning biomass represents one of the most prevalent ways of generating particulate matter (PM). Wind erosion of soil (mostly fine sandy and peaty soils) is another particulate matter source containing particles with larger sizes. This particle source can be significant at certain times of the year.*

Key words *particulate emission, biomass burning, open fires, crop yield, health risk*

1. INTRODUCTION

Natural sources of air pollution include volcanic eruptions, thunders, surface dust, and naturally occurring particle matter. The most significant contributors to air pollution include anthropogenic activities such as transportation, the burning of fossil fuels, industrialization, power generation, and agriculture [1]. Air pollution is one of the major environmental and health risks since annually it causes more than 4.2 million premature deaths worldwide [1]. Particulate matter (PM), which mostly appears as solid particles or liquid droplets, is one of the most important indicators of air pollution. PM sources are categorized as primary (natural and anthropogenic activities) and secondary (transformations in the atmosphere). According to air quality regulations, particles are categorized based on their diameter despite the fact that their size, shape, and chemical composition can vary a great deal. Fine particulate matter ($PM_{2.5}$) and coarse particulate matter (PM_{10}) consists of particles with maximal diameter of 2.5μm and 10μm, respectively. Both of them may result with serious health problems [2]. Sulfates, ammonia, nitrates, organic and black carbon, and metals are the main particle ingredients. Besides, there are also ultrafine particles with diameters up to 1μm. Many studies have indicated that combustion of agricultural residues, a large amount of ultrafine particles with diameters ranging from 0.1μm to 0.3μm is released [3-5]. Organic components make for more than 70% of ultrafine and fine particle masses, which make them more harmful to human health and the environment [2].

Agricultural activities (soil tillage, seedbed preparation, planting, harvesting, fertilizer and pesticide treatments), industrial processes, wood/fossil fuel combustion, construction and demolition activities represent some of the primary particle sources [6]. Agricultural air pollutants can cause human health problems through exposure to ammonia, hydrogen sulfide, toxic organic compounds, pesticides, particulate matter, and it can contributes to climate change due to greenhouse gas emissions and aerosols [7]. Except open-fire field burning, great problem and significant source of the air pollution represent wildfires. Due to climate changes, these occurrences are becoming more frequent. Except huge quantitiy of pollutants are emitted during wildfires, huge damages are caused and also often results in human casualties.

This article provides an overview of the contribution of different agricultural activities that generate particulate matter and leads to air pollution. Open-field fires are an important contributor to fine and ultrafine particle emissions in agriculture. The content of smoke emitted during open-fire burning of different agricultural waste is compared.

2. Contribution of agriculture sources to particulate matter emission

Agriculture contributes to primary $PM_{2.5}$ and PM_{10} emissions with 5% and 25%, accordingly [6]. As an example Figure 1 illustrates the portions of different agricultural activities as a particulate matter sources according to literature data for USA [8].

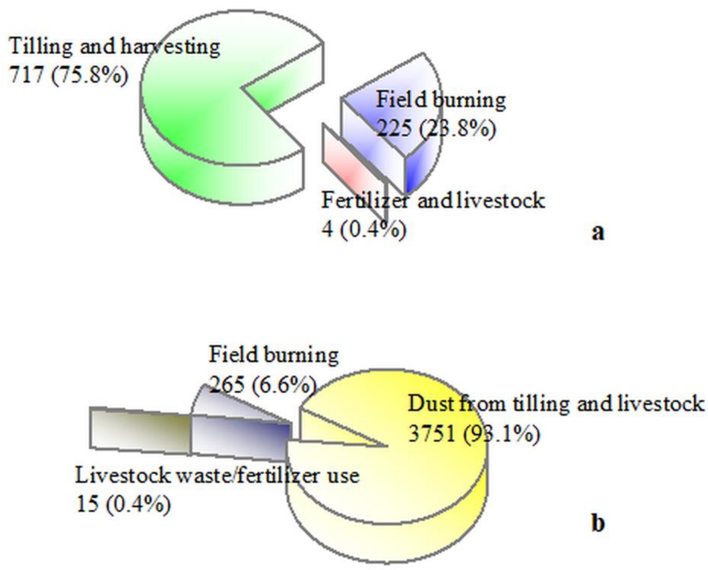

Figure 1. Agricultural activities in USA as a source of particulate emission (in kt); annual emissions of $PM_{2.5}$ (a) and PM_{10} (b)

The portion of particulate emission from agriculture to overall emission in USA was equal to 15.7% ($PM_{2.5}$) and 18.4% (PM_{10}) [8]. Among European countries in 2015, livestock farming was responsible for 85% of total agricultural emissions of PM_{10} and 22% of its overall emission [9]. The lowest emission of coarse particulate matter was noticed in Italy and Finland (around 580 kg/million euros), while the highest emission was noticed for Ireland (8 times higher) [9].

3. AGRICULTURAL WASTE OPEN BURNING

3.1. Advantages and disadvantages of open-fire burning of agricultural waste

Open-fire burning of agricultural and garden residues shows some advantages. It is a rapid method to reduce/dispose of vegetative debris, allowing for land clearance and the release of nutrients for the next growth cycle, fertilizing the soil, and pests and weeds elimination.

Simultaneously during a fire, smoke can raise PM content many times [10,11]. Open fires and wildfires impose considerable ecological and economic harm [12]; they are a significant source of harmful air pollutants into the atmosphere with short- and long-term negative effects on human health [13,14]. Many studies have shown that ultrafine and fine particles are more dangerous to human health than coarse PM, since smaller particles can penetrate the respiratory system more deeply [15,16].

3.2. Content of smoke generated from combustion of various agricultural waste

In China, agricultural burning accounts around 8% of anthropogenic annual $PM_{2.5}$ emissions and approximately 26% of overall $PM_{2.5}$ during harvest seasons [17]. Carbon dioxide (CD), carbon monoxide (CM), nitric oxides (NOx), particulate matter (PM) and non-methane hydrocarbons (NH) are major components of agricultural burning smoke. Depending on type of combustion, the emitted gases and content of particles differs. In Table 1, as an illustration, the comparison of smoke content is given.

In Table 1, the comparison of smoke content depending of agricultural crops combusted in open-field was done. Literature data concerning carbon dioxide, carbon monoxide, nitric oxides, particulate matter and non-methane hydrocarbons in corn, wheat, soybean, sugar cane and potato smoke generated during their burning. Average, minimal, and maximal contents are also given. For these five crops there is no significant difference.

Table 1. Details about content of smoke generated during burning of different agricultural waste

	Initial biomass*	CD	CM	NOx	Total PM	NH	Ref.
	Tg/year			Tg/year			
Overall	540	818	50	1.3	3.5	7.0	[18]
Cumulative	/	939	45.9	1.8	4.1	6.4	[19]
Crop		CD	CM	NOx	$PM_{2.5}$	NH	Ref.
			g/kg (of dry matter)				
Corn		1261	70.2	3.4	5.0	10	[20-22]
Wheat		1557	61.9	1.2	7.6	7.5	[20-23]
Soybean		1445	32.3	1.1	3.3	8.6	[21,23,24]
Sugar cane		1445	40.1	2.0	4.1	11.0	[21,22,24]
Potato		1445	55.1	2.1	5.8	8.6	[21,24]
Average		1430.6	51.9	2.0	5.2	9.1	
Min		1261	32.3	1.1	3.3	7.5	
Max		1557	70.2	3.4	7.6	11.0	

* Total dry mater

4. CONCLUSION

Among agricultural activities that generated the greatest amount of air pollution is open-field burning of agricultural waste since it is widely used as an inexpensive means of its disposal. Despite strict legal frameworks in many countries, this method for agricultural waste elimination is still used. It is very difficult to change people's consciousness on this issue, because it is necessary to involve farmer extension education, political will, and funding. Since climate changes become more intensive and the air is very polluted and harmful, it is very important to decrease the emission of pollutants.

Acknowledgement: This work was supported by the Ministry of Science, Technological Development and Innovation of Republic of Serbia; grant number 451-03-47/2023-01/200017.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19^{th} – 21^{st} Oct 2023, Belgrade–Zemun, Serbia

MEDICINAL PLANTS IN PROTECTED AREAS: A STRATEGY TO PRESERVE THE ENVIRONMENT AND BIODIVERSITY

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Abstract: *Agricultural innovations during the 60s led to a significant increase in crop production, primarily driven by advances in technology, crop breeding, and agricultural practices. While they had many positive outcomes, it's important to acknowledge the negative consequences, more notably environmental damage. The increasing awareness of the need to combat environmental degradation, coupled with a heightened focus on making healthier dietary choices, has prompted a resurgence in the exploration of the therapeutic potential of medicinal plants. This includes spontaneous varieties, which have historically been used in pharmacopoeia, food and cosmetics. Farmers are progressively embracing the cultivation of medicinal plants, often without the necessity for substantial investments; moreover, they don't come at an environmental cost, because synthetic products such as fertilizers and pesticides aren't used. A shift away from this reliance reflects a more sustainable approach from both a landscape and environmental perspective. This study investigates the cultivation of various medicinal plants in a protected area in Basilicata, with the main focus on assessing the potential presence of agricultural plastic waste streams and their corresponding management practices. Initial findings confirm the scarcity of such waste, highlighting the sustainability of the medicinal plant supply chains.*

Key words: *Agricultural plastic waste, sustainability, landscape, environment, life quality*

INTRODUCTION

The Green Revolution unfolded between the 1940s and 1970s and marked the integration of pioneering technology into the agricultural sector. This period witnessed the growth of cutting-edge techniques, primarily revolving around plants, their genetic enhancement, the creation of hybrid varieties and the selection of new varieties. Substantial capital investments were also made. The key elements are summarized here:

- formulation of new synthetic products namely fertilizers and pesticides;
- development of new irrigation methods, with a variety of uses;
- technical advancements in machinery and tools to automate work processes cultivate much larger areas more easily;
- adoption of agricultural plastic materials that have revolutionized cultivation practices and techniques and the marketing of agri-food products.

This undeniable surge in productivity has created significant environmental and health challenges. Towards the end of the last millennium, the excessive and indiscriminate use of chemicals, wastewater, machinery and plastic materials resulted in a notable increase in environmental pollution, affecting air, water and soil [1]. In recent years, a heightened awareness of widespread environmental degradation has driven the incorporation of socio-environmental concerns into the core objectives of the common agricultural policy. A prominent example of this can be seen in the adoption of stringent European Union Regulations that impose limits on the use of hazardous chemical substances, especially in protected areas. Farmers who actively embrace environmentally responsible practices are duly recognized and incentivized for their efforts [2].

In line with the most recent regulations, consumers are increasingly prioritizing environmental concerns and their personal health, leading to a shift in dietary preferences, favouring high-quality food and a heightened awareness of production methods and product origins [3]. Traditional food crops are gradually declining in popularity, leading farmers to opt for the cultivation of traditional plants, now considered niche. These plants serve a purpose, not only in the agri-food sector but also in pharmaceutical, herbal remedies and nutraceuticals. Medicinal plants are a natural fit within this category as they possess dual qualities of nutritional and medicinal value. Moreover, they can be produced using sustainable techniques and methodologies.

2. MEDICINAL PLANTS (MPS)

MPs encompass a wide and diverse array of species, each distinguished by unique botanical traits, biology, habitat and practical applications. However, they share a common feature – the presence of active substances, albeit distinct ones, that hold remarkable efficacy across various fields of application [4]. These substances can be consumed in their natural form or following suitable processing or extraction methods. In Italy, MPs are referred to as “officinal plants” drawing their name from the Latin word "officina" meaning a pharmaceutical "laboratory". Italian law, specifically Law No. 99, 1931, classifies MPS into a diverse and expansive group of plant species, categorizing them into three distinct classes: medicinal, aromatic and perfumed plants. Around over 300 plants in Italy are categorized as medicinal, however, literature often presents conflicting data due to their diverse range of applications, for example, lemon balm is not only used for its healing properties, it is also found in cosmetics. According to Assoerbe, 45% of Italian MPs are for pharmaceutical use, 40% for food use and 15% for cosmetic use" [5]. With the advent of the new millennium, the abundance of wild MPs, particularly in areas untouched by human contamination proved adequate to meet the market’s demand for whole or part plant (leaves, roots etc.) active ingredients. In recent years, farmers have started cultivating MPs which generally do not require large investments such as greenhouses or tunnels, or an excessive use of synthetic products like fertilizers and pesticides. This makes the cultivation of MPs inherently environmentally friendly. The cultivation of medicinal plants, therefore, is a sustainable practice from a landscape and environmental point of view. The cultivation of traditional medicinal plants has the potential to combat environmental and cultural degradation. In Italy, the cultivated medicinal plants sector demonstrates significant dynamism and remarkable entrepreneurial spirit, despite its status as a relatively niche crop compared to those more widely used.

2.1. Medicinal Plants in Basilicata

Between 2010 and 2019, the MPs sector in Basilicata, a small region in southern Italy (Figure 1), experienced substantial and consistent growth, in line with the national trend. In fact, the cultivated area for MPs in the region expanded almost tenfold [6]. Table 1 provides a schematic representation of the key milestones characterizing the growth in this sector. Today, MPs have become a defining feature of many landscapes, integral to local food, gastronomic and production traditions, as they are woven into the history and culture of many places. In many regional areas they represent important production entities, so much so that micro-supply chains have been active for over a decade (Table 2) [7, 8]. These are well established, robust organisations catering to an increasingly broad and discerning consumer seeking products with high nutritional standards and medicinal properties.

The project entitled “MEdicinal PLAnts in a Sustainable Supply chain – experience of land use practices. Experience of land use practices”, MEPLASUS, received funding in 2021 from the 2014/2020Basilicata Regional Operational Programme. Its main objective is to strengthen the local MP micro-supply chains in a protected area of the Pollino-Lagonegrese Rural District. The project aims to foster collaboration between key research institutions in Basilicata, including CREA-PB, UNIBAS and ALSIA, which specialise in agricultural experimentation, along with entities engaged in the production and transformation phases of MPs.

Figure 1 Map of the Basilicata Region (also known as Lucania)

Table 1 Evolution of the Lucanian sector of the MPs

When	Where	Who/what	Note
60's	In many areas of Basilicata, especially in Pollino/Lagonegrese	Local collectors	They confer voluntary MPs to intermediaries of national processing industries for the production of perfumes and cosmetics.
End 70's	In Pollino/Lagonegrese area	Italian Quadrifoglio Law no. 984/77 Regional Law no. 4/78	They have financial interventions in favour of research, cultivation and increase of medicinal plants
90's	Pollino area	TumTum Cooperative	Mixed and disappointing results
	Lands of the Land Reform in Irsina (MT)	Sud Officinale Cooperative	Grows many species of MP, especially herbs and licorice
Year 2000	Regional area	no. 60 farmers	They cultivate 15.54 hectares in MP
Year 2010	Regional area	no. 10 farmers	They cultivate 23.60 hectares at MP
Years 2012–2013	Southern area of Basilicata = Pollino area	ALSIA (MEPLASUS project partner)	Tenders for demonstration fields of various species, technical assistance and territorial animation ➒ strong increase in terms of farms, surface area and cultivated species
Year 2018	Regional area	Italian Law (no. 75/2018)	On cultivation, harvesting and first transformation of MPs, it is the new and most recent regulation of compartment
Year 2019	Regional area	ALSIA (monitors)	More than 50 companies on about 80 hectares
Year 2020	Irsina (MT)	Sud Officinale Coop.	Develops organic production
Year 2021	Transnational Cooperation Project (n. 5 PP and n. 20 stakeholder)	ME.PLA.SU.S.	Foresees the enhancement of the MP supply chain according to innovative models including circular economy and reuse of production and processing waste

MEPLASUS is a transnational cooperation project, partnering with the Hellenic Agricultural Organization research and experimentation centre, DEMETER in Athens, Greece and the University of Belgrade in Serbia. Italian, Greek and Serbian stakeholders are involved in various steps of the micro-chain. The initial phases of the project involved historical, landscape and socio-economic analyses of the Basilicata area. The project advanced through the exchange of best practices and knowledge between the partners involved [9]. The project is in its final stages, with ongoing analyses of results stemming from diverse activities. As part of the project's efforts to verify the environmental sustainability of the cultivation of MPs, one of its tasks focused on exploring the possible use of agricultural plastic materials, the management of resulting waste streams and their associated practices.

Table 2 Lucanian's micro supply chains of MPs

PRODUCER	**NOTE**	**PROCESSING COMPANY**	**PRODUCT**
Sud-Officinale Coop. in Irsina (MT)	Over 16 hectares of biological agriculture	**Bioplanta Company**	ESSENZIAL OILS
F.L.E.O. partnership (n. 53 partners, 3 public)	Produces 17 MPs for "Amaro Lucano"	**Amaro Lucano** in Pisticci (MT)	LIQUOR
	Plants for small and medium distribution	**SpeSì (brand)**	SEASONING PLANTS
Lucana Officinali Society Cooperative in Pisticci (MT)	Over 70 hectares	**EVRA Italia srl** in Lauria (PZ)	FOOD SUPPLEMENTS
Lucanian Regional Association of MPs and Saffron Producers in Chiaromonte (PZ)	n. 40 producers	**EVRA Italia srl** in Lauria (PZ)	FUNCTIONAL FOODS and SAFFRON
Sud Aromatica in Senise (PZ)	Many MPs, over 100 hectares		ESSENZIAL OILS
ORTI LUCANI Piante officinali	Business network (270 companies)		

3. MATERIALS AND METHODS

To verify whether MPs were a key strategy to preserve the environment and biodiversity in the protected areas of Lucania, the authors analysed plastic waste flow, types and quantities from the cultivation and processing of medicinal plant. As a result, CREA-PB, Lead Partner (LP) of the MEPLASUS project, developed two questionnaires: one aimed at producers and the other at processors. Both questionnaires were designed with a structured format, featuring predominantly closed and multiple-choice questions to streamline the completion process.

The questionnaires were originally written in Italian and sent to the Lucanian Agency for Development and Innovation in Agriculture (ALSIA), a Project Partner (PP). ALSIA distributed the questionnaires to some companies in the Pollino-Lagonegrese area, a

Lucanian protected area where there are a large number of producers and where there are traditionally abundant and spontaneous MPspecies.

The LP translated the questionnaires into English and sent them to the Foreign PPs (Faculty of Agriculture of the University of Belgrade and HAO Demeter) for research to be carried out in Serbia and Greece.

The main questions were:

- What kind of plastics do you use (films, nets, containers, etc.), relative to your medicinal plants?
- What is the annual consumption for each type of plastic material?
- What is the amount of waste produced for each type of plastic material?
- Are there national (or territorial) laws that regulate agricultural plastic waste management? Do you know?
- How do you dispose your agricultural plastic waste (direct delivery, third-party pickup, etc.)?
- Do you know the final disposal site location for your waste (recycling plant, landfill, other)?
- Do you pay to dispose your waste?

At this initial stage, the authors considered it appropriate for ALSIA to distribute the questionnaires to 15 producers and 2 processors.

In addition, the authors asked the same questions to some Italian producers and processors at two events:

1) November 8-10, 2022 study visit "A stroll through the history of medicinal plants in Basilicata" organized by CREA-PB, the UniBas Science Department and ALSIA, attended by researchers, producers, processors and stakeholders. Study days allowed for an in-depth study of some typical issues of the Lucanian MPs microsector and fostered the exchange of knowledge; all aimed at the enhancement of quality production, such as MPs, to valorise protected and/or marginal areas;

2) February 3, 2023 the first Interregional and Transnational Cooperation Projects Communication Day, financed by the 2014/2020 Basilicata Regional Operational Program, Call for Projects. Organized by the Managing Body of the Basilicata ERDF Operational Programs. This day provided a valuable platform to gain insights into the projects' goals and objectives. It also facilitated the exchange of ideas, knowledge and experiences among diverse researchers and stakeholders from various projects. Additionally, it attracted the interest of engaged attendees, including those with a keen interest in the topics under discussion, notably MPs.

4. RESULTS AND DISCUSSION

4.1 What emerged from the face to face interviews

Through firsthand interviews with Italian producers, processors and stakeholders, it emerged that the main and most widespread MPs cultivated are saffron (Crocus sativus L.), helichrysum (Helichrysum italicum), rose hip (Rosa canina), pulegia mint (Mentha pulegium L.), peppermint mint (Mentha piperita) and lemon balm (Melissa officinalis L.). Here are the key observations regarding Lucanian producers:

MP producers typically fall into the category of opportunistic farmers who are driven by personal passion or perceive economic advantages in cultivating native plant species on their land. However, MP producers are not specialist growers willing to invest heavily in equipment for growing, harvesting, initial processing and, in some cases, post-harvest processing of herbs for direct production of extracts.

Generally, they fulfil the requirements set by processing companies who are more attuned to market demand. However, if farmers fail to carry out thorough feasibility studies and market surveys, they run the risk of making ill-fated investments.

A case in point involved a group of Lucanian young farmers who benefited from the first liquidation loan (PSR 2007-2013 Measure 112 Setting up of young farmers). These entrepreneurs ventured into growing oregano, lavender and coriander without carrying out market analyses. Since demand for these herbs was already well-saturated at that time, they encountered numerous obstacles that ultimately forced them to cease their activity.

To compensate for the lack of mechanization and their reluctance to make substantial capital investments, some Serbian farmers, either through cooperative affiliations or collaborative efforts with neighbouring farmers, contemplated the idea of using communal machinery. However, they quickly realized that this concept had its limitations due to logistical challenges. In fact, if more farmers require access to machinery in the same time, co-ordinating shifts should become logistically difficult, potentially leading to production losses for some growers.

Fortunately, there has been a positive shift among younger operators who have expressed a willingness to invest in small-scale mechanical equipment.

The majority of these farms are small in size, with cultivated areas for MPs typically covering less than one hectare. The choice of plant species and the production objective determines the specific acreage.

Producers commonly sell medicinal plants either in their entirety or in parts, such as roots, stems, leaves, etc.) to processing companies. The latter produce an intermediate or final product. In particular, producers in the Pollino-Lagonegrese area deliver most of their crops to the EVRA s.p.a. plant in Lauria which produces supplements.

Finally, the interviews revealed how difficult it is to find manufacturing companies that are also final processors and distributors of the final products, due to many complex rules and regulations. The transformation of MPs involves laboratory processes, authorizations and quality controls. Moreover, standards vary depending on the intended final product (food, cosmetics, supplements, etc.). While this complexity does not render the activity impossible, it does make it a pursuit that is certainly not accessible to everyone, as stated by one Greek producer.

The most well-established processing companies in Basilicata predominantly specialize in the production of essential oils, primarily for cosmetics and perfumes as well as dried herbs used in the preparation of infusions and semi-finished medicinal products.

4.2 Questionnaire results

These results only refer to the questionnaires distributed in Italy and are pending the arrival of all the questionnaires distributed in the Greek and Serbian territories. In reference to the consumption of plastic materials (Table 3), it emerged that:

- Producers do not use agricultural plastic materials as covering or mulching films for various reasons:
- MPs are not profitable enough to be grown in protected environments; only one producer grew basil in greenhouses and sold it as a whole seedling;
- The results confirmed findings in literature that the production of dry or essential oils yields superior results when MPs are grown in open fields and in full sun; in fact, greenhouses are not conducive to such cultivation, as even partial reduction light (20%) through the greenhouse panels would negatively affect production;
- Shading nets are not used for this reason;
- Mulching is not practiced;
- 77% adopt drip irrigation using polyethylene-PE pipes and header pipes;
- 40% administer small quantities of fertilizers, e.g. too much nitrogen makes the plants tender, fragile and unfragrant. Fertilizers are sold in bags (traditional or biodegradable plastic), bottles (plastic or glass) or cardboard boxes (Figure 2);
- Less than 5% resort to the use of synthetic products for defence providing further confirmation of the resilience and tolerance of medicinal plants to various adversities, including parasites and fungi. Furthermore, there are no pesticides available to combat cryptogamic diseases. In Italy only 24 active ingredients are sold, primarily used for preserving the freshness of certain species such as sage, thyme and rosemary. In contrast, other European countries, such as France, Germany, Austria and Poland have access to 53 different substances for this purpose. The application of herbicides is limited to only a few species such as peppermint, fennel, parsley and celery. Pest control measures against insects are seldom necessary, as medicinal plants are not typically susceptible to aggressive species;
- Everyone declared that they use paper bags to transport the raw material to the processing companies.

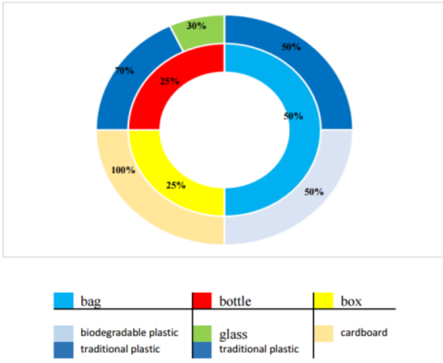

Figure 2 Types and consumption of fertilizer packaging for MPs

The converters stated that they make very little use of plastic materials; in fact, their products are mostly packaged in paper bags or glass containers.

Wrapping films represent the type of agricultural plastic products that yield higher quantities of waste, due to the large volumes used and the need for frequent replacements due to their "degradation" (characterised by a decline in spectro-radiometric properties). However, due to the limited adoption of protective structures and measures, there is an absence of plastic films, sheets and nets resulting in no waste generated (Table 2).

Table 3 shows the waste stream is considerably limited since these productions started no more than five years ago, as such some products are still "new" in terms of their lifecycle.

The minimal generation of agricultural plastic waste in the MP sector can be even attributed to two additional factors:

- MP cultivation is not extensively practices on a large scale;
- MP cultivation typically adheres to techniques and methods commonly associated with organic farming practices.

No specific directives are necessary to farmers for waste management, given the absence of substantial quantities of plastic waste. Questionnaire responses clearly highlight the conscientious and responsible conduct of producers who are well-versed in environmental regulations and demonstrate exemplary waste disposal practices. They ensure clean plastic is directed to municipal recycling centres or ecological recycling

Table 3 Agricultural plastic materials and waste

Plastic waste	**Useful life**	**Notes on waste**
Cover film	3 -4 (years)	Respondents do not use it: NO WASTE
Mulching film	seasonal	Respondents do not use it: NO WASTE
Net	10-15 (years)	The few manufacturers that use the nets have stated that they have been buying them for no more than three years*: NO WASTE
Irrigation pipe	15 - 20 years (with good and periodic maintenance)	The Italian producers irrigate (drip system) but rather recent systems (max 5 years) while growers said they mainly practice emergency irrigation after prolonged dry spells; moreover the irrigation systems are recent* (max three years): NO WASTE
	Head irrigation pipes	20 years (with good and periodic maintenance)
Manure/fertilizer containers		Generally, plastic waste is produced with each treatment, but the number of treatments MODEST WASTE is minimal
Pesticide containers		Generally, plastic waste is produced with each treatment, but as previously indicated, the producers cultivate the MPs above all according to techniques and methods typical of organic farming: POOR WASTE
Bags for transport from the producer to the processor	Paper bags are generally used, if plastic they are reused POOR WASTE	
Packaging for the trade of finished products	POOR WASTE	

centres. This involves delivering recyclables directly or scheduling collection through specialized companies direct from the premises.

3. CONCLUSION

The research findings have revealed that within the scope of MP cultivation in Basilicata, the generation of agricultural plastic waste are negligible. This confirms their role as "benefactors of the landscape and the environment", and further supports their potential for wide spread cultivation, also in protected areas. Cultivating MPs in marginal areas can serve as a means of enhancing them without imposing substantial financial burdens on producers. Finally, the widespread cultivation of MPs can have significant impacts on both life quality and ecosystems, while also playing a pivotal role in the preservation of biodiversity.

***Acknowledge**: This study was carried out as part of the activities envisaged by the interregional and transnational cooperation project MEdicinal PLAnts in a SUstainable Supply chain. Experience of land-use practices (ME.PLA.SU.S.) (CUP C45F20000540002)*

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Economics in agriculture

ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

DIGITALISATION AS A TOOL FOR FARMERS COOPERATION CONCERNING PROCUREMENT AND DISTRIBUTION MANAGEMENT

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Abstract: *Aim of this paper is to introduce a model, which provides effective solutions and support for establishment of the agricultural input and output market systems. Input used in agriculture are mostly technical systems, chemical materials and biological products. The output are the crops, livestock products and energy.*
Consequently, profit of agriculture is extremely low and production enlargement is not possible. Possibility to change this situation can be the online-marketplace, which can be created at the input or/and output side. These fields could improve procurement and distribution conditions of agriculture and imply chances to enlarge production through better profit.
The system should foster the producers, should foster more successful production, and must not restrain them. Hence it should provide market advantages at all the elements of the production (regardless the size of property and production system). Therefore, a real solution could be made for practical development of agriculture by increase of suppliers' competition situations.

Key words: *farmers cooperation, online-marketplace, procurement, distribution, price competitions*

1. INTRODUCTION

In Hungary the former system, which worked intensively has been the "production systems" based on big factories (Tardos and Sári, 2003), (Balogh, 2012). These systems have been established along production paths (Szabó, 2000, 2001). The system administrators have provided the input, they have worked up the production experience, and hence a "self-learning" system has been made. They have taken expectations of the market that time into consideration. For the time being the production structure and the market have been altered and we have not found the production system that could meet the challenges (Tóth, 2000), (Széles, 2003)

Changing of the present European Common Agricultural Policy (CAP) can be expected (Walenia, 2022). Decreasing the deforming impact of the supporting system the role of innovation is more and more important (Fieldsend, 2020). Our model supports it effectively in many areas (e.g. optimization of invests and operation, reducing of production costs, increase of the research efficiency). Our unique agricultural possibilities are capitalized using the planned up-to-date information system, making competitive advantage for farmers and food industry. In addition, the system will be advantageous for inputs production, mostly for agricultural machine industry (Teuteberg, 2020), (Kusumawati et al., 2022).

In a small-scale farm environment significant savings can be achieved by the common utilisation of the machines and by the employing professional machine works both in the investments and the machine operation (Nagy, 2007), (Magó, 2009). Those beneficial machine service and collaboration forms are used worldwide, especially in the agriculture of the developed countries (Nagy and Magó, 2004), (Tot et al., 2018). In past years status quo analyses and the evaluation of experience showed that there is need for the farmers cooperation in the East European countries including Hungary for the rational utilisation of resources and to improve the efficiency of assets and to minimize costs (Takács, 2001). However, the organizations, structures, schemes, models and frames of standard forms has not been formed as yet, so that the utilisation of the advantageous solutions is on quite a low level (Magó, 2007), (Schnicke, 2011).

The successful formulation of machine utilisation and business supporting forms decisively depend on the conditions and the appropriate knowledge about the properties of the different forms (Baranyai and Takács, 2007). It is highly important that all the factors and characteristics should be discovered for the benefits and disadvantages of forms from the organisational, operational, economical, and all the other points of view in order to determine and declare the criteria of introduction for each economy circles of farmers (Takács-Baranyai, 2010), (Yuan, 2022), (Etro, 2021).

2. METHOD

As estimated, in Hungary the turnover of the input could approach a several billion EUR annually. It is supposed that the input side pressure is indicated in 15-20 % of extra profit from traders towards producers, which means that producers' profit possibilities are reduced by this rate in the rate of utility. On the other hand, annual sponsored limits of agriculture have been realized to a great extent by purchasers of produced materials through the pressured purchase price.

The relationship between producers and input providers is quite determined in the field (Koester, 2020). It means that input users are connected tightly by the agency of manufacturers and traders and their relationship is determined by traders' profit maximisation. In this relationship a producer has hardly any possibility to compare complete supply portfolios and validate suppliers' most favourable proposals (minimal procurement price, the best quality, etc.)

Aims of this model are:
- establishment of competition situation among input providers,
- enlargement of supply side,
- discontinue inflexible trade structures.

in order the most favourable procurement conditions could be made.

The system enables the producers' common tender announcement. This could be resulted in a more favourable position in the tender announcement through quantity increase of claims arisen in one transaction by competiting the participants in the supply position.

The information system, which substitutes effects of large-scale plant and the self-learning structure provide that the solutions described in our model provide an intensive development path for the agriculture.

The alteration in the online-marketplace and interests could be seen on Figure 1.

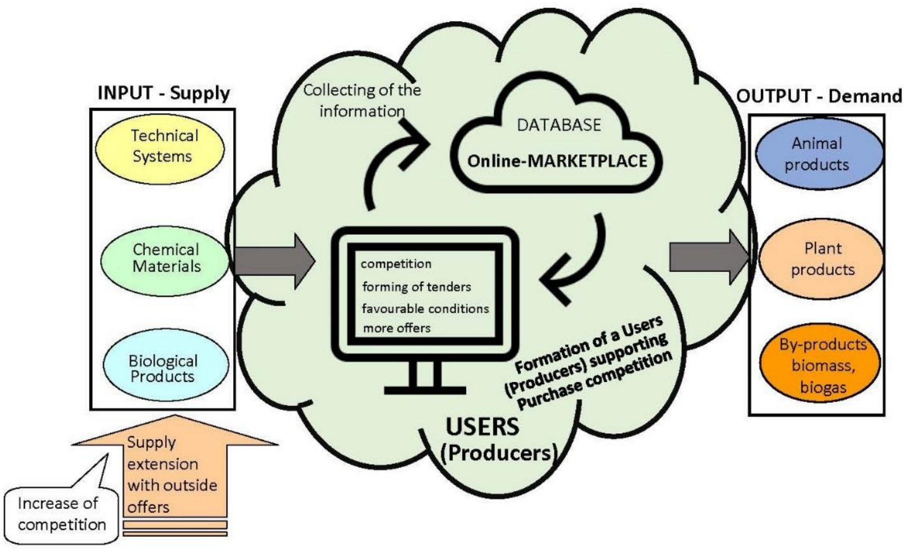

Fig. 1 The online-marketplace and interests (based on: Magó and Fenyvesi, 2009, own editing)

3. RESULTS

3.1. Elaboration of the procurement and sales competition supporting producers

Central element of development is the database, which is the basis of the online-market place. For users (producers) the market field collects proposals as well as helps to write procurement tenders and sales tenders, hence it fosters competition of suppliers and purchasers. Producers can achieve more favourable positions by this system in terms of procurement price level, quality and other product qualities regarding their input materials (technical systems, chemical materials, biological products).

Despite the fact that participants in the supply market will compete with each other, they will have also advantages since supply market of the input products provided by them will be more transparent also for them and can be planned in an easier way and specification of participants in the market will be more simply. Therefore, efficiency of their trade will increase.

Number of participants in the supply can gradually increase since the system expects new members. As a consequence, competition can increase, number of products in supply can increase and their quality features improve.

3.2. Advantages realized by participants of the online-marketplace

By using the "online-marketplace", it will be the producers on the first place who will have advantages since their agriculture can be planned in an easier way and can be transparent. Besides the faster information flow, they can achieve decrease in their cost. Quality assurance and standardization guarantee utility and marketing of quality products.

Table 1 Advantages realized by participants of the online-marketplace

Benefits		
from the viewpoint of **distributors**	Plannable input claim, demand supply balance	
	More efficient trade	
from the viewpoint of **farming**	Plannability	
	Transparency	
	Cost reduction	
	From the view of input output quality assurance, standardisation	
	Fast information flow	
stimulation of **cooperation**	Forming of common machine usage forms, machine circles	
	Development of modern technological solutions, introduction	
	More efficient appearance into loan offices' direction	
	Global market information	
	Common logistical solutions	
from the viewpoint of concerned **authorities**, **government**, **market players, experts, R&D&I**	Forming of a regional informational system	Accurate data from the use of the inputs (qualitative, quantitative features, temporal)
		Statistics to the subsidy-, aid systems, market forecasts, (crop estimation based on inputs and a sowing construction
	Registration of expenditures, realizations	
	Optimisation of EU and national subsidies	

By inducing this system, cooperation among producers will be fostered. Creation of common utility forms of machines and machine types can increase efficiency regarding machine procurement and utility of machines. Cooperational solutions foster use of results achieved due to modern technological solutions. Apart from production devices, access to money assets can be improved. The method how to obtain market information can be developed, as well. Also a common logistical solutions could be improved.

Besides producers and distributors, the system provides advantages also for the government, authorities, experts and other participants of the R+D+I market.

A field informatics system can be accomplished by which we could get an exact picture and data about utility and time-quality-quantity features of inputs. Collection of data can be provided for the supportive market forecast systems (estimation of production on the basis of structure of inputs and products). It can contribute to optimization of the national and the EU subsidies.

Structure of costs and marketing can be monitored at traders and producers implied in the system.

On the Table 1 we can follow the benefits of the usage of online-marketplace.

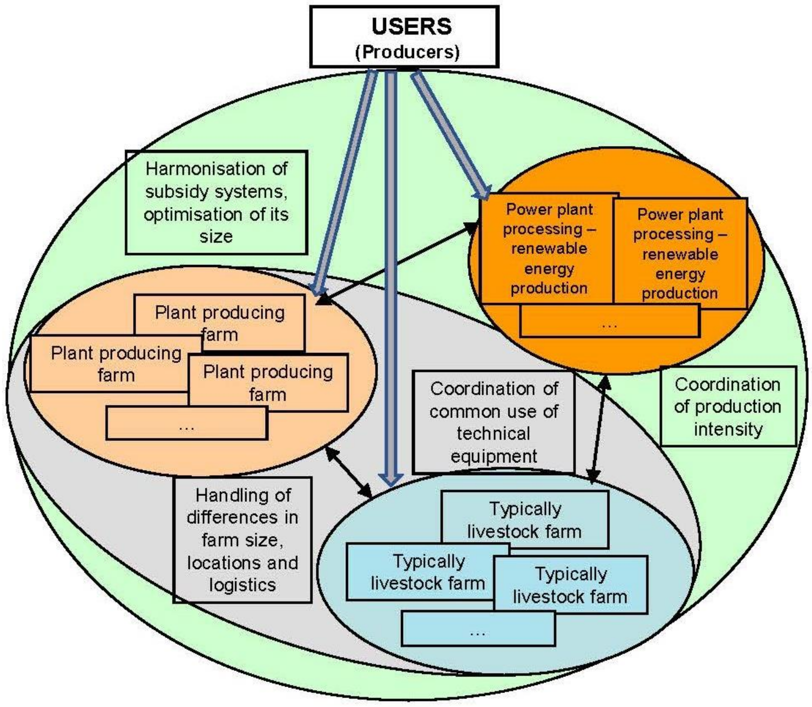

Fig. 2 Structure of participants in the online-marketplace (source: Magó and Fenyvesi, 2009, own editing)

3.3. Structure of participants in the market field

Considering structure of users (producers), they can belong to different branches. Plant production and livestock farms can be emphasized (these can be also mixed plant production and livestock farms). The energy plant process factories using products of plant production agriculture produces energy out of agricultural renewable materials. By using the system, these factories can enter by their claims regarding input materials for procurement while they are interconnected no matter where they are located or how big or small they are. Cooperation can extend to harmony concerning common utility of technical devices as well as accomplishment of a more effective access to money assets. Coordination of intensity regarding production can be accomplished on a higher, more comprehensive level by participation of more producers. Moreover, harmony of supportive systems and their optimization in accordance with their different stimulating measures could be more accurate and deeper professionally. (Figure 2.)

3.4. The system covering participants of the online marketplace

The information system that is going to be established stimulate users (producers) to cooperate with each other. It provides conditions of effective information flow by covering all of the users. It provides a common base for application of innovation systems. Coordination of R+D+I tasks can be accomplished mutually by covering a bigger production structure. (Figure 3.)

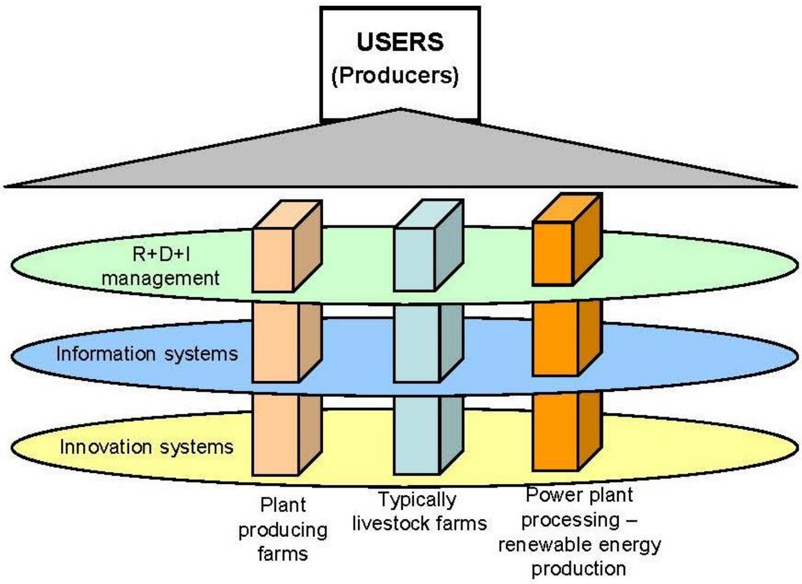

Fig. 3 The system covering participants of the online-marketplace (source: Magó and Fenyvesi, 2009, own editing)

4. Conclusions And Recommendations

Agricultural production is largely carried out by small and medium-sized enterprises and farmers. These enterprises and farmers can accomplish concentration necessary for obtainment of market advantages very hard. Therefore, such a system is necessary, which can coordinate and keep in touch with producers and is self-assertive in an effective way.

By the model of a marketplace, which can be considered a trade and production system in agriculture and its aims to take the following stipulations into consideration, so the characteristics of users in the market field should be (Magó-Fenyvesi 2009)

- We consider producers autonomous and equal farmers/organizations, which could have the best situations to make decisions. We do not restrict their decisions about production.
- Market relations are essential, and activities as well as production must meet the requirements set by the market.
- The system must comply with the market and all the requirements that arise during its operation, such as environmental regulations and subsidies. It is these requirements that determine the conditions of operation, not the functioning of the scheme.

The system should foster the producers, should foster more successful production and must not restrain them. Hence it should provide market advantages at all of the elements of the production (regardless the size of property and production system). As a consequence, a real solution could be made for practical development of agriculture by increase of suppliers' competition situations.

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MACHINE FLEET MANAGEMENT OF PLANT PRODUCTION FOR BIOMASS AND BIOETHANOL PURPOSES CONCERNING LOGISTICAL AND MACHINE WORK COSTS

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Abstract: *This work is a comprehensive examination that analyses the machine fleet formation and machine use of plant production farms that grow sweet sorghum too by using computer aided modelling. It considers the characteristics of machines used at the production technologies of different plants and it especially focuses on the appliance of machines with the convenient capacity and power level from the side of costs at different farm sizes.*

We can conclude that the difference between the costs of the small and the large-scale farm size is significant. This all can be explained with the efficiency of the machine exploitation.

In the field of costs there is also a difference between the use of modern and less modern machines. In case of small-scale farm size, with using less modern power-machines a more advantageous cost level can be reached, although the quality of the work and the circumstances of the working must be considered. In case of large-scale farm size, the difference between the operational costs of the less modern and more modern machines decrease significantly, because the operation of the less modern machines is more expensive at larger strain and the high-level constant costs of the modern machines decrease significantly, according to their better exploitation, considering one unit of work.

Key words: *renewable plant production, farm size, machine fleet management, machine usage, machinery cost*

1. INTRODUCTION

The goal of the research is the technical-economic analysis of the production-technology system of the sweet sorghum that is known as energy plant and nowadays as a promising base material of biotechnological industries [1].

Work done *by an efficiently developed machine system* is a significant condition of the fruitfulness of farming [2]. The machine prices and the cost of their utilization are extremely high and all these result in extraordinarily high production costs. *Rational machine utilization* is a definitive factor of the efficiency of farming [3].

We have accomplished the examinations by taking power-machines from different quality and cost levels as base. Through this we have showed that not only the size of the farms effects the amount of the operational costs, but the standard of mechanization too [4].

2. MATERIALS AND METHOD

2.1. The sweet sorghum *(Sorghum vulgare saccharatum)*

The sweet sorghum is one of Hungary's plants that is capable to produce the greatest amount of biomass and it's production can be fitted in the conventional alternation of the cereals and industrial plants and the outstanding yields can be ensured at lower costs than other cultures. From the point of view of energetic use, the component of the sweet sorghum that is classed as secondary product, the high sugar content solution that can be pressed from the spears, that is a suitable base material for bioconversion methods. The amount of the productable sugar reaches or exceeds the amount of the glucose that can be produced from cereals grown on a land with the same size. The complex use of the components that can be obtained from the sweet sorghum can significantly increase the reachable profitableness of agriculture [5].

The plant is subtropical, needs hot weather and takes drought significantly. It is also called durra or sweet-cane. It was grown in a higher amount between the two world wars. After the II. World War, until the start of the sugar production, the sugar containing syrup pressed and condensed from the plant was used instead of sugar. Nowadays it is mainly used to produce silage fodder, planted with silage corn. The growing conditions are very advantageous, because the sweet sorghum gives a stable yield even in case of poor water supply (60-70 tons/hectare) [6].

2.2. The surveyed crops

The surveys can be conducted by *modelling* the machine working processes of agricultural production. On the base of field crop production, a crop plan including cereal plants for human consumption and for *energy* production purposes, *sweet sorghum* for animal breeding and for *energy* production purposes and oil seeds – as sunflower and the nowadays very popular oilseed rape - appropriate for human consumption and energy production as well and reflecting the special features of production in Hungary has been applied. Depending on farm size the proportion of the crop area of the individual plants has been stipulated in view of the agronomical and production technological conditions.

2.3. The significance of machine utilization, the machine families applied, the parameters of model calculations

In the utilization costs of the more and more up-to-date and expensive power machines the proportion of *fixed costs*, especially amortization and maintenance is very high [7]. This expense can be decreased by increasing *utilization*. If the applied means are coupled to the individual field work operations at their effective operation cost – i.e., taking the rate of utilization into account – the effect of *working-hour performance* on costs will become measurable [8].

Basically, the cheapest power machine families used in Hungary on the one hand, and the ones with the highest possible investment cost demand available on the market of agricultural machinery on the other have been the subject of the survey [9, 10].

The basic figures of machine utilization have been determined with the help of the data base of the Hungarian Institute of Agricultural Engineering [11].

The machine cost calculations on which the study is based were made in 2022, and were based on the mechanisation cost data for Hungary in 2021 [12]. In this way, the effects of the significant input material-, and agricultural product price fluctuations in the production year 2022 have not been incorporated into the model.

The *model-calculations* have affected the farm size points of machine stock development in a farm size of 30 and 1000 ha. On this basis we can come to statements affecting a wider segment of the agricultural property structure, resp. To conclusions concerning mechanization and machine utilization [13].

3. RESULTS

3.1. The constitution of the machine system in case of the examined operating sizes

The power-machine system that can be ordered to serve the examined operating size of 30 hectares to finish the soil preparation in a good quality consists of the minimal 40 kW output power machine and the attachable soil tilling, nutritive spreading and plant protection working machines. In case of the 1000 hectare farm size that is the base of the large-scale examination, the minimum is the tractors with 60-120 kW of output that can be the base of the machine works. The different output-categories are represented by two power-machines in each case. The easier nutritive supply and plant protection tasks are done by the machines with smaller output and the heavier tasks are done by the machines with higher output. The *materials handling to the depot* can also be done by these tractors by using tow-cars to increase the exploitage of the machines.

In case of farm size of 30 hectares, the finishing of the harvesting works as wagework is the most efficient. According to the calculations, on a 1000 hectare sized farm, to reach the acceptable capacity-utilization, one *cereal combine-harvester machine* can be operated as the property of the farm. The appliance of the self-propelled silage harvester that does the gathering of the sorghum as a property, highly increases the machine costs of the farm, therefore it can be seen in the chapter *results* in details that it is more advantage out to use a self-propelled silage harvester for commission work.

3.2. The number of the executed working-hours in function of the power-machine category, the mechanical level and the farm size

The number of the executable working-hours of the power-machines in case of different farm sizes determines the composition to each category of the power-machine system;

In case of the examined *smaller sized farm* (30 hectares) based on our calculations *low exploitage* can be reached to the tractors: maximum 435 working-hours/year.

In case of large farm sizes (1000 hectares) the executed machine working-hours of the farms power-machine fleet, based on our model calculations is 6650 working-hours, from which the tractors represent a major (1100 working-hours/year (power-machine with 60 kW output) and 1700 working-hours/year (power-machine with 120 kW output)) part.

With a clever-chosen cereal harvesting machine at *one thousand hectare* farm size executing about 450-500 working-hours it reaches *significant* exploitage, that results in *acceptable* operational cost. The annual capacity exploitage of the self-propelled silo combine in case of own property is only 150 working-hours, that makes the idea of purchasing the machine as property to think it over.

In case of a 30 hectare sized farm the machine work demand of sweet sorghum that's production is fitted in the rotation of crops is 120 working-hours, that is 14,8 working-hours/hectare. This value is slightly higher than the economic average. In case of a 1000 hectare sized farm the machine work demand of sweet sorghum that's production is fitted in the rotation of crops is 1675 working-hours, that is 6,7 working-hours/hectare. This marks well that the production of sweet sorghum is a labour-intensive activity, because this value is also higher than the value that is specific to the whole farm. By using *modern machines,* the shown working-hour execution parameters will decrease with 4-5 % [14, 15].

In case of small-scale production, the significant number of shift-hours increases the living work outlay, thereby *increases the employment*. In the farms with this size the use of small output machines is reasonable. However, the proper usage of the small capacity machines is not ensured either, so the significant constant costs induce *higher operational costs* [16].

3.3. The analysis of the machine usage costs

Applying *low-level* power-machine fleet, the annual machine use cost of a 30 hectare farm that produces sweet sorghum too is 11.785 EUR, that is 393 EUR per hectare. The specific machine cost of the produced crops is the following: wheat 365 EUR/hectare, sunflower 375 EUR/hectare, rape 395 EUR/hectare, sweet sorghum 440 EUR/hectare. In the sowing plan the ratio of the plants is the following: wheat 40%, sunflower 25%, sweet sorghum 25%, rape 10%.

Applying *modern power-machines* the annual machine use cost is 14.645 EUR, that is 491 EUR per hectare. In case of the produced plants the machine costs are the following:

wheat 460 EUR/hectare, sunflower 475 EUR/hectare, rape 500 EUR/hectare, sweet sorghum 540 EUR/hectare.

Those who work on small sized farm can count with low power-machine utilization, that also has effects on the use costs per working-hour of the tractors. This value is 19 EUR/working-hours in case of the 40 kW tractors that are usually used in small works. At this production size, the calculated cost of the borrowed used cereal harvester and self-propelled silo combine is 52,5 EUR/working-hours and 72,7 EUR/working-hours. In case of *modern machines,* the specific cost of the mentioned tractor to a time unit is 24 EUR. The cost of the cereal combine is 73,6 EUR/working-hours. In case of an ensilage cutter, we can also count with the given values, because in the database that we used for the calculations we haven't found two different technical levels from the harvesting machines with these functions.

Considering a 1000 hectare sized farm in case of *low level* mechanization, taking the above mentioned sowing plan ratios the annual use cost of the machines is 303,5 thousand EUR, that is 303,5 EUR/hectare. The machine cultivation cost per hectare to each of the plants: wheat: 240 EUR, sunflower 270 EUR, rape 245 EUR, sweet sorghum 465 EUR.

If the use of the self-propelled ensilage cutter machine is not as an own property, than it is *leased work*, the machine use cost of the whole farm is 267,8 thousand EUR. The specific value for a hectare is 267,8 EUR. And the specific machine cost of the sweet sorghum production is the advantageous level of *320 EUR/hectare*.

With the appliance of *high-level* power-machines the annual machine use cost projected to the whole farm is 339 thousand EUR, specifically 339 EUR/hectare. In case of wheat, it is 275 EUR/hectare, sunflower 305 EUR/hectare, rape 275 EUR/hectare and sweet sorghum 505 EUR.

It can be observed that the machine cost of sweet sorghum is the highest in every case, compared to the other plant cultures. This is mostly because great volume of the harvesting and crop transporting tasks: at least 60-80 t/hectare of crop has to be harvested and transported to the processing plant.

If the ensilage cutter machine does it's tasks as *leased work*, the costs decrease. As a result of the calculations, the total machine use cost of the whole farm is 303,5 thousand EUR. Specifically it is 303,5 EUR/hectare. The machine work cost of the sweet sorghum production is *365 EUR/hectare*.

The Figure 1 also shows the previously introduced things, where the upper and lower limit of the machine use costs are shown in function of the farm size, that are determined considering the use of low-level power-machines and implements and the expensive power-machines that represent the modern machine technologies.

In large-scale production the exploitage of the power-machines is more advantageous. The tractor with 60 kW output works 1100 working-hours and the medium sized universal power-machine with 120 kW output works 1750 working-hours annually. The use cost of them to one working-hour is 15,7 EUR, and 27,3 EUR. According to our calculations the use cost of the cereal harvester and self-propelled silo combine as own property is 83 EUR/working-hour, and 243,2 EUR/working-hour. If we borrow the ensilage cutter for work, the cost reduces significantly to 97,4 EUR/working-hour. In case of *modern power-machines* the specific cost of the mentioned tractors to a time unit are 19,7 EUR and 31,4 EUR. The cost of the cereal combine is 93,4 EUR/working-hours. In case of an ensilage cutter as we have mentioned, we can calculate with the above given values.

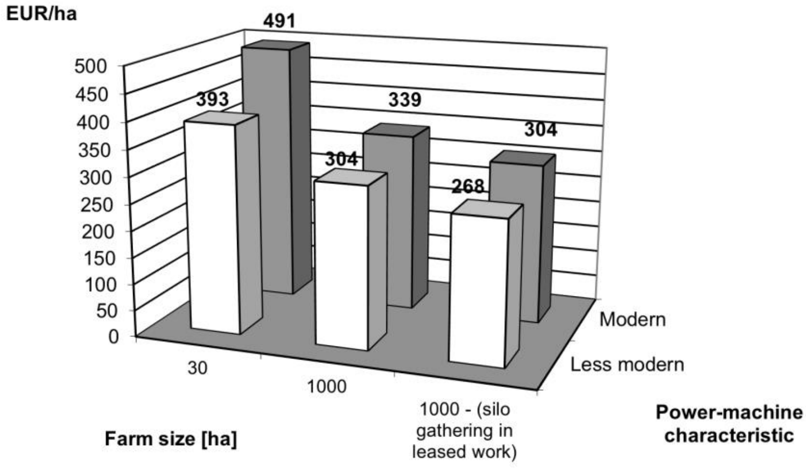

Fig. 1 The specific machine utilisation costs in case of different mechanization levels at farms with the investigated sizes (own editing)

The operational costs of the work processes of the sweet sorghum production calculated after the computer modelling can be seen on Table 1.

The marked costs in the chart show the direct costs of the machine operation, plus the accessory costs (farm level costs) that increase the discussed values with almost 20%.

The difference between the costs of the small and the large-scale farm size is well-marked. This all can be explained with the efficiency of the machine exploitage. In the field of costs there is also a difference between the use of modern and less modern machines. In case of small-scale farm size, with using less modern power-machines a more advantageous cost level can be reached, although the quality of the work and the circumstances of the working must be considered. In case of large-scale farm size, the difference between the operational costs of the less modern and modern machines decrease significantly, because the operation of the less modern machines is more expensive at larger strain and the high level constant costs of the modern machines significantly decrease, according to their better exploitage, considering one unit of work.

The values in brackets show the first-cost of the leased work.

Table 1 The direct machine operation costs of the work processes of the sweet sorghum production

	In case of using low-cost power-machine		In case of applying modern power-machines	
Farm size	**30 ha**	**1000 ha**	**30 ha**	**1000 ha**
Dimensional unit	EUR/ha	EUR /ha	EUR /ha	EUR /ha
Stubble ploughing	23	15,4	28,6	17,6
Fertilizer distribution	11,8	8	14,8	8,3
Muck-spreading		34,9		39,8
Stubble care	23	15,4	28,6	17,6
Deep ploughing	69,4	33,8	78,9	37,5
Plough levelling	23	15,4	28,6	17,6
Herbicide spraying	10,9	7	13,4	7,8
Chemical pouring	15,5	10,6	19,2	12,1
Preparation of seedbed	15,5	10,6	19,2	12,1
Sowing	22,3	18	25,9	19,8
Chemical plant protection	10,9	7,0	13,4	7,8
Within-the-row cultivation	19,6	7,7	23,8	9
Harvesting	*(65,2)*	171 *(64,1)*	*(65,2)*	171 *(64,1)*
Crop transportation to depot	*(57,1)*	32,9	*(65,3)*	38,5

4. Conclusions

Besides the introduced machine costs, we must count with the prices of the input materials of the sweet sorghum production to know the whole cost of the production of the plant. Adding all the cost of the nutrient supply, the seeds and the cost of the pesticide, we face that a minimal input material cost is 600 EUR/hectare. Beside this we must not forget about the cost of the insurance and other supplemental expenses that is connected to the production.

Adding everything, the total production cost of the studied plant per hectare in case of small-scale farm size is minimum 1065 EUR. Examining the large-scale industrial production the costs reduce, but they can not be reduced under the 960 EUR/hectare level.

The aim of our research work and the exposition of its results is the professional support of the machine investment decisions and the machine utilization practice of the different size farms promoting hereby the creation of the conditions of fruitful farming and rational machine investment decisions.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

ECONOMICS IN AGRICULTURE: ECONOMIC EFFICIENCY OF DIFFERENT TECHNICAL SOLUTIONS IN AGRICULTURE. A STUDY OF NIGERIAN CONTEXT

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Abstract:
This paper examines the economic efficiency of precision farming, irrigation systems, and mechanization in Nigeria's agricultural sector. A mixed-methods approach combining primary and secondary data was used to assess each solution's impact on productivity, profitability, and overall economic efficiency. The study found that each solution offers substantial benefits, including increased yield, improved water productivity, and time and labor savings. However, their adoption is hindered by challenges such as high initial costs, lack of technological literacy, and limited access to affordable credit. The paper recommends increased investment in agricultural technology, enhanced farmer training, favorable policies, and promotion of research and development to facilitate the adoption of these technical solutions. The findings underscore the importance of a tailored, farm-specific approach in leveraging these solutions for optimal economic efficiency in Nigeria's agriculture sector.

Keywords: *Economic Efficiency, Precision Farming, Irrigation Systems, Mechanization, Nigeria Agriculture.*

1. INTRODUCTION

Agriculture remains a vital sector in Nigeria's economy, contributing significantly to the country's GDP, food security, and employment generation. However, the agricultural sector is currently characterized by low productivity and inefficiency due to various challenges, including limited adoption of modern technologies, reliance on manual labor, and inefficient use of resources. As a result, this study focuses on the economic efficiency of different technical solutions in agriculture, and it explores how modern technologies and methods can be harnessed to drive an increase in productivity and economic efficiency in the Nigerian agricultural sector.

The study will investigate diverse technical solutions such as precision farming, irrigation systems and mechanization analyzing their applicability and economic efficiency within the Nigerian context. This research aims to build a comprehensive understanding of the potential benefits and drawbacks associated with each of these technical solutions. It also seeks to offer insights on how the deployment of these technologies and methods could affect key indicators like production cost, productivity, profitability, and overall economic efficiency in Nigeria's agriculture sector.

By providing empirical evidence on the performance of various technical solutions, this research could inform policy-making, facilitate the strategic development of the sector, and contribute to the ongoing discussions on sustainable agricultural practices in Nigeria. It could also guide farmers, investors, and other stakeholders in making informed decisions regarding the adoption of these technologies and methods, in order to improve economic outcomes and sustainable development.

2. THEORETICAL FRAMEWORK

The theoretical framework of this research is based on the following key concepts:

Economic efficiency in agriculture is a multifaceted concept and can be viewed from several perspectives, including allocative efficiency, technical efficiency, and cost efficiency. It essentially implies making the best use of available resources to maximize agricultural output and profits, while minimizing costs.

Allocative efficiency relates to the optimal distribution of resources in a manner that maximizes the net benefits gained. In this context, it refers to the optimal allocation of inputs like land, labor, and capital among different farming activities.

Technical efficiency, on the other hand, refers to obtaining the maximum possible output from a given set of inputs. It involves utilizing the available technology to its full potential.

Cost efficiency relates to the relationship between input costs and output, with the goal of minimizing the cost of production for a given output.

Technical solutions in agriculture refer to the various technologies and methods applied to improve productivity and efficiency. They can be categorized broadly into precision farming, irrigation systems, mechanization, and other innovative techniques.

Precision farming involves the use of technology (like GPS, remote sensing, and data analytics) to monitor and manage agricultural activities, aiming for optimal efficiency and productivity. It enables farmers to apply inputs such as fertilizers, water, and pesticides more precisely, reducing waste and improving crop yields.

Irrigation systems help control water application for agricultural crops, optimizing water use, and increasing water productivity. Different irrigation systems, including sprinkler, drip, and surface irrigation, have their own merits and drawbacks, affecting their adoption and effectiveness.

Mechanization involves the use of machinery and equipment to perform agricultural tasks, replacing manual labor. It can significantly increase productivity, save time, and reduce drudgery. However, its adoption can be limited by factors like cost, availability of equipment, and technical know-how.

Table 1: Overview of Different Technical Solutions

Technical Solution	Description	Benefits	Challenges	Potential Impact on Economic Efficiency
Precision Farming	Use of technologies (GPS, remote sensing, data analytics) to monitor and manage agricultural activities.	Increased precision of input application, waste reduction, enhanced profitability.	High initial investment costs, lack of technological literacy.	Significant, depending on level of adoption and proper use.
Irrigation Systems	Use of advanced methods to control water application for crops, e.g., drip irrigation.	Improved water productivity, increased crop yield.	High installation costs, maintenance issues, lack of awareness.	Significant, particularly in areas prone to water scarcity.
Mechanization	Use of machinery to perform agricultural tasks.	Increased productivity, time-saving, reduction in manual labor.	High acquisition costs, lack of access to affordable credit, scarcity of maintenance services.	Significant, particularly on large farms and for crops requiring intensive labor.

The table above provides an overview of the three technical solutions under investigation. For each solution, it summarizes the primary benefits, potential challenges, and the estimated impact on economic efficiency. This offers an initial understanding of the distinctive advantages and constraints of each solution, setting the stage for the further analysis in subsequent sections.

3. REVIEW OF EMPIRICAL STUDIES

This section will evaluate past research and empirical studies conducted in the Global and Nigerian context

3. 1 Global Context

3. 1. 1 Precision Farming: The global application of precision farming is marked by its transformative potential for modern agriculture. In an exhaustive study, Schimmelpfennig (2016) demonstrated a strong positive correlation between the application of precision farming techniques and increased profitability in U. S. corn farming. However, the study also highlighted a variable adoption rate, largely driven by the technological and financial capacity of different nations.

3. 1. 2 Irrigation Systems: Hussein and Hanjra (2004) focused on the importance of efficient irrigation systems. Their research findings emphasized the potential of modern systems like drip and sprinkler irrigation in enhancing water productivity, thereby increasing crop yields, especially in arid regions with water scarcity issues. They highlighted the success of these systems in several developed nations, attributing the effectiveness to advanced technological adoption and the ability to invest in these systems.

3. 1. 3 Mechanization: Mechanization, according to Binswanger-Mkhize (2012), substantially impacts agricultural productivity across the globe. The study presented compelling evidence indicating increased yield and time efficiency in countries with high mechanization levels. However, the research also noted challenges such as high acquisition costs and access to credit, limiting mechanization adoption in developing nations.

3. 2 Nigerian Context

3. 2. 1 Precision Farming: While global studies indicate the efficiency of precision farming, its adoption in Nigeria is comparatively slow. Pedroso (2018) discussed the varying adoption rate of precision farming techniques in developing countries, with specific reference to Nigeria. The research highlighted key hindrances such as high initial investment costs, technological illiteracy among farmers, and lack of robust infrastructure as primary reasons for the slow adoption rate.

3. 2. 2 Irrigation Systems: Prokopy et al. (2008) examined the challenges associated with the implementation of modern irrigation systems in developing countries. The researchers noted that while irrigation systems have the potential to boost agricultural productivity in Nigeria, factors such as high installation costs, maintenance challenges, and lack of awareness among farmers limit their widespread adoption.

3. 2. 3 Mechanization: A study by Takeshima & Salau (2015) focused on agricultural mechanization in Nigeria. The study found that while mechanization can significantly increase productivity, key barriers such as high costs, lack of access to affordable credit, and scarcity of maintenance services hinder its widespread adoption in Nigeria.

Table 2: Summary of Primary and Secondary Data Sources

Type of Data	Data Source Description	Use in Research
Primary	Structured questionnaires and personal interviews with farmers, agricultural experts, stakeholders.	Used to gather first-hand information on practical implications, challenges, and benefits associated with adoption of technical solutions.
Secondary	Published reports, articles, agricultural databases, governmental and non-governmental statistical reports.	Used to gather historical and current information on the performance of different technical solutions, their adoption rates, and impacts on economic efficiency.

This table outlines the data sources utilized for the research. It distinguishes between primary and secondary data and provides a brief explanation of how each data source contributes to the research. This helps to appreciate the comprehensive approach taken for data collection, combining first-hand information from key stakeholders with extensive secondary data.

4. METHODOLOGY

The methodology provides a detailed description of the research design and the methods used for data collection and analysis.

4. 1 Study Area

This research focuses on Nigeria due to its significant agricultural sector. It considers diverse agricultural regions across the country, including areas that are primarily rain-fed as well as those that are irrigation-dependent.

4. 2 Data Collection

Data for this study are collected from two primary sources. Firstly, secondary data are obtained from published reports and articles, agricultural databases, and statistical reports by governmental and non-governmental organizations. This data includes historical and current information on the performance of different technical solutions in agriculture, their adoption rates, and impacts on economic efficiency.

Secondly, primary data are collected through structured questionnaires and personal interviews with farmers, agricultural experts, and other stakeholders. This allows for an in-depth understanding of the practical implications, challenges, and benefits associated with the adoption of different technical solutions in agriculture.

4. 3 Analytical Techniques

This research employs a mixed-methods approach, combining quantitative and qualitative analysis. Quantitative analysis is conducted using descriptive statistics and econometric models to determine the relationship between the adoption of different technical solutions and economic efficiency. Stochastic Frontier Analysis (SFA) is particularly utilized to measure technical efficiency, providing a more nuanced understanding of how different technical solutions influence productivity and profitability.

In the qualitative component, thematic analysis is used to interpret the data collected from interviews, providing insights into the experiences, perceptions, and attitudes of the respondents towards these technical solutions.

Table 3: Summary of Key Findings

Technical Solution	Impact on Productivity	Impact on Profitability	Barriers to Adoption
Precision Farming	Significant increase in crop yields.	Enhanced profitability due to waste reduction.	High initial investment costs, lack of technological literacy.
Irrigation Systems	Improved water productivity, increased crop yield.	Increased profitability, particularly in areas prone to water scarcity.	High installation costs, maintenance issues, lack of awareness.
Mechanization	Increased productivity, time-saving.	Increased profitability due to reduction in manual labor.	High acquisition costs, lack of access to affordable credit, scarcity of maintenance services.

The table above encapsulates the main findings of the research, revealing how each technical solution impacts productivity and profitability and the barriers to their adoption. It presents a condensed view of the results, helping to understand the significant outcomes of the study.

5. RESULTS AND DISCUSSION

This section provides the findings from the data analysis and discusses them in light of the research objectives. The results are broken down by each technical solution.

5. 1 Precision Farming

The research finds that precision farming techniques have a significant positive impact on the economic efficiency of agriculture in Nigeria. The use of GPS technology, data analytics, and other precision farming tools improves the precision of input application, reduces waste, and ultimately enhances profitability. However, barriers such as high initial investment costs and lack of technological literacy among farmers limit the widespread adoption of these techniques.

5. 2 Irrigation Systems

The study reveals that the use of modern irrigation systems improves water productivity, crop yield, and overall economic efficiency. Drip irrigation systems, in particular, are associated with higher water efficiency and productivity than traditional flood irrigation. Yet, factors such as the cost of installation, maintenance issues, and lack of awareness restrict the extensive use of advanced irrigation systems.

5. 3 Mechanization

Our research indicates that mechanization significantly improves agricultural productivity in Nigeria by reducing the time and labor required for various farm operations. The adoption of mechanized farming leads to cost efficiency, higher output, and increased profits. However, constraints such as high acquisition costs, lack of access to affordable credit, and scarcity of spare parts and maintenance services pose challenges to the uptake of mechanization.

5. 4 Comparative Analysis

In comparing the different technical solutions, each presents distinct benefits and challenges. While all three contribute to improving economic efficiency in agriculture, the optimal choice of technology depends on the specific circumstances, including the type of crop, availability of resources, farmer's skill level, and the local agro-climatic conditions.

The research, therefore, suggests that a blended approach, which combines precision farming, improved irrigation systems, and mechanization based on individual farm needs, could potentially optimize economic efficiency in Nigeria's agriculture sector.

6. RECOMMENDATIONS AND CONCLUSION

Based on the findings of this research, several recommendations are proposed to enhance the economic efficiency of agriculture in Nigeria through the adoption of different technical solutions.

Firstly, there should be increased investment in agricultural technology and infrastructure. The government, in partnership with private entities, should facilitate access to affordable and suitable agricultural technologies to boost the adoption of precision farming, irrigation systems, and mechanization.

Secondly, efforts should be made to enhance farmers' technical skills and knowledge. Training programs, workshops, and extension services can be utilized to educate farmers about the benefits of these technologies and train them in their use.

Thirdly, policies should be enacted to provide favorable conditions for the adoption of these technologies. This could include financial incentives, such as subsidies or credit facilities, to assist farmers in acquiring necessary equipment and technology.

Finally, research and development should be encouraged to innovate and adapt these technologies to local farming conditions and needs.

In conclusion, this study has demonstrated that different technical solutions – precision farming, irrigation systems, and mechanization – can significantly enhance the economic efficiency of agriculture in Nigeria. While these technologies present numerous benefits, their adoption is influenced by various factors. Hence, a comprehensive, tailored approach that considers the specific circumstances of each farm is recommended to optimize their potential. It is hoped that the insights provided by this research will contribute to the development of effective strategies to promote the sustainable and efficient growth of the agricultural sector in Nigeria.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

THE FUTURE OF INFORMATION SYSTEMS FOR ROMANIAN FARMING SECTOR

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Abstract. *The process of digitizing economic activity, in general, and agricultural activity, in particular, is on a growing trend in world-wide policies. Along with the development of information technology, the concern of scientific research has also increased in finding IT solutions aimed at leading to an increased efficiency of the use of resources (natural, financial and human) in the context of climate change.*
Information systems for agricultural and farm management are discussed in this paper, for providing conceptual framework for future design of an information system.
An information system framework is comprised of various interlocking components, each playing a pivotal role in its functionality. Subsystems act as specialized segments, contributing their distinct expertise to the greater system's functioning. Processes ensure the smooth flow and efficient transformation of information, while mechanisms guarantee the synchronization of operations and optimize the system's performance. Altogether, these elements form a cohesive structure that not only empowers agricultural producers but also enhances the overall efficiency and sustainability of the agricultural industry

Key words: *digital agriculture, precision agriculture, farmer's needs, digital tools*

1. INTRODUCTION

In recent years, the development of information systems has evolved continuously, being implemented in many areas of activity. Along with the development of information technology, the concern of scientific research has also increased in finding solutions aimed at leading to an increased efficiency of the use of resources (natural, financial and human) in the context of climate change (Melzer et al., 2013, Dwivedi et al., 2022) . In agriculture, information systems are used towards improvement of efficiency and productivity of farming sector. They can be used to manage and monitor daily activities, to collect data releted to soil, crops and livestock, waste generated and biomass produced, to plan and allocate resources and to make better and more informed decisions (Kljajic et al., 2022, Rodino et al., 2019). In addition, information systems can be used to improve communication between farmers, suppliers and customers and to improve access to market information and trends in agriculture.

Farm management information systems are software programs for supporting farmers to manage their farms and maximize productivity (Cofas et al.,2014). These systems have evolved from simple farm record systems to large, comprehensive systems that integrate the entire list of farm functions and activities into a customized system. A farm management information system involves the maintenance of records utilizing a database management system, often employing a client-server architecture, which is essentially an information system. This information system is complemented by an array of tools, methods, and models aimed at facilitating decision support (Doluschitz et al., 1988, Fountas et al., 2015, Kovacevic et al., 2016).

These programs are capable of tracking every square inch of a farm in micro and macro detail and can include sophisticated satellite monitoring or other remote sensing technologies to identify areas that may require additional water or fertilizer through spectrographic analysis. As the world's population continues to grow and more parts of the planet become urbanized, the economy becomes increasingly dependent on agriculture. Maximizing the amount of food produced and the productivity of a farm is therefore essential to ensure food security (Lorencoviwicz et al., 2018).

Having this in mind, information systems for agricultural and farm management are discussed in this paper, for providing conceptual framework for future design of an information system.

MATERIALS AND METHODS

A comprehensive presentation of information systems suitable for agricultural applications was conducted. Key modules are presented, overall advantages and bottlenecks are presented. Moreover, two practical examples developed within the Institute are described. Finally, future research directions are projected towards designing a decision support system for farmers.

RESULTS AND DISCUSSIONS

Agricultural management is undergoing a significant transformation, prioritizing environmental impact, quality documentation, and sustainable practices due to pressure from external stakeholders like the government and the public. This shift marks a departure from a focus solely on production quantity, driven by regulatory changes and subsidies encouraging sustainability.

Generally, an information system is made up of various interconnected components, each of which plays a key role in its functionality (Figure):

The importance of information systems lies mainly in the effective and responsible understanding by all leaders (managers) or individuals in an organization of the need to adapt to the global information society. Information systems are today increasingly becoming a vital component of business success for an organization or entrepreneur.

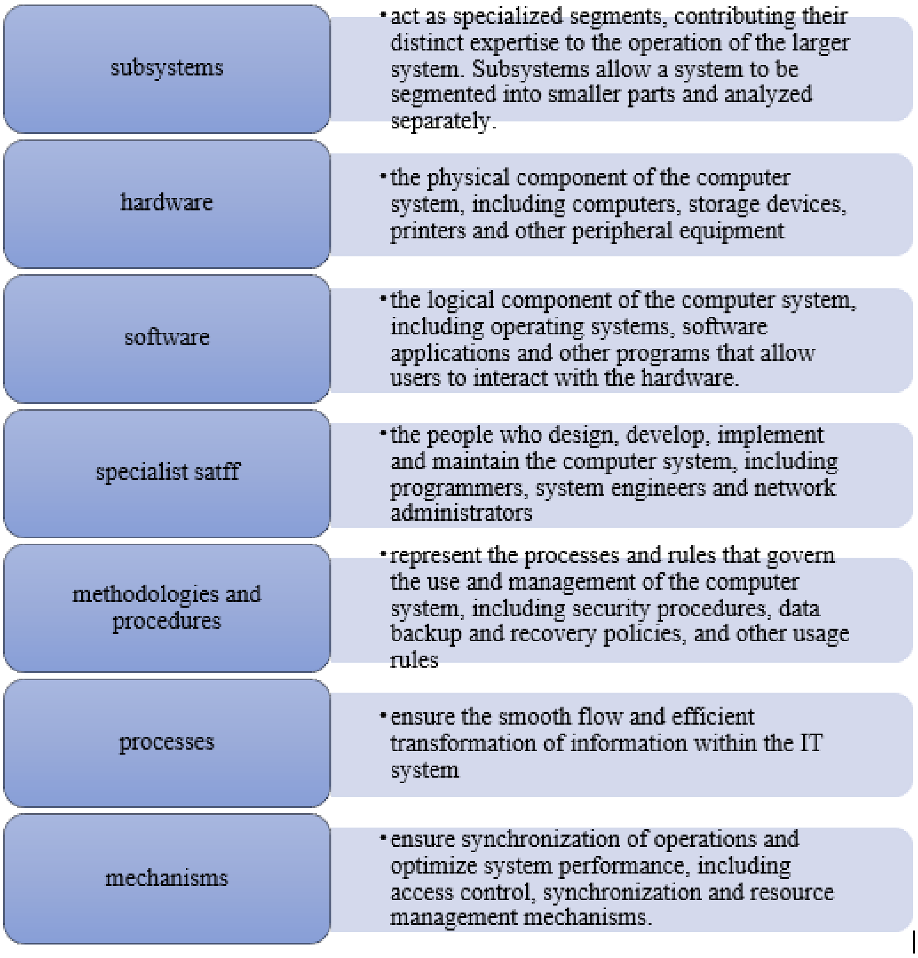

Figure 1. Basic components of an information system

The importance of information systems lies mainly in the effective and responsible understanding by all leaders (managers) or individuals in an organization of the need to adapt to the global information society. Information systems are today increasingly becoming a vital component of business success for an organization or entrepreneur.

The advantages of using information systems in the farming sector include an improved resources (financial, human and technical) management by the introduction of digitization in the current farm management. Of course, implementation of information systems may come with disadvantages as well, such as that these can be expensive and need qualified training for utilization.

Practical examples from Research Institute for Agricultural Economy and Rural Development Bucharest, Romania

At national level, the Research Institute for Agricultural Economy and Rural started several years ago to develop practical farm management systems.

In the following, we are going to briefly describe two of them:

1. SITEFA (Technical-economic information system for the farm)

SITEFA is an IT system for analyzing technical and economic indicators of production technologies for crop products applied to improve environmental performance (costs, productivity, profitability, gross margin). Basically, it is a program-product designed and intended for the technical-economic analysis of the economic performance of the agricultural holding and the efficient use of production factors, under conventional farming conditions. From a functional point of view, the SITEFA system has the following basic functions:

(a) Generation of the technology/technological plan and the income and expenditure budget for each of the types of crop recognized by the system on the basis of input data.

b) Determination of technical-economic indicators of production technologies for crop products under conventional/modern/ecological farming conditions.

c) Maintenance of all subsystems (nomenclatures and tables) used to obtain the results generated by the computer system.

d) Creation/update function: the system is equipped with a special function for creating and updating its constants.

e) The functions of searching, locating, calculating, extracting information from the database and preparing for listing are the most important component of the system in which the procedural algorithms of calculation are incorporated.

The computer system created is a program product built on a Microsoft Excel platform, using the Visual Basic utility because it allows the description of control structures, procedures and user functions.

2. ZOOSYST (Information system for livestock farms)

ZOOSYST is an application built on a Server Side Scripting platform because it allows the creation of complex web applications by processing data on the server and generating pages dynamically, providing increased speed and security. In this way, Web applications can be interfaced with database servers, with the ability to access data read in HTML forms and implement libraries to access external resources.

The following languages/frameworks were used as technologies for the development of the ZOOSYST product:

1. PHP - Programming language, interpreter and communicator;

2. CakePHP - Back-end framework;

3. HTML 5 and CSS 3 - Front-end languages and BOOTSTRAP - framework;

4. MySQL - Database management system.

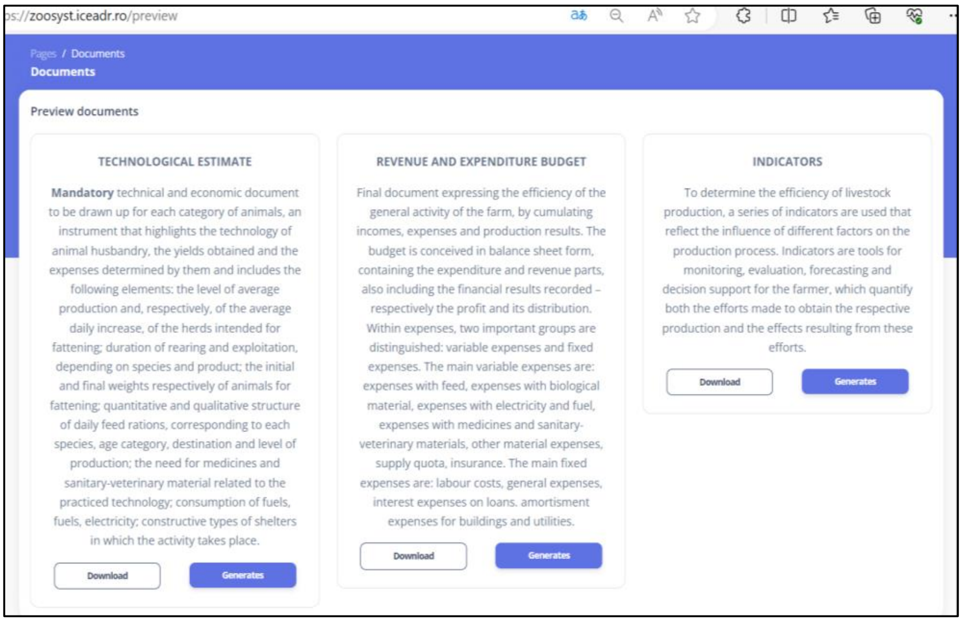

Figure 2. Documents generated by Zoosyst

From a constructive point of view, the ZooSyst IT system uses the following content elements:

- input data (entered by the user): username and password; number of heads/series (number of heads); number of years of operation; average production; quantities for feed and biological material; price lei/U.M. for feed and biological material; values for energy and fuel, medicines and medical supplies, other material expenses, insurance, labor costs, overheads, depreciation, interest on loans, subsidies; no. of calves valued/farm, no. of bullocks/farm, no. of kids/farm, no. of lambs/farm, live price/cap, price/cap cull, quantity of manure valued/farm, price manure/tone; market price; input weight; delivery weight; average daily gain; number of workers/farm; gross wage/month; number of hours/day/man; number of days worked/man/year.
- system Constants like nomenclatures, internal tables and program link tables, percentage lists: animal category table; table of feed types; table of Standard-Output (SO) coefficient values; lists of percentage values for Supply costs and Interest costs on loans.
- output: reports generated by the system after loading input data and constants, defined above, based on calculation algorithms specific to each design module; examples: technological estimate/animal category; income and expenditure budget / animal category; economic and financial indicators.

The ZooSyst software is a novelty in the field, very useful for bull, bubaline, sheep and goat farmers, who need both to check the level of economic efficiency of their activities and to plan the level of indicators they want to reach, by allocating a certain level of expenditure and by reaching certain values of technical-economic indicators. The system also calculates activity risk indicators, which warn of the farm's economic vulnerability.

FUTURE DEVELOPMENT DIRECTIONS

The use of farm management information systems can bring multiple benefits to farmers, such as improved farm management and increased productivity. For this, our objective is to create an expert system to for decision support to farmers in their daily activity.

For this, an analysis phase involving the main stakeholders, namely the farmes, will be implemented. It encompassed the examination of the system components pertinent to farm management and operations. It will involve considering the organization's processes, conflicts, and perspectives as the fundamental starting point for creating a specialized Farm Management Information System (FMIS). Discussions with farmers will be focused around several key aspects such as:

- identifying the external entities with which the farm interacts, such as input providers, public agencies, logistics providers, services providers and consumers. The focus is on clasyfing relationships, connections, influences, causes and effects among the external partners.

- evaluating the farm's current practices, especially concerning information management and exchange processes. The aim will be to determine what is functioning effectively and what is not, as well as the farmer's aspirations for improvement.

-farmer's requirements for information processing to streamline their daily work and enhance overall farm efficiency. This will be a cornerstone in identifying tools or resources that could facilitate their tasks.

Acknowledgement: *The paper is a part of the research done within the project ADER 22.1.1. funded by sectorial programme of Ministry of Agriculture and Rural Development Romania.).*

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ADVANCE OF DATA DRIVEN TECHNICAL-ECONOMIC MODELS FOR OPTIMIZATION OF ROMANIAN FARMER PRODUCTION PROCESSES

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Abstract: *The agriculture sector relies heavily on knowledge and information. Farmers need to deal and process a range of data, including financial, climatic, technical, and regulatory details, to effectively manage their farms. In this context, in this paper we report on advancement and integration of data driven digital tools in current agricultural practices in Romania. Other concepts such as digitization, digitalization and precision agriculture are also discussed. Data driven systems for agricultural sector are sophisticated infrastructures designed to facilitate the entire spectrum of agricultural knowledge management. In essence, these systems serve as dynamic hubs where of agricultural information is not only generated but also seamlessly transformed and synthesized. The overarching purpose of this complex transposition is to provide a solid foundation for agricultural producers to effectively harness and employ the affluence of knowledge available to them. For improving the farmers' activity, both public and private sector is interested to provide them with pertinent data-based visions and analyses. However, deficiencies within this agricultural information framework, manifested as the inability to consistently deliver precise, timely, and easily accessible information, pose various obstacles for farmers.*

Key words (bold): *data driven agriculture, digitalization, production efficiency*

1. INTRODUCTION

The agriculture sector relies heavily on knowledge and information. Farmers need to deal and process a range of data, including financial, climatic, technical, and regulatory details, to effectively manage their farms. Digitalization has become an important pillar in the modernization of the agricultural sector in recent years. The technological evolution brings along innovations and advanced technologies with a significant impact on the way agricultural practices and resources management are performed[1]. From the use of data analytics to the deployment of agricultural robots and monitoring technologies, digitalization is fundamentally reshaping the way farmers and researchers approach the adaptation of agriculture to current bottlenecks and challenges [2].

In a global context marked by climate change, population growth and pressure on natural resources, agriculture faces complex challenges. In this context, including digitalization into current on-farm practices may offer innovative tools and solutions for improvement of the efficiency, productivity and sustainability in the agricultural sector [3]. Monitoring sensors, data analytics technology and digital platforms provide real-time information on climate, soil conditions, pest and diseases attack and livestock status enabling informed and improved decision-making process and resource optimization. The implementation of precision agriculture techniques for plant protection offers a pathway to achieve elevated crop yields while concurrently safeguarding our valuable natural resources. This advanced approach to farming capitalizes on cutting-edge technologies and data-driven strategies, allowing for a more granular, precise, and environmentally conscious application of agricultural chemicals [4].

In addition to the impact on farming practices, digitalization is also impacting consumer behavior. Today, food shopping is no longer just a necessity, but an informed act, involving conscious decisions and multiple considerations [5].

Given the growing imperative to enhance agricultural productivity sustainably, the integration of technology within this sector stands as a prominent concern for European governments and specialized European Union entities [6,7]. Concurrently, this scenario presents a valuable opportunity for entrepreneurs actively engaged in developing such solutions, as they may access institutional baking and financial support [7]. At the European level, the key authority managing the digitalization of agriculture was the European Innovation Partnership on Agricultural Productivity and Sustainability (EIP-AGRI), now part of EU CAP NETWORK since 2023. Examining whether the digitization of agriculture can lead to income growth for farmers and identifying the specific avenues to achieve this goal play a crucial role in shaping the trajectory of agricultural digitization [8]. In this context, in this paper we report on advancement and possibilities of integration of data driven digital tools in current agricultural practices in Romania, from the farmers's point of view.

2. METHODOLOGY

The work used the main theoretical methods: study of literary sources, analysis of statistics, generalization of internal practice of using large volumes of data in the agricultural sector of the economy. The source of information was scientific journals and open data from official statistics bodies. To have an in-depth view of the use or possible of data driven systems in Romania, a survey was carried out among vegetal and livestock farmers attending a big agricultural fair and trade in Romania. A number of 210 farmers filled in the questionnaire, and 197 valid answers were analyzed. The survey consisted of three sections and included a section for collecting personal information from the respondents, which focused on their social and demographic details. The second section contained questions related to fundamental information about the farms managed by the participating farmers. The last section included questions on understanding data driven models and tools, digitalization and possible future use of these in the practical farm management.

3. RESULTS

Optimization of production processes by the use of data driven technoeconomic models is inevitable liked to digitalization and broadband access. According to European Commission, there is a notable gap between EU rural and urban areas regarding broadband access. In 2016 only 40 % of rural households had access to high speed internet. In 2022, the share of EU households with internet access has risen to 93 % from 72 % in 2011. Over the last years, the urban-rural gap closed pretty much and approximately 86% of the rural households had access to broadband internet, while in urban areas the share was 93% (Eurostat data). The latest situation (Figure 1) concerning broadband internet connections by urbanization level across EU Member States vs Romania is shown below.

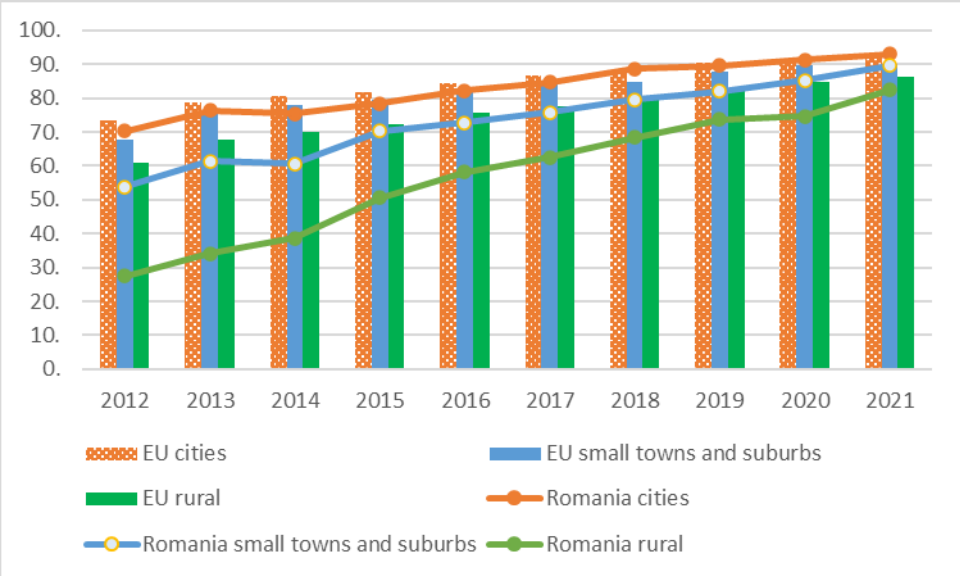

Figure 1. Share of households with access to broadband interned by urbanization area, EU vs Romania

Data retrieved from Eurostat

In 2021, a high share of households in cities had a broadband connection. Compared with the situation in urban area, broadband connectivity rates were lower in rural areas. The overall situation is very much improved in Romania vs EU beginning with 2016.

Today, business generates huge amounts of data, through the analysis and management of which can be generated new knowledge to make effective management decisions. Data is becoming more and more unstructured and the requirements for the speed of their processing are increasing. Traditional business intelligence systems are focused on working with structured data, and big data technologies are designed to process semi-structured and unstructured data. There are three main characteristics that distinguish Big Data from other types of data: volume, rapidity (high speed of data generation and the need for fast data processing) and variety. The rapid growth of big data systems popularity has been influenced by the following factors: progress in computing performance; increasing the number of processor cores; reducing the cost of information storage; extensive distribution of cloud services.

In the following pages we report on advancement and possibilities of integration of data driven digital tools in current agricultural practices in Romania, from the farmers's point of view.

Generally, the key trends that farmers identified when asked if they are including innovation in agriculture consist of: using Internet of Things in agriculture; closing the gap between farmers and final consumers, precision farming, biotechnology, improved nutrition and health.

All of the interviewed farmers (100%) identified the internet of Things in agriculture as belonging to the innovative approaches to the future development of agriculture sector. In the same time, precision farming was appreciated as being innovative by most of them (92%). Other helping techniques and strategies were identified as being closing the gap between farmers and final consumers (40%), improved nutrition and health for animals (30%) and biotechnology (85%). The liaison with end consumers was probably least mentioned as most of the farmers belong to livestock and intensive vegetal production, and they sell their harvest/production to traders and wholesale contracts.

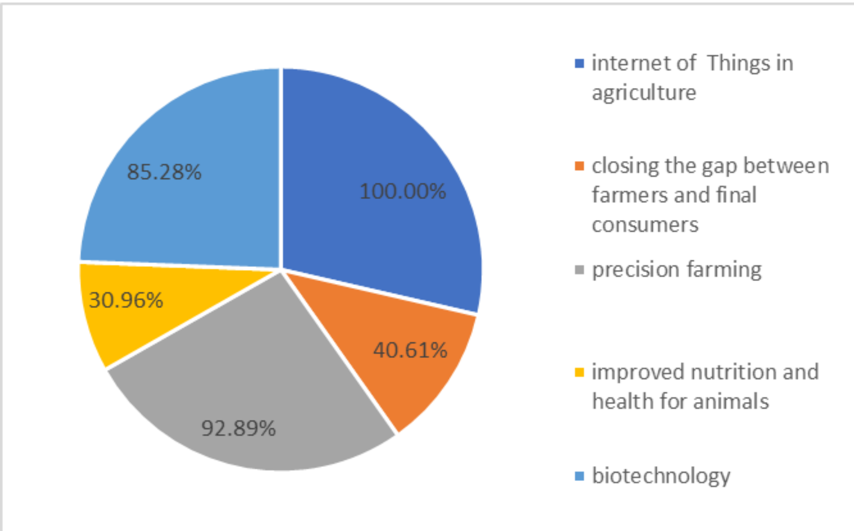

Figure 2. Innovative approaches to agriculture development mentioned by farmers

In the same time, most of the farmers are well familiar with the concept of digital farming 26% definitely aware, and 40 % well aware. A share of 20% of the farmers answered that they are not at all familiar with this concept, and they do not distinguish between digitization, digitalization and digital transformation.

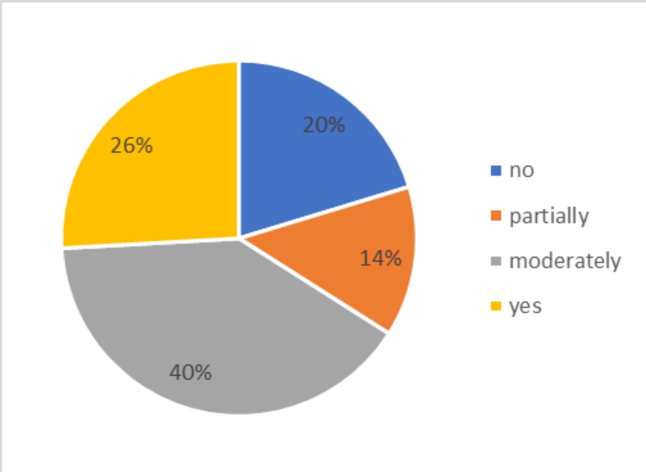

Figure 3. Farmers' awareness on digital agriculture concept

At this moment, the interview paused for those answered with no, moderately and partially, while the farmers were given a short overview on the different aspects of these concepts. The ones answering yes were asked if they are willing to be informed on the different concepts mentioned above. More than half of those agreed to be informed.

The digitization was explained as the shift from analog to digital representation, by the action of converting information into digital format [9,10]. As an example, the farmers were explained the we convert paper records into digital formats for archival and retrieval purposes, and then the information is made available online.

Furthermore, the processes are streamlined through digitalization. Digitalization involves the utilization of digital technologies and data to conduct specific institutional operations (such as payroll, procurement, research administration). What distinguishes digitalization from digital transformation is the deliberate, coordinated effort aimed at reshaping the entire institution.

Finally, digital transformation constitutes an institutional strategy focused on redefining the organization's strategic direction or value proposition. It necessitates comprehensive and synchronized changes in culture, workforce, and technology. Therefore, we digitize data and information and we digitalize processes towards organizational digital transformation.

The survey continued with asking which aspects of their business they consider suitable for digitalization (Figure 4). Most of the farmers (91.37 %) agreed that information platforms are often part of digitalization transition and farm management as well (76%). About one third considered that health and nutrition for both human and animals may be subject to digitalization. Only about one half (48%) consider that marketplace should be developed with digitalization. The most probable cause is that most of the farmers were rather big farms or livestock farmers that sell their products to industrial wholesale market

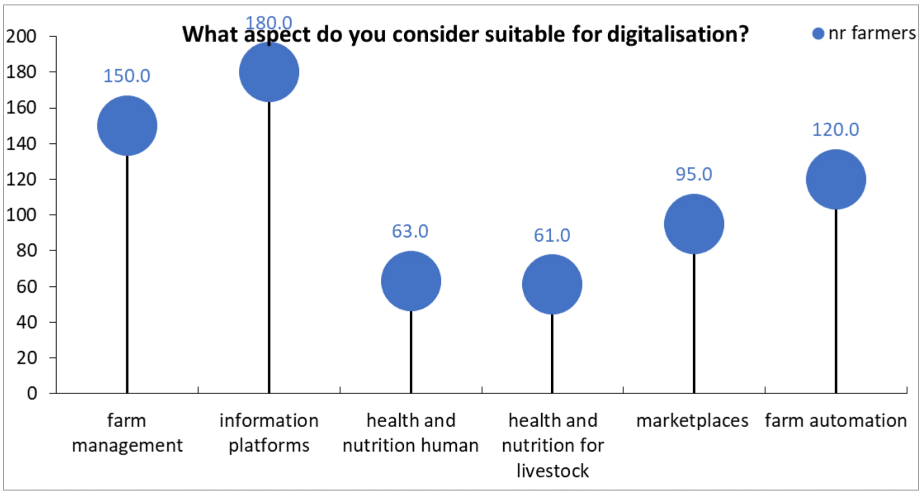

Figure 4. Sectors identified as being proper for digitalization

When inquired if they intend to link their production to digital technologies in the next 5 years, most of the farmers intend or take into account this possibility. Surprisingly 42% of them answered they have no intention to include digitalization in their investment list.

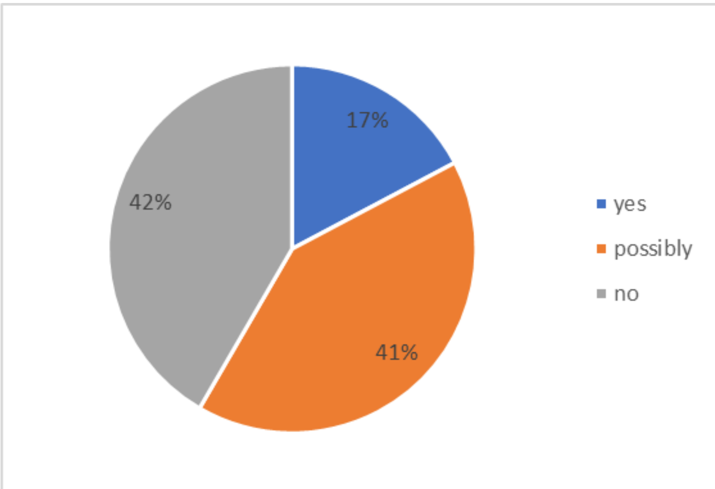

Figure 5. Farmers' willingness to introduce digitalization within their practices

The reasons for not doing so, were mainly related to lack of own technical skills (80%), unsure if they can find qualified workforce (95%). High costs are as well considered a barrier, a share of 62% of the farmers considering the investment and maintenance effort too high. Surprisingly, about 20% of the denial was due to the resistance to change, the responders considering that the traditional conservative methods are better. Around 12 % are concerned with regulatory issues.

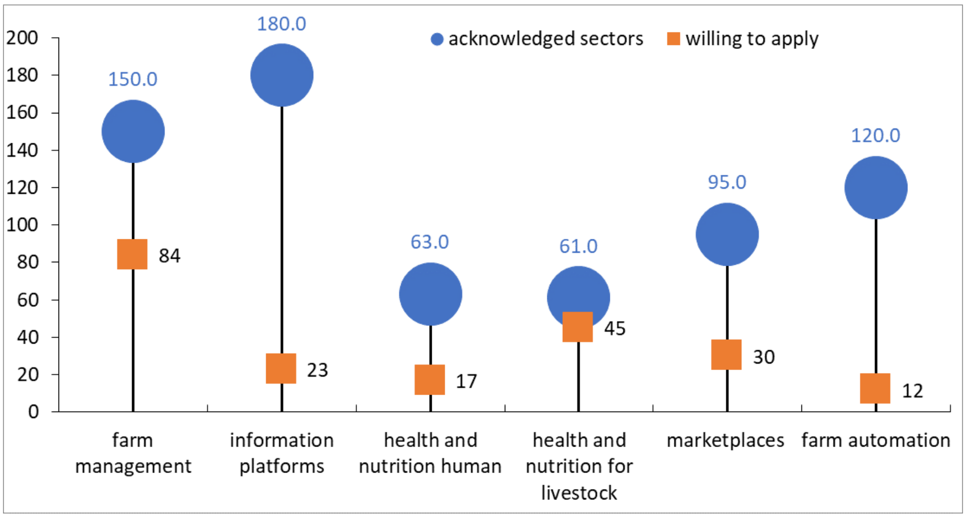

Figure 6. Farmers willing to apply digitalization processes into their practices

Most of those willing to introduce digitalization are planning to start with farm management systems and part of them to health and nutrition of livestock (Figure 6.).

When asked which they consider as benefits that digital transition is binging along the farmers pointed as positive influence on increased efficiency of production, better planning and management, higher productivity, data driven decision making, added value of end product, acceleration of "time - to - market", reduced waste, improved pest and disease monitoring, improved livestock health monitoring.

Finally, several policy recommendations and measures for supporting the digital transition were pointed, and farmers choices are given below.

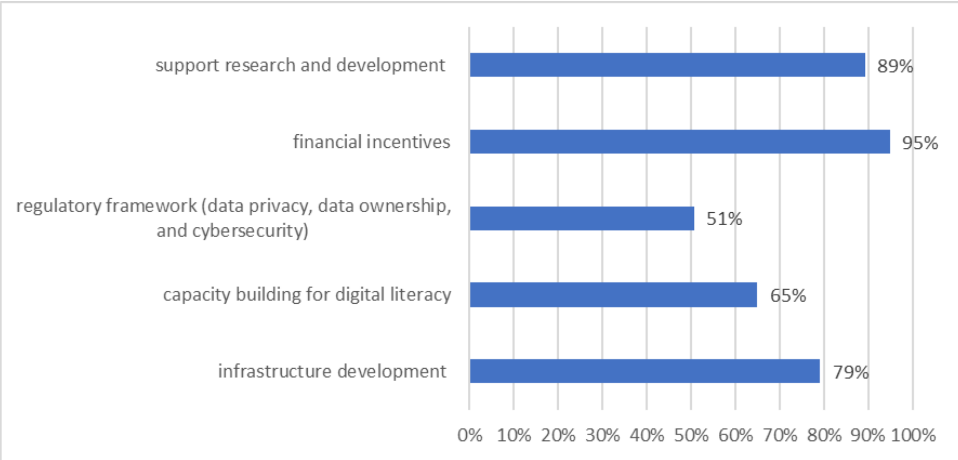

Figure 7. Identified policy recommendations

Other measures pointed by farmers were related to: provide financial incentives, subsidies, and grants to farmers and agricultural businesses to be used for purchasing equipment, software, and training; establish clear policies regarding the collection, use, and sharing of agricultural data; create feedback mechanisms for reporting issues concerns or suggestions related to data-driven systems; foster collaboration between the government, private sector, research institutions, and farmer associations. Overall farmers consider thar state administrations should take a proactive role in creating an enabling environment for the successful integration of digital technologies into agriculture, ensuring that farmers can harness the full potential of these tools to improve their livelihoods and contribute to food security and sustainability.

Data driven tools and technologies are a subject of debate for scientific research as well. Efficient record-keeping plays a pivotal role in the success of any agricultural enterprise, and the integration of data-driven technology has significantly enhanced this function with the advent of advanced agricultural management systems [11]. These systems empower farmers to digitize their record-keeping, guaranteeing the precision and currency of data concerning crop yields, livestock inventory, and resource utilization. Armed with access to comprehensive and dependable data, farmers are self-confident to make more educated judgments regarding their operational machinery. They can methodically compute and compare data points such as net profits, operational capacities across different fields, and workforce requisites. This allows them to fine-tune their strategies, striving for the utmost efficiency and profitability in their endeavors [12].

Farmers face complex financial management, but data-driven technology simplifies it. Tailored for agriculture, these solutions integrate financial data with crop yields and input costs. This holistic view helps farmers spot cost-saving chances, optimize resources, and streamline revenue cycles. Real-time financial analysis empowers data-driven decisions, boosting profitability and sustainability [13].

4. CONCLUSIONS

Of course, the adoption of data-driven technical-economic models in Romanian agriculture has the potential to revolutionize the sector by improving efficiency, sustainability, and profitability. To maximize the benefits of implementation, the farmers consider as being essential to be created an ecosystem that supports data collection, analysis, and application while addressing challenges related to infrastructure, education, and data security.

Acknowledgement: The paper is a part of the research done within the project ADER 22.1.1. funded by sectorial programme of Ministry of Agriculture and Rural Development Romania.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

INTEGRATION OF AGRICULTURAL PRODUCTION TOWARDS CIRCULAR ECONOMY PRINCIPLES

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Abstract *In the context of contemporary arguments regarding the constraints posed by finite natural resources, the expansion of global populations, and the escalating impacts of climate change, the demand for active circular processes has grown more obvious. Circular economy, as a strategic approach, stands as a potential route towards cultivating more sustainable routes for our collective future. This paper is reporting on pathways for transforming agricultural sector through implementation of circular economy principles.*

The most important principle of this approach lies in preserving the utility and functionality of products for the maximum duration within the continuum of their life cycle, effectively perpetuating their value within the cyclical framework. An integral pillar of this paradigm involves the transformation of waste materials into newfound resources, effectively extracting (additional) value from what once might have been considered discarded remnants. This transformation not only strengthens the economic landscape but also holds the potential to catalyze additional revenue streams by bringing new life into materials that might have otherwise been overlooked.

Of course, transitioning from a linear economic model to a circular one within the agrifood sector necessitates the introduction of inventive business frameworks. It is not enough to design innovative circular technological processes but is important to employ economic and social costs as well. Such kind of strategy encompass concepts like reverse logistics, novel perspectives on the dynamics between customers and suppliers, and fresh modes of organization and marketing strategies that converge at the juncture of diverse value chains.

Key words: *circular economy, sustainable agriculture, biobased value chains*

1. INTRODUCTION

The concept of **c**ircular economy has a long history in time and it is difficult to track back to a specific author or exact date of arising of this concept. An early mention of the idea belongs to Kenneth Boulding, a British economist, who, in early 1069's described the Earth as a closed spaceship and that human society should take into consideration finding ways to recycle the available resources and adapt human activity to earth ecological cycles. The author claimed that our planet is a closed sphere, comparable to a spaceship, so that despite appearances the resources are limited and this spaceship owns finite capacity to tolerate pollution and the resource extraction. One decade later, in the 1970s, the Club of Rome released "Limits to Growth" concept, according to which humanity will only be able to withstand existence by limiting production and consumption. Several other theories enhanced the development of circular economy concept, and these include Cradle-to-Cradle, Ecodesign, Biomimicry, Industrial Ecology, Performance-based Economy, Blue economy, Green economy, Bioeconomy.

The global population growth and the corresponding increase in food demand exert significant pressure on natural resources. Worldwide, it is estimated that the population will reach 9.8 billion by 2050 and is projected to grow to 11.2 billion by 2100. This hypothesis implies a surge in the consumption of both natural resources and food. Research in the field indicates that global agricultural production needs to increase by approximately 70% to meet the food demand by 2050 (Aznar-Sánchez et al., 2019).

For the agri-food supply chain, the growth of the global population necessitates sustainable food production while simultaneously adhering to high-quality standards (Velasco-Muñoz et al., 2021; Pakseresht et al., 2022).

Agriculture ranks among the four sectors of the economy with the most significant negative environmental impact, following transportation, energy, and industry. As agricultural production increases, so will the quantity of agricultural waste. In this context, the application of circular economy principles in agriculture production becomes a priority (Litvak, O. & Litvak, S., 2023).

The concept of circularizing agriculture revolves around minimizing dependence on external resources by creating a closed-loop system for nutrients and mitigating environmental impacts caused by waste discharge. For decades, agricultural waste has been utilized as an energy source for agriculture, providing a multitude of valuable resources that can be transformed into bioenergy, biofertilizers, and value-added products (recycled goods). Biomass waste, including crop residues and animal waste, can be converted into nutrient-rich fertilizers (e.g., nitrogen, phosphorus, and potassium). In doing so, not only can reliance on synthetic fertilizers from external sources be reduced, but agricultural waste can also be appropriately managed with resource recovery (Mieldažys et al., 2016).

MATERIALS AND METHODS

Bibliometrics is considered a quantitative method for measuring scientific publications within a specific field, and this method emerged in research as early as 1969, in a documentary note by Alan Pritchard (Donthu et al., 2021).

Bibliometric analysis is based on mathematical and statistical methods for evaluating bibliometric data. By employing this research method, efforts have been made to understand the connections between the number of documents published in the field of agricultural production integration towards circular economy principles, the research topic, the citation frequency of articles, and the interest in the research topic by country.

Literature search for this review was conducted by retrieving academic studies using the Web of Science (WoS) database to identify concerns in the successful implementation of a circular economy in the agricultural sector. Article search was performed by configuring the "Subject" field in WoS, which filters the search based on title, keywords, author, and abstract. The keywords used in the search were "agricultural production" and "circular economy principles." This resulted in a sample of 132 documents. Through the VOSviewer software, the data was graphically presented, mapped, and subsequently interpreted.

RESULTS AND DISSCUSION

The first figure depicts the annual publication trend from 2016 to 2023, with a total of 132 published works. The data reached its peak in 2022 with 41 scientific papers. (Fig. 1)

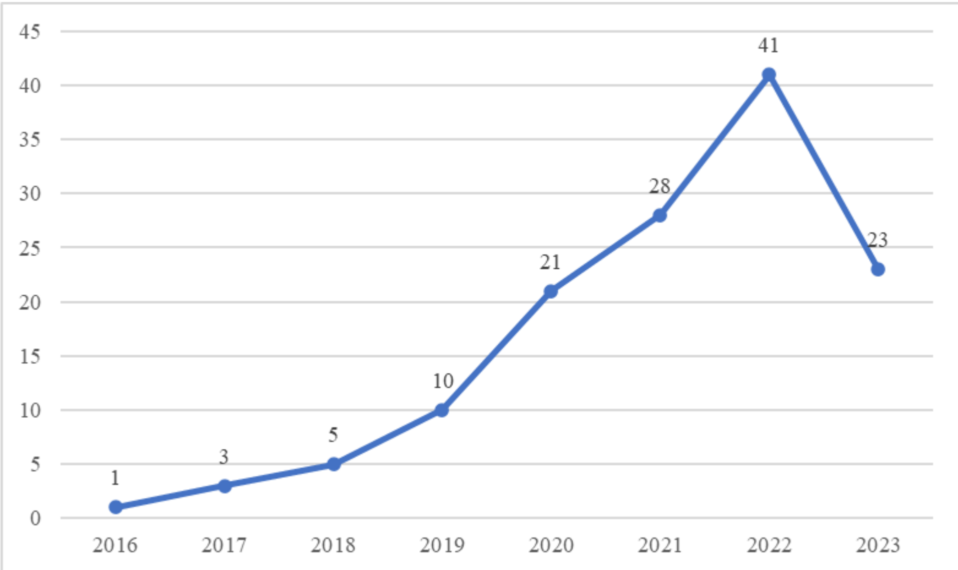

Fig. No. 1 - Annual Publication Trend from 2016 to 2023
Source: Own representation based on data provided by Web of Science, accessed on August 25, 2023.

Publications can only be relevant if the documents are cited in other scientific studies. Therefore, the total annual citations are represented in the following figure. Over the period from 2016 to 2023, there has been a noticeable trend in terms of citations, reaching a total of 738 citations in 2022, noting that 2023 is an incomplete year. (Fig. 2)

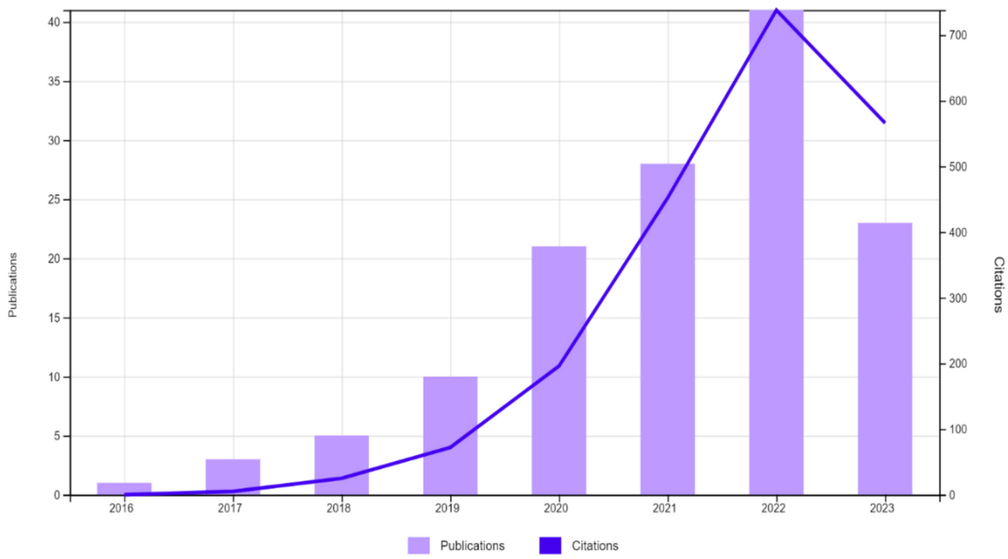

Fig. 2 - Times Cited and Publications Over Time
Source: Web of Science database, accessed on August 25, 2023.

Analyzing the connectivity of the keywords used, four clusters were identified. The first cluster (red) contains terms related to the bioeconomy, such as bioactive compounds, biodiesel, circular bioeconomy, products, quality, and sustainable agriculture. The second cluster (green) includes keywords like activated carbon, biochar, biomass, degradation, energy, feasibility, plants, and sustainable development. The third cluster (blue) comprises keywords such as anaerobic digestion, bioenergy, biogas, carbon, food waste, renewable waste, and waste management.

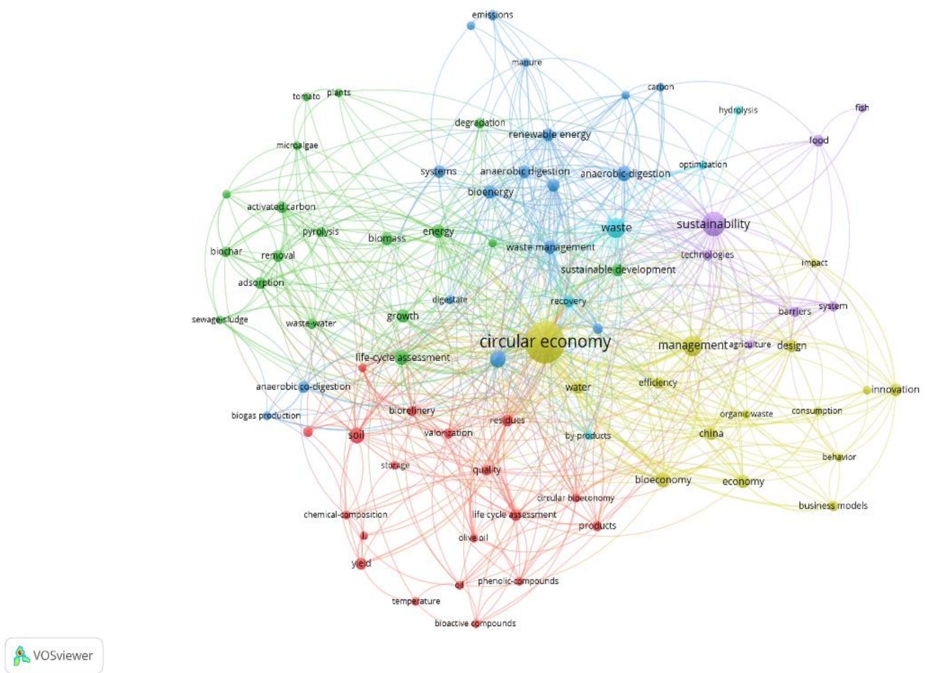

Fig. 3 - Connectivity of Keywords Used ("circular economy principles" and "agricultural production")
Source: Own representation based on data provided by Web of Science.

The fourth cluster (yellow) includes keywords like bioeconomy, circular economy, innovation, management, and efficiency.
The fifth cluster (purple) encompasses keywords such as agriculture, food, sustainability, system, and technologies.
The last cluster (turquoise) consists of keywords such as optimization, recovery, waste, and hydrolysis.

Table 1. Top 5 Most Relevant Articles Found in the Web of Science Database Based on the Query for the Terms "agricultural production" and "circular economy principles."

#	Title	Authors	Journal	Year	Nr. citations
1	Implementation of the circular economy model in the agricultural sector of Ukraine	Litvak, O. and Litvak, S.	BALTIC JOURNAL OF ECONOMIC STUDIES Volume 9, Issue 2, Page 146-156, DOI10.30525/2256-0742/2023-9-2-146-156	2023	0

#	Title	Authors	Journal	Year	Nr. citations
2	Addressing nutrient depletion in tanzanian sisal fiber production using life cycle assessment and circular economy principles, with bioenergy co-production	Colley, TA; Valerian, J; Hauschild, MZ; Olsen, SI; Birkved, M.	SUSTAINABILITY, Volume 13, Issue 16 DOI10.3390/su13168881	2021	3
3	Circular economy in agriculture: conceptual basis and implementation possibilities in Belarus	Batova, NN; Tochitskaya, IE; Sachek, PV	PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF BELARUS-AGRARIAN SERIES Volume 59, Issue 3, Page 277-291, DOI10.29235/1817-7204-2021-59-3-277-291	2021	1
4	Circular economy paths in the olive oil industry: a life cycle assessment look into environmental performance and benefits	Ncube, A; Fiorentino, G; Panfilo, C; De Falco, M; Ulgiati, S.	INTERNATIONAL JOURNAL OF LIFE CYCLE ASSESSMENT, DOI10.1007/s11367-022-02031-2	2022	11
5	Identification of opportunities for applying the circular economy to intensive agriculture in Almeria (South-East Spain)	Aznar-Sanchez, JA; Velasco-Munoz, JF; Garcia-Arca, D; Lopez-Felices, B.	AGRONOMY-BASEL, Volume 10, Issue10 DOI10.3390/agronomy10101499	2020	26

The study of existing international and national scientific research in the field of the circular economy has made it possible to conclude that most published works focus on theoretical analysis and methodological foundations. Therefore, research is primarily centered on the application of circular economy principles in industry, with minimal attention given to agriculture. This is mainly due to limited access to macroeconomic empirical data.

In the study conducted by Mieldažys et al. (2016), four domains representing significant challenges for the successful implementation of a circular economy in agriculture were identified. The authors presented potential improvement strategies to bridge the knowledge gap hindering the implementation of the circular economy concept. These strategies include existing conversion technologies (e.g., anaerobic digestion) to efficiently and sustainably produce quality products, a business model and material flow in the supply chain, analytical tools for the circular economy, including life cycle analysis and stakeholder engagement involving government, farmers, consumers, and the general public.

Aznar-Sanchez et al. (2020) argue that intensive food production systems are one of the main alternatives for ensuring food supply in the coming decades. They conducted an analysis of intensive agriculture in Almería to identify its limitations and its contribution to sustainability. The results indicated that there are circular economy-based solutions at every stage of production, both in greenhouses and handling and packing centers. While measures have been taken in greenhouses to manage organic and inorganic agricultural waste properly, there are still opportunities for further development. In handling centers, irregularities were observed in applying circular economy principles in processes like food waste reduction. Despite production planning efforts in Almería to prevent overproduction, large amounts of waste are generated during the production process. Therefore, both farmers and handling centers should prioritize investments that facilitate production processes, improve efficiency, and reduce waste.

Batova et al. (2021) highlighted that the digitalization of agriculture based on technologies that allow waste reduction, increased productivity, and resource efficiency also reduces environmental impact. Circular agriculture provides a wide range of areas for waste and secondary resource utilization while adapting to natural, economic, and social specificities. The authors emphasize the advantages of sustainable agriculture, particularly its focus on resource efficiency and waste reduction, promoting technological innovation. They also stress the importance of scientific sector development in facilitating the transition to circular agriculture. The research project AgroCycle11, part of the Horizon 2020 collaboration, involves researchers from eight EU countries and China, aiming to develop the most efficient ways of waste utilization in agriculture.

The main results of the analysis conducted by Colley et al. (2021) revealed that the circular economy potential of recycled waste in the sisal supply chain has a high potential to improve efficiency and reduce environmental impact through responsible waste management. The authors found that several subdivisions of the Tanzanian economy presented the necessary C:N ratio (carbon-to-nitrogen ratio, useful for identifying the rate of organic matter decomposition in soil) required for sisal waste encoding, such as dairy, beef, poultry, and marine fish processing. Reusing cooking oil, considered waste, was found to have ecological and economic benefits by replacing fossil fuels.

Ncube et al.'s study (2022) on the application of circular economy principles in the olive oil supply chain in Italy showed that in all production stages of organic extra virgin olive oil, the most affected impact categories were human carcinogenicity, marine ecotoxicity, and terrestrial ecotoxicity. Major contributions to these impact categories were identified in the agricultural phase (92.65%), followed by bottling (7.13%) and oil extraction (0.22%). The authors considered the valorization of by-products by expanding the system's boundaries to ensure environmental sustainability through circular economy models that redirect waste materials upstream in the same process. The analysis resulted in reduced environmental impact in almost all impact categories.

Pakseresht et al. (2022) believe that transitioning to a circular economy in the agri-food sector requires improving resource efficiency, preventing food loss or waste, and simultaneously adopting regenerative agricultural practices. Besides technical challenges, the agri-food industry must address food safety concerns arising from biomass recycling processes.

In the study conducted by Litvak, O. & Litvak, S. (2023), which includes an analysis of the implementation of circular economy principles in agricultural production in Ukraine, the authors argue that creating and developing a circular economy model in the agricultural sector can not only address environmental safety concerns in agri-food products and the natural environment but also solve social issues in rural areas by increasing the employment rate of rural populations. It also addresses an important economic issue regarding food security. The authors emphasize the importance of aligning agricultural enterprises with scientific and educational institutions to address innovation implementation, workforce skill improvement, technical and technological modernization, close collaboration with government and local governmental institutions, financial and credit structures, investors, as well as material and technical resource suppliers.

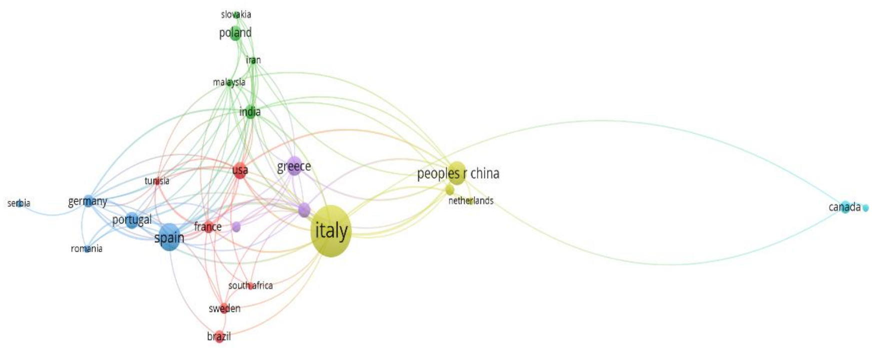

Fig. 4 - Graphic Representation of Co-Authoring Countries ("circular economy principles" and "agricultural production")

Source: Own representation based on data provided by Web of Science.

According to the map, there are six research directions, with Romania, Germany, Portugal, Serbia, and Spain following a similar research direction. Romania closely collaborates with Germany, Portugal, and Spain. The close collaboration among authors from European Union member states can be attributed to various research programs funded by the European Union that promote partnerships between these countries.

ȚĂRI	**NR. ARTICLES**	**%**
ITALY	42	31,82
SPAIN	18	13,64
CHINA	14	10,61
GREECE	11	8,33
PORTUGAL	9	6,82
USA	9	6,82
UK	8	6,06
POLAND	8	6,06
INDIA	7	5,30
GERMANY	6	4,55

A total of 132 articles related to "circular economy principles" and "agricultural production" were identified from over 60 countries. The table above presents a list of the top 10 countries with the highest number of published documents, representing 93.19% of the total publications found in the Web of Science database. Italy has the highest number of scientific articles (42), followed by Spain (18) and China (14).

CONCLUSIONS

The analysis results have identified numerous publications, from which several significant perspectives can be derived. Firstly, the number of scientific articles related to integrating agriculture into circular economy principles has substantially increased between 2016 and 2022, with the majority of them published in journals such as Environmental Sciences (52 articles), Green Sustainable Science & Technology (37 articles), and Environmental Engineering (23 articles). Secondly, in terms of global impact, Italy leads the ranking among the top 10 countries with the highest number of publications in this field, accounting for 31.82% of the total identified scientific articles (42 articles). The topic of integrating agricultural production into circular economy principles requires special attention, primarily concerning the development of sustainable agriculture development strategies.

Acknowledgement: *The paper is a part of the research done within the project ADER 22.1.4 funded by sectorial programme of Ministry of Agriculture and Rural Development Romania*

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

ANALYSIS OF COSTS RELATED TO BUILDINGS, MACHINERY AND EQUIPMENT BASED ON FADN DATA

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Abstract. *Successful agricultural production requires appropriate fixed assets, while investments in their improvement and modernization are necessary for long term sustainability of agricultural holdings. As a consequence, costs related to fixed assets have significant share in total costs (total input) of farm activity. This research primarily analyzes costs related to buildings, machinery and equipment. As a base for the research FADN methodology is applied as well as EU FADN public database as a source of data. Within the analysis authors primarily discussed elements of Total faming overhead (SE336), such as Machinery and building current costs (SE340), Energy (SE345) and Contract work (SE350). Above mentioned FADN indicators cover variety of costs, such as costs of current upkeep of machinery and buildings, costs of fuel and electricity and costs linked to the hire of machinery, among others. Costs are discussed and compared for 14 farm types in the EU (TF14 classification of farms is applied). The results of the analysis enabled better insight and understanding of costs related to machinery, equipment and buildings in agricultural production of the EU, while the conclusions could be useful for Serbian agricultural holdings, as well.*

Key words: fixed assets, overhead costs, FADN, costs of current upkeep, energy costs

INTRODUCTION

Analysis of business performance of EU farms is commonly based on FADN (Farm Accountancy Data Network) methodology, and appropriate database (as reliable source of data). FADN system offers information on farm revenues and costs (Njegovan and Nastić, 2011) while enabling determination of "the impacts of Common Agricultural Policy for Member States of the EU" (Dabkienė, 2016). It is necessary to keep in mind that FADN collects only limited volume of data, so that certain analysis (such as determination of gross margin for individual enterprises) require additional data or specific methodological approaches (Ivanović et al., 2018). Total costs (total input) in FADN methodology are made of following four elements (European Commission, 2022): Total specific costs, Total farming overheads, Depreciation and Total external factors. Apart from depreciation costs (which are not subject of this analysis) other costs related to buildings, machinery and equipment are presented within Farming overheads (SE336). Farming overheads include:

- Machinery and building current costs (SE340),
- Energy (SE345),
- Contract work (SE350) and
- Other direct inputs (SE356).

Machinery and building current costs are "Costs of current upkeep of equipment (and purchase of minor equipment), car expenses, current upkeep of buildings and land improvements, insurance of buildings" (European Commission, 2022). On the other hand "major repairs are considered as investments", so that they are not an element of farming overheads. Energy assumes "motor fuels and lubricants, electricity, heating fuels". When it comes to contract work it covers "costs linked to work carried out by contractors and to the hire of machinery". Other direct inputs are the only element of farming overheads which is not necessarily strongly connected to the use of machinery and buildings (containing costs of water, insurance etc).

FADN data are increasingly used to determine cost structure of EU farms. Hloušková et al. (2018) analyzed Czech FADN data for years 2001 and 2014 determining that share of energy costs in total costs significantly increased in observed period (from 1.8% to 11.1%) while opposite trend could be noticed when it comes to maintenance costs (their share have decreased from 7.6% in 2001 to 5.9% in 2014). After testing various approaches to cost forecasting authors concluded that "not only one of the tested methodologies can be selected to predict various cost types". Dachin (2016) observed farms of different economic size producing field crops in Romania, while data for the research were provided by FADN. In year 2013 farming overheads were dominated by energy costs which are followed by costs of contract works (the same pattern is observed for all farm sizes). Koloszko-Chomentowska and Vilkeviciutė (2020) also used FADN data to analyze performance of farms in Poland and Lithuania (two farm types were observed - farms specialized in field crops and farms specialized in milk production). Authors determined that (when it comes to field crops) total farming overheads participate in total costs somewhere between 25.54% and 26.29% in Poland and between 19.60% and 21.63% in Lithuania (considering period 2015 - 2017). Similar share of total farming overheads in total costs is recorded for milk production farms in both countries. Besides, it can be concluded that overhead costs of both production types are dominated by energy costs which are followed by machinery and building current costs.

Strzelecka and Zawadzka (2019) used FAND data from Poland to determine cost structure for farms of various production types. Authors show that the highest share in total costs (regardless of the production type) could be attributed to intermediate consumption (comprising of direct costs and farm overhead costs). Similar, but more elaborate research conducted by Galecka (2021) compared data covering farms in Poland and the EU (the analysis was performed on FADN dataset for various farm types). During observed period in the EU (from 2013 to 2018) participation of total farming overhead in total costs decreased (except for other grazing livestock and granivores). The highest share of total farming overhead (EU farms) in year 2018 was recorded for field crops (29.85%), while overhead costs were the least important in granivores production (15.31%).

Parzonko et al. (2019) discussed energy costs related to dairy farms operation in seven EU countries, while the research was based on FADN data. The results indicated that share of energy costs in total costs varied depending not only on country but also on farm size. It was concluded that "an increase in the economic size of farms focused on milk production, resulted in energy cost savings in relation to 100 kg of milk produced". Mixed crop and livestock production type of farming was in a focus of research conducted by Špička (2014). Author intended to determine production efficiency of such farms in different EU regions (in total 101 EU regions were discussed for year 2011), as well as factors influencing production efficiency (based on FADN data). Some of analyzed factors were energy costs, machinery & building current costs, as well as contract work. The regions which are more efficient have higher "energy productivity, capital productivity and productivity of contract work" comparing to less efficient regions.

Biekša (2016) used FADN data to evaluate cereal farms using ecological footprint approach. The results of the analysis show that use of agricultural machinery have significant impact on the environment. Therefore, according to author "reduction of energy use and increase of energy efficiency should be the main goal for farming activities". At the same time Wysokiński et al. (2020) explained importance of energy use for GHG emissions, and suggested the ways for limitation of such a negative impact on environment, such as "the development of energy based on renewable sources" and "the improvement of energy efficiency". Authors also claimed that "economic and energy efficiency can be understood as a concept referring to the efficiency of energy use as a resource". Rokicki et al. (2021) observed features of energy consumption related to agricultural production activities (for 28 EU counties in period 2005-2018 on the basis of EUROSTAT data set). The data have revealed that oil and petroleum products are the most important energy source used in agriculture, while agricultural production "produced more renewable energy than it consumed". Authors also found out that increased use of energy is linked to better economic situation. On the other hand, use of renewable energy is related (but not strongly) to economic situation, due to its dependence on environment protection issues. Because of increasing use of mechanization, agricultural production in future will use more energy, while "increase in mechanization will be faster than the development of energy-consuming technologies". According to the authors, this is the reason why renewable energy will become even more important. Ivanović et al. (2012) have determined that an increase in fuel prices leads to a decrease in family farm profit by 35.56%, which makes this input distinguished for its importance for profitable operations of the observed farms. Todorović et al. (2018) used model of family crop farm to determine how the change of diesel fuel market price (authors started from the assumption that market price of fuel fluctuates in interval ±10%) influences the change of efficiency ratio of the total farm production. Calculations were made for production with subsidies and without them, as well as for two initial presumptions – when the sowing structure of farm was not optimized and when it was. The results of the analysis indicated that (if optimal sowing structure was used) production is economically efficient even without subsidies, except for the case with maximized fuel price.

Having above mentioned in mind, this research tends to analyze costs related to buildings, machinery and equipment for 14 farm types present in the EU (TF14 classification of farms), while the focus is on the costs included in farming overheads (SE336).

MATERIAL AND METHOD

The analysis is based on FADN methodology covering EU countries for period 2004 – 2021, while the source of the data was FADN public database. The data are related to classification of farms in 14 types describing specialized and mixed farms types, such as: Specialist COP (Specialist cereals, oilseeds and protein crops), Specialist other fieldcrops, Specialist horticulture, Specialist wine, Specialist orchards – fruits, Specialist olives, Permanent crops combined, Specialist milk, Specialist sheep and goats, Specialist cattle, Specialist granivores, Mixed crops, Mixed livestock and Mixed crops and livestock.

Total assets and fixed assets are discussed (depending on farm types) as well as value of specific fixed assets (Buildings, Machinery and equipment), and costs related to their use. To perform the analysis authors also used data on total input and total output of observed farm types, and determine energy efficiency of the farms as relation between their total output and energy costs. Trends of important indicators are determined, while cumulative growths of asset value and certain costs are discussed.

RESULTS AND DISCUSSION

The analysis revealed that there has been an increase in value of total assets (SE436) and fixed assets (SE441) of average EU farm during period 2004 – 2021. At the same time negative trends are observed concerning participation of fixed in total assets (Fig. 1).

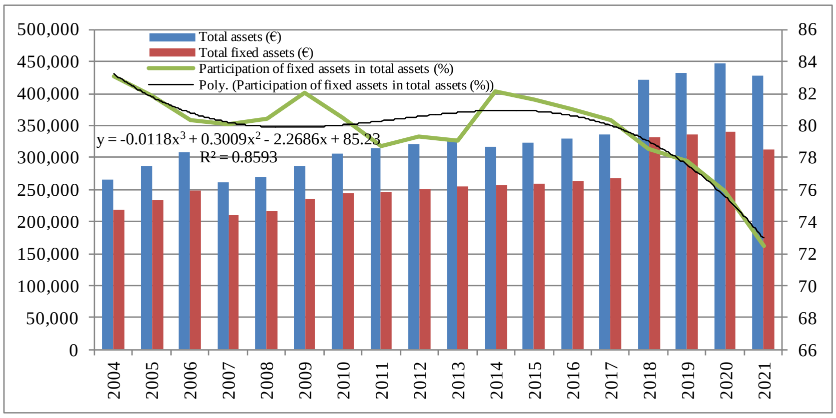

Fig. 1 Value of total and fixed assets (EUR) and participation of fixed in total assets (%)
Source: FADN public database and authors calculation

During observed period total assets increased by 61.4%, while fixed assets increased only by 42.2% (in average) (Table 1). The highest increase of total assets and fixed assets was recorded for mixed livestock. On the other hand, specialized sheep and goats farms were the only farm type with decreased value of both types of assets (total and fixed). When it comes to changes in value of buildings as well as machinery and equipment – mixed livestock type of farming performed the best (has the higher percent of increase). Specialist sheep and goats farms were the only one with deceasing value of machinery and equipment. It could be noticed that during the observed period value of buildings (in average) has the lowest cumulative growth (32.4%). It was caused by decrease of value of buildings for 6 types of farming.

Table 1 Cumulative growth of assets for various farm types (%)

14 Types of Farming	Cumulative growth (2004-2021) (%)			
	Total assets	Total fixed assets	Buildings	Machinery and equipment
(15) Specialist COP	13.0	4.7	-10.4	21.9
(16) Specialist other fieldcrops	37.4	27.2	-1.8	12.8
(20) Specialist horticulture	65.4	34.3	8.8	25.7
(35) Specialist wine	36.2	9.0	15.8	8.2
(36) Specialist orchards - fruits	48.9	30.1	14.0	53.7
(37) Specialist olives	154.0	71.6	-36.4	0.6
(38) Permanent crops combined	74.6	38.8	6.3	73.0
(45) Specialist milk	64.2	54.7	45.5	89.9
(48) Specialist sheep and goats	-10.1	-22.1	-22.7	-15.7
(49) Specialist cattle	31.4	22.1	-4.0	29.9
(50) Specialist granivores	146.1	116.2	82.7	110.6
(60) Mixed crops	37.9	23.9	20.6	24.8
(70) Mixed livestock	264.3	252.3	150.6	187.2
(80) Mixed crops and livestock	31.6	21.4	-5.0	18.5
All	61.4	42.2	32.4	46.0

Source: Authors calculation

During the observed period (2004 - 2021) increase of total fixed assets could be noticed, but decreasing participation of buildings in fixed assets is also present (for an average farm) (Fig. 2).

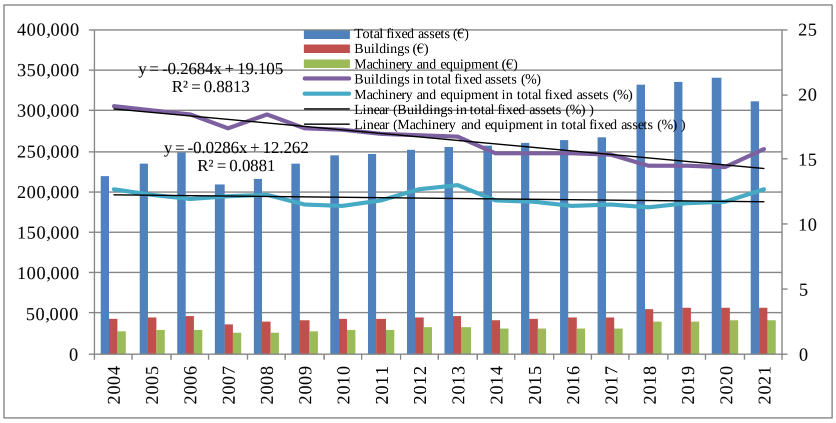

Fig. 2 Value of different assets (EUR) and participation in value of fixed assets (%)
Source: FADN public database and authors calculation

Similar tendecies (but with less pronounced decline) are determined for participation of machinery and equipment in fixed assets of an average EU farm.

More detailed analysis performed for 14 farm types in year 2021 revealed that buildings generally have higher participation in fixed assets (Fig. 3), except for specialized COP farms, farms specialized in production of other fieldcrops, specialized orchard – fruits, specialized olive producers and permanent crops combined.

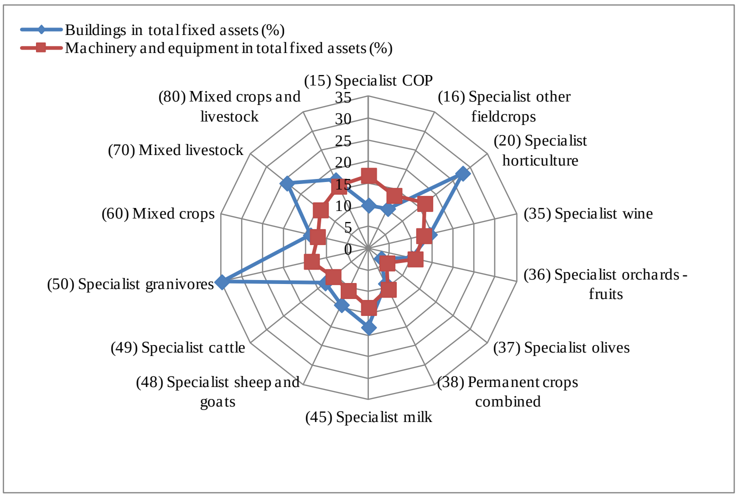

Fig 3. Participation in total fixed assets for TF 14 in 2021
Source: Authors calculation

When it comes to costs, this research is primarily devoted to machinery and building current costs, energy costs and costs of contract work. Sum of all these costs (for an average EU farm) has rather small participation in total inputs (total costs) – during the observed period it was usually under 20% (Fig. 4). Nevertheless, increasing trend of their importance in total costs could be noticed.

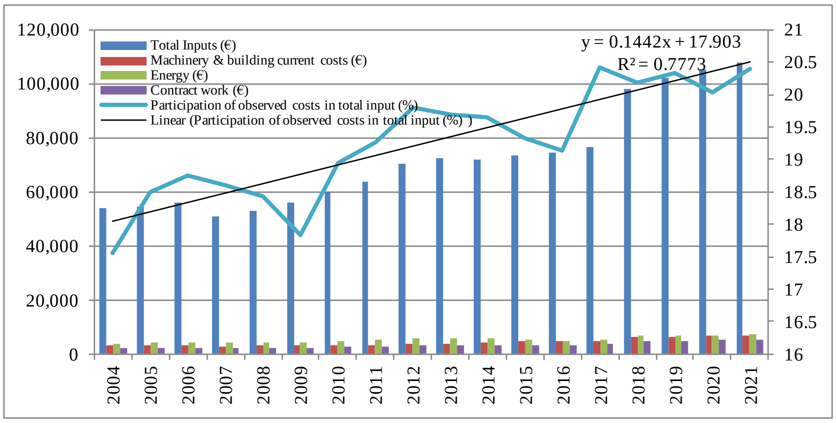

Fig. 4 Amount of certain costs (EUR) and their participation in total inputs (%)
Source: FADN public database and authors calculation

More detailed analysis (per various farm types) on the basis of the data for year 2021 revealed that energy costs are dominant (for 10 out of 14 farm types). Machinery and building current costs are dominant for three farm types (specialist milk, specialist cattle and mixed livestock production), while costs of contract work dominate for farms specialized in wine production (Fig. 5). Therefore, for majority farm types the attention should be primarily paid to energy costs.

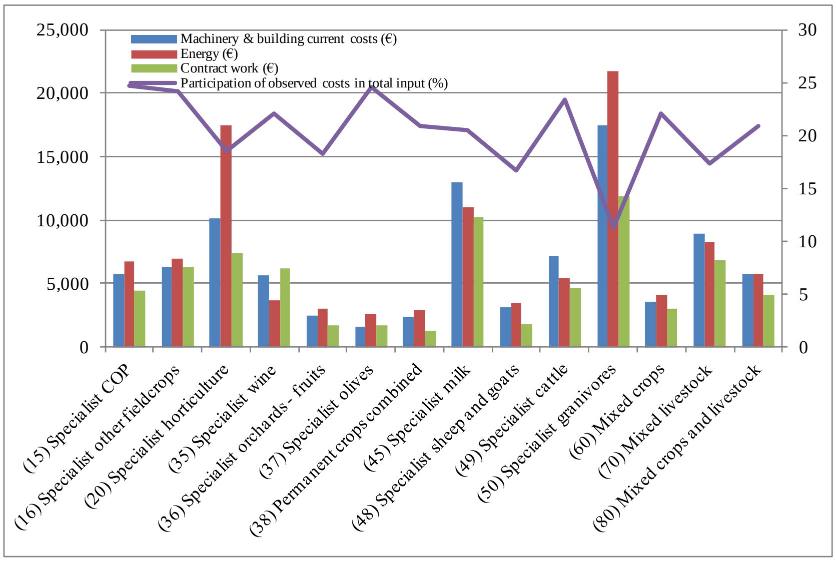

Fig. 5 Amount of costs (EUR) and their participation in total input (%) in 2021
Source: FADN public database and authors calculation

At the same time, sum of observed costs (SE340, SE345 and SE350) participate in total input from 11.36% (specialist granivores) to 24.75% (specialist COP production) (Fig. 5). The results lead to the conclusion that the biggest farms (specialized in granivores breeding) have the higher absolute amount of observed costs. On the other hand, relative importance of costs in question is the higher for specialized COP farms and farms specialized in other fieldcrops (apart from specialized olives production, which is irrelevant for Serbian production conditions).

All 14 farm types experienced cumulative growth (2004-2021) of total inputs (the higher for mixed livestock farm type) (Table 2). Even higher cumulative growth is observed for costs, while (in average) the most important growth was recorded for costs of contract work. The higher increase of all the observed costs is noticeable for mixes livestock type of production, while specialized sheep and goat farms had the lowest growth rates. More elaborate analysis of EU livestock production (primarily sheep and goat farms) based on FADN data were performed by Nastić et al. (2017a) and Nastić et al. (2017b).

Table 2 Cumulative growth of costs for various farm types (%)

	Cumulative growth (2004-2021) (%)			
14 Types of Farming	Total Inputs	Machinery & building current costs	Energy	Contract work
(15) Specialist COP	30.3	49.5	54.8	37.5
(16) Specialist other fieldcrops	37.4	49.9	65.9	65.1
(20) Specialist horticulture	64.4	118.3	43.8	163.5
(35) Specialist wine	51.8	80.6	123.0	226.9
(36) Specialist orchards - fruits	88.9	105.7	137.5	143.4
(37) Specialist olives	165.1	201.1	224.4	251.0
(38) Permanent crops combined	147.6	200.4	225.0	162.8
(45) Specialist milk	113.2	129.6	141.0	129.9
(48) Specialist sheep and goats	24.1	15.3	68.4	7.4
(49) Specialist cattle	39.4	64.9	85.1	51.2
(50) Specialist granivores	186.8	183.0	181.3	193.8
(60) Mixed crops	75.5	140.8	99.0	122.6
(70) Mixed livestock	338.5	399.6	284.2	351.6
(80) Mixed crops and livestock	42.0	68.9	52.0	61.9
All	99.4	112.4	104.0	123.0

Source: FADN public database and authors calculation

Having in mind that (among analyzed costs) energy costs are the most interesting for agro-food sector, special attention should be paid to energy efficiency. According to Diakosavvas (2017) energy efficiency assumes "using less energy to provide the same level of output and services". Discussing energy efficiency in entire agriculture author assumed that it is "the ratio of agricultural GDP per unit of direct use of energy". In the more comprehensive research (based on FADN data) discussing energy costs on the EU farms (conducted by Martinho, 2020a) total production was discussed as an output, while several inputs were observed (hours of paid labour, value of fixed assets and energy costs). Martinho, 2020b) also considered relations between farm output and energy costs, discussing possible redesign of CAP. Having above mentioned in mind, energy efficiency in this research is established as a relation between total output of farms (SE131) and their energy costs (SE345). Nevertheless, it should be noticed that such indicator does not take into account indirect energy used at the farm. Besides, there could be some other indicators of energy use, such as energy use per hectare or energy use per fattening pig equivalent (Meul et al., 2007), specific energy input, energy ratio, energy productivity, and net energy gain (Dimitrijević et al., 2020) and alike.

Detailed analysis of energy efficiency during period 2004 – 2021 for all 14 farm types (as well as for average EU farm) including trends of energy efficiency is presented on Fig. 6.

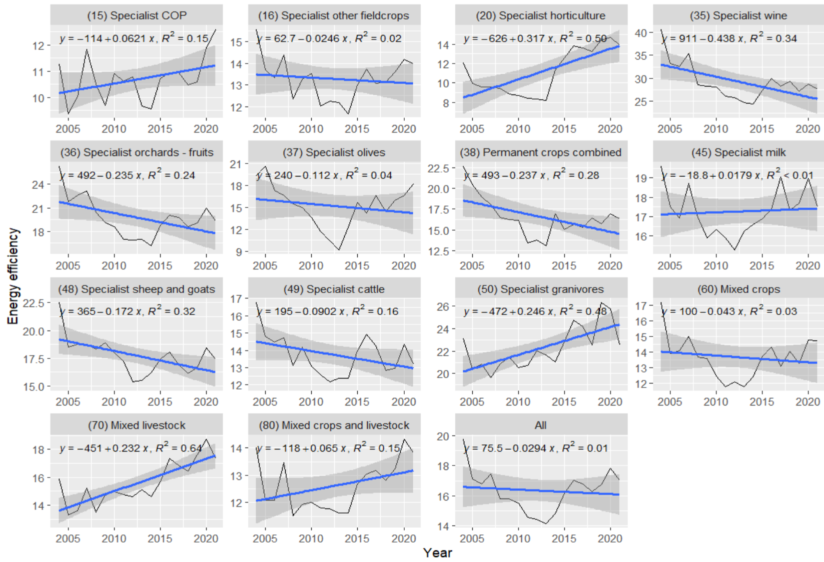

Fig. 6 Trends of energy efficiency for various farm types
Source: FADN public database and authors calculation

While average of all farms indicate slightly decreasing trend of energy efficiency, there are some farm types having much favorable trends. To have better insight in this problem, energy efficiency is discussed for year 2021 for all farm types (Fig. 7).

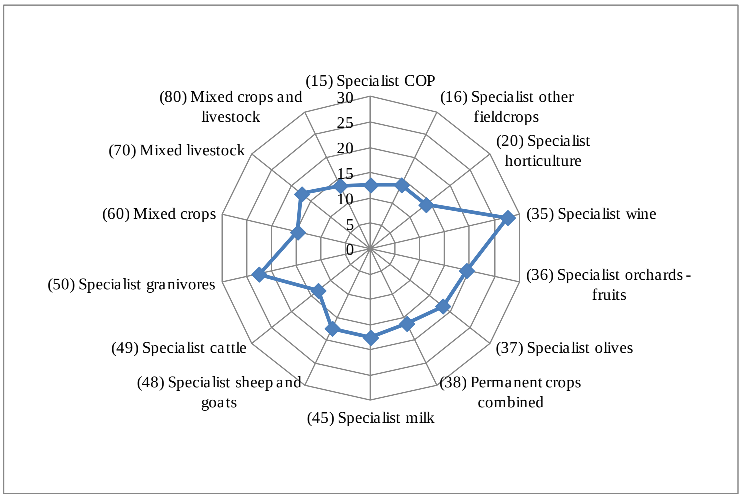

Fig. 7 Energy efficiency of observed farm types in year 2021
Source: Authors calculation

The highest energy efficiency is recorded for farm specialized in wine production, followed by specialist granivores. On the other side, the lowest level of energy efficiency is attributed to specialist COP farms, while slightly better results are determined for specialist cattle, mixed crop and livestock, specialist horticulture and specialist other fieldcrops.

CONCLUSION

Agriculture of the EU can be analyzed from various perspectives using FADN data. One of the most common ways is to discuss farms performance according their production type. Although there were some research devoted to costs of buildings, machinery and equipment, they are primarily related to energy costs. On the other hand costs of current upkeep of equipment and buildings, as well as costs of contract work are less discussed. Nevertheless, the results of this research indicated that for some farm types farming overhead costs are dominated by costs of contract work (farms specialized for wine production) while energy costs are rather low. Therefore, specialist wine farms have the best performance concerning energy efficiency analysis.

Besides, there are three farm types which overhead costs are dominated not by energy costs, but by machinery and buildings current costs. Such farms are dealing with livestock production, predominantly some types of cattle breeding (specialist milk, specialist cattle and mixed livestock production).

If we discuss the sum of all observed costs (energy, contract work, current upkeep of building and machinery) their participation in total costs is the highest for specialist COP farms. At the same time, specialized COP farms have the lowest level of energy efficiency. These farms are also characterized by much higher participation of machinery in total fixed assets, comparing to participation of buildings. Having in mind that specialized COP farms (producing cereals, oilseeds and protein crops) are the most numerous farm types in the EU, they should be in focus of future research in this field. Similar direction of research should be recommended for Serbian agriculture, concerning importance of cereals, oilseeds and protein crops production for Serbian agriculture.

Acknowledgement: This paper is a result of the research funded by the Ministry of Science, Technological Development and Innovations of the Republic of Serbia based on the agreement between the Ministry and the Faculty of Agriculture, University of Belgrade (Contract No. 451-03-47/2023-01/200116) and the Institute of Agricultural Economics, Belgrade (Contract No. 451-03-47/2023-01/200009 from 03.02.2023.) on the realization and financing of scientific research in 2023.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19^{th} – 21^{st} Oct 2023, Belgrade–Zemun, Serbia

SMALL FAMILY FARMS IN THE REPUBLIC OF SERBIA - ANALYSIS OF ENTREPRENEURIAL ORIENTATION AND THE NEED FOR SUPPORT

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Abstract. *Family farms in the Republic of Serbia are mostly small agricultural producers with arable land of small and medium size and with a low degree of process mechanization, where family members work mostly, and farm management is assigned to one family member. Such farms are often in a subordinate position, with weak bargaining power compared to large agricultural producers and large enterprises engaged in agricultural production. Nevertheless, the chance of further development of such farms lies in their positive entrepreneurial orientation and readiness for innovation and change. This paper presents research on the entrepreneurial orientation of family farms in the Republic of Serbia. The survey sample consisted of 72 farms from different locations in the Republic of Serbia. Entrepreneurial orientation was observed through the following elements: readiness of farms to join efforts, participation in large supply chains, readiness to standardize products and processes, readiness to export, readiness for changes and delegation of management processes, as well as readiness for farm development by improving knowledge about agriculture, management, and entrepreneurship. The results presented in the paper provide a clear insight to the support creators about the potential for improving the position of small farms in the Republic of Serbia.*

Keywords: *small agricultural farms, entrepreneurship, entrepreneurial orientation, Republic of Serbia*

1. INTRODUCTION

The dynamic world of today, in which abundance reigns, as well as great availability of resources for life and well-being, creates conditions for a constant increase in the number of inhabitants that must be fed to survive. Therefore, the need for food has become more than crucial. It is estimated that in 2050, almost twice as much food will be produced to feed humanity than today [5]. Having this in mind, agriculture represents an important economic sector in each national economy. It has powerful growth effects on the other sectors as well, including providing a growing demand for nascent industries [10]. Agriculture also draws great policymakers' attention [11]. This is especially the case in underdeveloped and developing countries and regions. Farming and agricultural businesses are crucial for many rural regions in Europe.

The main role in providing food for humanity is played by large agricultural producers. However, with the increasing need for a healthy life, natural and organic foods, as well as due to the increasing variability of the environment, small farms are becoming more and more important players for meeting the future food demand of the population [17,18]. The reason for this is their greater flexibility, which leads to faster adaptation to change, but also the quality of their agricultural products. Development of small farms is one of the main ways to reduce poverty in low-income countries [25] because small farms make residence of two-thirds of world population [10]. For such small agricultural farms, which are often in a subordinate position, with a weak bargaining power compared to large agricultural producers and large companies engaged in agricultural production, to survive, they must improve their skills and knowledge, be creative and engage in innovation. There are different strategies available to farmers to survive and be successful in a changing economic environment. Entrepreneurship stands out as one of the key strategies that drives innovation, efficiency, and the sector's economic growth.

Observing a group of family farms, their entrepreneurial orientation holds immense significance as it empowers these farms to evolve and thrive in a dynamic agricultural landscape. Entrepreneurialism of small farms is often equated with a farmer's spirit of acting in an entrepreneurial manner which focuses on gaining profit, efficiency, specialization, expansion, and optimization of management (Lance et al., 2014). It encourages a mindset of innovation, risk-taking, and adaptability, enabling family farms to identify and seize new opportunities, diversify their income streams, and effectively manage resources. Understanding the importance of the topic, this paper analyses entrepreneurial orientation of family farms and their need for support in the Republic of Serbia, which is one of the countries with highest potential for agricultural development in the Southeastern Europe. Serbia demonstrates great potential for digital transformation of agriculture as well, as it is noted in the national report on AgTech in the Republic of Serbia for 2023 [20]. Last, but not the least, Serbian government initiatives and EU integration efforts aimed to modernize the agricultural sector and promote entrepreneurship among family farms.

The paper is organized as follows. Section 2 provides a brief review of literature on the importance of entrepreneurship in agriculture, as well as entrepreneurial orientation of small agricultural farms. Section 3 explains the methodology, survey sample and data collection. Section 4 presents and discusses the obtained results. Section 5 concludes.

2. LITERATURE REVIEW

Entrepreneurship in agriculture is of high importance as it drives innovation, efficiency, and economic growth within the sector. Entrepreneurs in agriculture bring fresh ideas, adopt modern technologies, and develop sustainable practices that not only enhance farm productivity but also contribute to food security and environmental sustainability. They create new markets, value chains, and employment opportunities, fostering rural development. Moreover, entrepreneurial endeavors in agriculture are essential for adapting to changing climatic conditions and global market dynamics. In essence, entrepreneurship is a catalyst for the continued growth and resilience of the agricultural industry, ensuring its capacity to meet the ever-evolving demands of a growing world population. For the purposes of this paper, the literature review is focused on these two areas, namely: the importance of entrepreneurship in agriculture, and more specifically, the entrepreneurial orientation of small agricultural farms.

1.1. The importance of entrepreneurship in agriculture

Entrepreneurship as a term in agriculture is often confused with the term - small business. The majority of small agricultural farmers manage their farms using various conventional management methods and techniques. These farmers are not considered as entrepreneurs, they are considered as small business managers. However, entrepreneurship in agriculture is much more than that, it is considered as a business driven by leadership in change and innovation with the use of modern technology and methods of conceptual thinking and problem solving [14].

According to [13] there are five different groups of farmers, namely: (1) *Economic entrepreneurs*: those who create significant change; (2) *Socially responsible entrepreneurs*: those who, in addition to economic profit, are also concerned about the profit of society and the impact of their work on the environment; (3) *Traditional growers*: those who use traditional, well-established breeding methods that have been tested and guarantee safety; (4) *New growers*: those who diversify their production linked to their existing product portfolio; and (5) *Doubtful entrepreneurs*: those farmers who are held back and try to avoid change.

Based on their analysis, *Fitz-Koch* et al. [7] have determined that entrepreneurship within the agricultural sector takes on various forms, including diversification into food processing, the cultivation of new crops, and engagement in retail and agritourism. Farms facing less favorable financial conditions, such as those with lower liquidity and reduced returns on assets, like small agricultural farms, tend to branch out into non-traditional agricultural activities. Despite an increase in the number of farms venturing into new endeavors, it is noteworthy that these endeavors generally make up only a small portion of the total income for large farms. In contrast, smaller farms experience significant boosts in net income, both in the short and long term, because of these diversifications. Additionally, entrepreneurship in agriculture plays a role in reducing reliance on agricultural subsidies [1,7].

In terms of external impacts, small agricultural farms benefit from entrepreneurial activities in several ways, including mitigating the effects of resource scarcity and environmental impact, increasing employment opportunities, fostering rural development, and offering incentives for individuals to remain in rural areas [7].

To sum up, key conclusion is that entrepreneurial activities within farming create synergies between food production and the provision of supplementary services, such as landscape maintenance, cultural enrichment, and tourism, thereby contributing to the well-being of the rural economy and community. Furthermore, it is important to highlight that entrepreneurial actions can yield benefits on multiple fronts, benefiting individuals, small agricultural farms, and the environment. Notably, the consequences of entrepreneurship are diverse and far-reaching, spanning across various levels [1,7].

1.2. Entrepreneurial orientation of small agricultural farms

In addition to the importance of entrepreneurship in agriculture, it is significant to emphasize the entrepreneurial orientation of small agricultural farms, precisely what triggers the entrepreneurial behavior among them and what are the obstacles and limitations of it.

During the long history of small agricultural farms' development, they have gained great traditional experiences through work and have always reached the goal of economic independence and sustainability through entrepreneurship. The reason for the development of entrepreneurship among farmers can come from three perspectives: a socio-economic perspective, as a means of survival, an opportunity perspective, as a source of new development opportunities and areas, and finally a resource perspective as a source of ways to ensure and better use of farm resources [2]. According to [2], there are three types of farm-based entrepreneurs, namely: pluriacitve farmer, the resource-exploiting entrepreneur and portfolio entrepreneur. Pluriacitve farmer type refers to farmers that undertake entrepreneurial ventures aimed at expanding and increasing the sustainability of the farm, and it concern the expansion of the product offer and placement. Resource-exploiting entrepreneur refers to farmer who aims to better use of the existing farm resources to generate new income through related activities, but also completely unrelated activities such as ethno-tourism. Finally, portfolio entrepreneur is considered as an innovative entrepreneur who, in combination with his own and borrowed resources, creates new solutions, new ways of working, new products or, in other words, creates innovations in agriculture [2].

According to [3], entrepreneurially inclined small agriculture farms are likely to encounter the following difficulties: (1) narrowing the gap in technological advancement, enabling the agricultural sector to better address the challenges posed by climate change; (2) enhancing the effectiveness of the food supply chain and the competitiveness of the agricultural and food industry; (3) ensuring a consistent source of income and a favorable business environment for farmers and other entrepreneurial stakeholders; and (4) attaining the economic, environmental, and societal objectives of sustainable development, with special emphasis on the significance of multifunctional agriculture and rural development.To achieve the successful development of entrepreneurial orientation of small agriculture farms, it is necessary to work on the entrepreneurial training of farmers and, in addition to the development of entrepreneurial know-how, to work on the development of entrepreneurial skills such as innovation, risk-taking, conceptual thinking, etc. which can be classified into three large groups: personal skills, interpersonal skills and process skills [19]. In addition, the model of cooperatives and farmers association can also be an excellent model to furthermore raise and develop the entrepreneurial orientation of small agricultural farms [23].

3. Research design: Questionnaire and sample structure

The survey on the entrepreneurial orientation of family farms, presented in this paper was carried out during 2020 and 2021. The survey technique used is a structured interview with each owner of the farm individually. The survey was conducted on the group of 72 family farms in the Republic of Serbia. To create a realistic picture of the development of family farms, the survey was carried out in different geographical areas. It was conducted among the family farms in the following municipalities: lowland villages near Pančevo, predominantly represented farms with crop farming activities; hilly village in Smederevo, that are represented by growing fruit and vegetable; highland village near Čacak which predominantly represent the livestock farming. In the observed sample, there was an equal number of farms from all three locations. The structure of the survey sample is presented in Table 1. It represents the sample with three observed characteristics of agricultural farms: the level of farm mechanization, the size of arable area and the level of professional workforce engagement at farm.

Table 1 Survey sample: Categorical variables and frequencies

Categorical variables (for N = 72)		Frequencies (%)
Municipality	Pančevo	33.3
	Smederevo	33.3
	Čačak	33.3
Activity	Crop farming	33.8
	Fruit and vegetable growing	42.8
	Livestock farming	23.4
Mechanization level	manual agricultural tools	1.4
	single-axle tractor	5.6
	tractor	25
	tractor with all auxiliary machines	54.2
	tractor and combine harvester	13.8
Size of arable area	lower than 1 [ha]	2.8
	between 1 and 5 [ha]	47.2
	between 5 and 10 [ha]	27.8
	between 10 and 20 [ha]	11.1
	higher than 20 [ha]	11.1
Workforce engagement	one member of family	4.2
	two members of family	20.8
	whole family (3-5 members)	70.8
	whole family plus one worker	2.8
	whole family plus more than one worker	1.4

The level of mechanization evaluates the degree to which an agricultural farm is equipped with machinery and tools, as well as the level to which the farm is automated and standardized. According to [9], farm mechanization is one of the several pathways of agricultural development. *The size of the arable area* is an indicator that measures the farm size on which the agricultural production of the observed farm is done. It is usually expressed in square meters or hectares of arable land. A well-known opinion is that the size of a farm's arable area is in relation to farm productivity and economy of scale. However, [22] highlight that the ability to access new technologies is a very important precondition for productivity improvement, especially among small farms. *The level of professional workforce engagement* at farms is an indicator that represents manpower on the observed farm. The study [4] stated that very few farm employees may have a positive impact on farm performance. This survey sample shows that dominant family farms in Serbia are characterized by arable land lower than 5 ha, with an average mechanization level concerning agricultural machines and where members of family are dominantly engaging in farming.

The questionnaire used for the interview contained three groups of questions. The first group of questions was about the farm owner's characteristics – owner's competency for agriculture, management, and entrepreneurship. *The owner's competency for agriculture* is an indicator that measures the competence of the farm owners for agricultural activities. According to [6], higher levels of formal farmers' education led to a positive effect on social and environmental outcomes of individual agribusinesses. These social and environmental outcomes are important attributes of sustainable development of farms. Owner's competency for agriculture is measured on the following scale: 1 – farm owner is willing to use the land for agricultural production; 2 – farm owner has only practical working experience in agriculture; 3 – farm owner has high school degree in agriculture; 4 – farm owner graduated in agriculture; 5 – farm owner has a master's degree in agriculture. *The owner's competency for management* is an indicator that measures the farm owner's professionally developed skills and experience in management which is of great importance for family farm development [16]. Owners' competency for management is measured on the following scale: 1 – farm owner doesn't have any managerial experience; 2 – farm owner has managerial experience from youth and sport organizations; 3 – farm owner has a high school diploma in management; 4 – farm owner has a faculty diploma in management; 5 – farm owner has managerial experience in leading managerial projects. *The owner's competency for entrepreneurship* measures the level of professional competencies and education for entrepreneurship. The main purpose of entrepreneurial education is to support and develop an individual's entrepreneurial intentions [15]. Moreover, participation in entrepreneurship education and training programs positively influences individual entrepreneurial orientation [8] and entrepreneurial readiness [21]. The levels of farm owner's competency for entrepreneurship is measured on the following scale: 1 – farm owner doesn't have entrepreneurial experience; 2 – farm owner had an entrepreneurship course at secondary school but doesn't have real entrepreneurial experience; 3 – farm owner had an entrepreneurship course at secondary school and high school and also has the entrepreneurial experience; 4 – farm owner graduated in the field of entrepreneurship and has real entrepreneurial experience; 5 – farm owner has a master diploma in the field of entrepreneurship and has real entrepreneurial experience. *The owner's readiness for change* is the fourth characteristic measured. According to [26], an organization's readiness for change refers to its belief, attitude, and intention regarding the extent to which changes are required, as well as its capacity to successfully undertake those changes. Readiness for change is measured with the next scale: 1 – farm owner doesn't accept changes; 2 – farm owner accepts changes if it is mandatory; 3 – farm owner accepts changes when it sees a positive effect on others; 4 – farm owner accepts changes and innovations easily; 5 – farm owner supports changes and innovation processes at his farms.

The second group of questions refer to the selected characteristics of entrepreneurial orientation of small family farms. The third group of questions was about desirable support activities. All variable groups are presented in the next section.

4. RESULTS AND DISCUSSION

Results from previously stated quantitative variables are shown in Table 2 with mean values, standard deviation, and coefficient of variation.

Table 2 Quantitative variables in the survey and their mean values in survey sample

Variables	**Mean score (M)**	**Standard deviation (SD)**	**Coeff. of Variation (CV)**
Owner's competency for agriculture	2.03	0.41	0.202
Owner's competency for management	1.17	0.56	0.476
Owner's competency for entrepreneurship	1.86	0.74	0.396
Owner's readiness for change	3.25	0.67	0.205

Presented results show that in average, owners of small family farms in the Republic Serbia dominantly have only practical work experience in agriculture without formal degree in agriculture education. Coefficient of variation (CV) of 0.202 indicates that the standard deviation is roughly 20% of the mean. Considering the next two variables – owner's competency for management and entrepreneurship, average results reveal that farm owner doesn't have any managerial experience (M=1.17), and that their entrepreneurship competence level (M=1.86) was only with entrepreneurship course at secondary school and without any other previous practical real entrepreneurial experience. Coefficient of variation (CV) of 0.476 and 0.396 respectively, showed relatively high variation (47.6% of mean) and moderate variation (39.6% of mean), which indicate that some family farms in the survey sample are on the lower and higher level from the presented mean. In addition to low level of competencies (agriculture, management, and entrepreneurship), small family farmer showed moderate level (M=3.25) of readiness for change (farm owner accepts changes and innovations easily or when sees the positive effect on other farms). Coefficient of variation (CV) of 0.202 indicates low level of variability in survey sample, which means that there is consensus in family farmers attitude about readiness and willingness to change.

Family farms variability in the sample makes a justification for comparison on selected characteristics of entrepreneurial orientation which are based on the second group of questions. The selected characteristics are about family farm owner's intention for farm enlargement, farm intention to participate and engage in cooperatives and large value chains, agricultural process and products standardization, willingness to support and promote village and local community/ecosystem development, intention to further continuous development of knowledge in agriculture, management, entrepreneurship, entrepreneurial orientation in creating innovation and implementation of innovation, perception of suitability of support, as indicator of support service compatibility with farm's problems and needs. All characteristics were measured using Likert scale form 1 – completely disagree to 5 – completely disagree. Furthermore, the owners' competencies are analyzed with suitability of obtained business support and the farm business results improvement. Business results improvement were measured in percentage using next scale: 1: 0-5%, 2: 5-10%, 3:10-25%, 4:25-50%, 5: over 50%.

Table 3 presents the results of Spearman's correlation coefficient that was conducted to investigate whether farm owner's competencies and readiness for change are in relation with farms entrepreneurial orientation that are based on different characteristics of economic and social behaviour. Spearman's correlation coefficient analysis is chosen as a versatile tool for assessing relationships between variables when the data are ordinal or subjective and where the exact numerical values are not as meaningful as the order or ranking of values, like a survey response on Likert scales [24].

Statistically significant Spearman's correlation coefficient results (Table 3) are further noted. Farm owner's intention for farm enlargement is in positive moderate and significant correlation ($p<0.01$) with competency for entrepreneurship (0.450), and readiness for change (0.331). Therefore, entrepreneurial education and change readiness can impact expansion of farming operation. Farm participation in cooperatives is in low positive and significant correlation ($p<0.05$) with competency for agriculture (0.233) and management (0.256). Entrance into large value chains is a positive decision of every entrepreneur. The results showed a positive low correlation with competence for agriculture (0.246). Product and process standardization correlate with competency for management (0.238) and readiness of changes (0.398). Product and process standardization is one of the critical prerequisites for successful management of a business. Willingness to village and local community/ecosystem development is in lower significant correlation ($p<0.01$) with competency for agriculture (0.267), management and entrepreneurship (0.331). Future development of knowledge showed lower positive correlation with farm owner's competency for agriculture (0.268) and entrepreneurship (0.441) as well as moderate positive correlation with readiness for changes (0.409). The suitability of support, as an indicator of support service compatibility with farm's problems and needs is significantly connected to competency for management (0.240) and readiness of changes (0.268). Finally, farm business results improvement is in higher positive correlation with readiness for change (0.502).

Table 3 Spearman's coefficient correlation: farms owner' competencies and entrepreneurial orientation

Spearman's rho (N=72)	Competency for agriculture	Competency for management	Competency for entrepreneurship	Readiness for change

Farm enlargement	0.123	0.181	0.450**	0.331**
Participation in cooperative	0.233*	0.256*	0.228	0.076
Large value chains	0.246*	0.164	0.132	0.095
Product and process standardization	-0.007	0.238*	0.193	0.398**
Village development	0.267*	0.236*	0.331**	0.187
Future development of knowledge	0.268*	0.15	0.441**	0.409**
Creation and innovation implementation	0.355**	0.236*	0.372**	0.519**
Suitability of support	0.146	0.240*	0.241*	0.268*
Business improvement	0.000	0.102	0.22	0.502**
Stat. significance	** p<0.05; ** p<0.01*			

The third group of questions were about the gap between expected and realized type of support activities. The results are presented in Table 4, for each support activity that is obtained as a difference among the percentage of small family farms that expect the specified support activity and percentage of family farms that obtained that activity.

Table 4: The gap between expected and realized forms of support

Nº	Support activities	Difference [%]	Rank
1.	*Well-timed information about agricultural businesses' conditions*	43.2	11
2.	*More favorable loans for agriculture*	52.3	9
3.	*Guaranteed selling price*	65.9	8
4.	*Tax relief*	75.0	7
5.	*Higher subventions for seeding, mechanization, fertilizing…*	75.7	6
6.	*Rural transport infrastructure development*	34.1	13
7.	*Modern electricity supply system*	36.4	12
8.	*The improvement of water supply system*	50.0	10
9.	*The improvement of sewage network*	86.3	3
10.	*The improvement of waste disposal*	65.9	8
11.	*The improvement of anti-hail protection*	88.6	2
12.	*Preventing drought*	65.9	8
13.	*Education development in villages*	77.3	5
14.	*Health service development in villages*	91.0	1
15.	*Trade development in villages*	81.9	4
16.	*Tourism development in villages*	52.3	9
17.	*Help in transport of agricultural products*	16.4	14

Observing the obtained results, the support activities with the largest gap between expected and realized are health service development in villages (91%); improvement of anti-hail protection (88.6%); the improvement of sewage network (86,3%). The results presented in Table 4 indicate that support is not at the adequate (expected) level yet, and that it is necessary to put effort to reach the expected levels.

5. CONCLUSION

Entrepreneurial orientation of family farms holds significant importance in contemporary agriculture. This orientation fosters innovation, adaptability, and competitiveness within the agricultural sector. Family farms that embrace entrepreneurial values are better equipped to respond to changing market dynamics, environmental challenges, and technological advancements. Moreover, their willingness to take calculated risks, seek new opportunities, and invest in sustainable practices contributes to the long-term viability of both the individual farm and the broader agricultural industry. Recognizing and promoting entrepreneurial orientation in family farms is essential for enhancing their resilience and ensuring the sustainability of agriculture in a rapidly evolving world.

This paper analyses entrepreneurial orientation of family farms in the Republic of Serbia, as well as their need for support. Entrepreneurial orientation of a farm may influence performance in small farm-based ventures. Even if earlier literature has described farmers as more conservative business owners compared to non-farm business owners, our study shows that those farm businesses that do engage in entrepreneurial efforts also get rewarded for these efforts. For the resource-based view scholars, our findings suggest that the firms' entrepreneurial orientation might be an important 'resource' that needs to be accounted for. In addition, the paper shows that support provided to small farms is not at the expected level. Thus, it is necessary to put effort to reach the expected levels. Family farms today require multifaceted support to thrive and contribute to sustainable agriculture. This support should encompass financial assistance, access to modern technology, education and training, and policy frameworks that prioritize their well-being. Additionally, fostering a supportive community and market environment is crucial. In conclusion, a holistic approach that addresses the diverse needs of family farms is essential to ensure their resilience, productivity, and long-term success in the face of evolving challenges.

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ISAE 2023

The 6th International Symposium on Agricultural Engineering, 19th – 21st Oct 2023, Belgrade–Zemun, Serbia

NAVIGATING THE PATH TO SUSTAINABILITY: AN ECONOMIC ANALYSIS OF BARRIERS, DRIVERS, AND POLICY FRAMEWORKS IN AGRICULTURAL FOOD AND FEED TECHNOLOGIES

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Abstract:

In response to the formidable challenges faced by the global agricultural sector in maintaining consistent food and feed production, there is an imperative to integrate economic considerations into the development of novel technologies and methodologies. This study delves into the potential applications of economics in fostering the evolution of sustainable food and feed systems, with a primary focus on efficiency, equity and environmental concerns.

By accentuating the pivotal role of financial incentives in driving the adoption of sustainable practices, this study examines the intricate interplay between technological innovation, market dynamics, and governmental regulations. Through an extensive review of pertinent literature and the utilization of case studies, empirical research and survey data analysis, this research seeks to identify the principal economic catalysts for, as well as impediments to, the uptake of sustainable agricultural technology.

Moreover, this study introduces an innovative paradigm designed to motivate policymakers, practitioners and researchers towards embracing eco-friendly yet economically viable agricultural practices. The unique insights provided herein have the potential to chart a groundbreaking course for the future trajectory of agricultural sustainability and food security.

This study underscores the urgent need to blend economic perspectives with agricultural advancements, illuminating a path towards harmonizing production efficiency, equitable distribution and ecological well-being. Through the proposals outlined, the groundwork is laid for steering global agricultural practices into a more sustainable and secure future.

***Keywords**: economics, agriculture, food security, economic incentives, environmental considerations, sustainable technologies.*

1. INTRODUCTION

The most important issues facing the world today, concerning food security, environmental preservation and economic development are centered on agriculture mostly. The necessity to reduce environmental damage along with the fast-increasing need for food and feed have fueled the hunt for creative and sustainable solutions. However, the contribution of economics to these solutions has frequently been overlooked or dispersed among many fields.

A potential solution to the problems at hand is the incorporation of economics into sustainable food and feed systems. The incentives, restrictions, and trade-offs involved in agricultural decision-making can be better understood via the lens of economics. We can therefore develop strategies that are in line with the more general objectives of sustainability by comprehending how economic considerations affect behavior, legislation, and technical innovation.

In order to close the gap between economics and sustainable agriculture, this study explain how economic concepts have influenced the development of food and feed technologies. The study focuses on the interactions between market pressures, governmental interventions, technical improvements, and personal preferences in this complicated environment.

2. LITERATURE REVIEW

The goal of the literature review part is to create a thorough grasp of the current environment by synthesizing the body of knowledge on economics in sustainable food and feed technology.

2.1. Agrarian Economic Principles

Reviewing foundational literature reveals a focus on important economic concepts, such as efficiency, externalities, and market equilibrium, as they relate to agriculture. Foundational understandings of the function of property rights and government action in managing agricultural integrity have been supplied by studies by Coase (1960) and Pigou (1920).

2.2. Agriculture and Sustainable Technologies

Regarding technology, a number of authors have emphasized how innovation can increase agricultural productivity while reducing environmental impact (Schumpeter, 1942; Solow, 1957). Recent research has examined the integration of renewable energy in farming, water-saving technology and precision agriculture.

2.3. Financial Rewards and Political Interventions

The usefulness of various economic incentives, such as subsidies, taxes, and market-based tools, in encouraging sustainable agriculture has been the subject of a considerable body of research (Stavins, 1998; Goulder, 2013). The Common Agricultural Policy of the European Union is one example of a policy intervention that has been thoroughly examined.

2.4. Environmental Points of Interest

In-depth research has been done on the relationship between economics and environmental sustainability in agriculture (Dasgupta, 2008; Turner, 1993). The Resource management, coping with climate change, and the economic value of ecosystem services are among the topics to be covered.

2.5. Adoption Drivers and Obstacles

Access to finance, risk perceptions, and knowledge asymmetry have all been cited as economic hindrances and factors that prevent the adoption of sustainable practices (Rogers, 2003; Knowler, 2015).

Table 1: Summary of Key Research Themes

Theme	**Key Authors**	**Main Findings**	**Methodology**
Economic Principles	Coase, Pigou	Externalities, property rights	Theoretical
Sustainable Technologies	Schumpeter, Solow	Innovation, efficiency	Empirical, Case Study
Economic Incentives	Stavins, Goulder	Subsidies, taxes, market instruments	Empirical, Policy Analysis
Environmental Considerations	Dasgupta, Turner	Resource management, valuation	Theoretical, Empirical
Barriers and Drivers	Rogers, Knowler	Capital access, risk, information	Surveys, Case Study

3. METHODOLOGY

The summary of this study data collecting are analysis and research methodologies is given in this section. It provides justification for the methodologies that were picked, tying them to the goals of the study.

3.1. Research Approach

The study uses both qualitative and quantitative analysis in a mixed-methods approach. This case studies and the content analysis are part of qualitative component to be discuss, whereas the statistical analysis and econometric modelling are part of the quantitative component.

3.2. Data Gathering

Methods of gathering data include:

Secondary data: A thorough analysis of the body of current research, as well as government and business publications.

Primary data: Surveys and interviews with farmers, policymakers, technologists, and other stakeholders.

Field observations: Site visits to farms employing sustainable practices and technologies.

3.3. Methods of Analysis

The analysis includes:

Qualitative analysis: Thematic coding of interviews and content analysis of case studies are some examples.

Quantitative Analysis: Econometric modelling with regression methods to analyze how economic factors affect the uptake of sustainable technologies.

3.4. Sampling and Population

The study aims to provide a representative view by concentrating on diverse agricultural industries across various areas. The sample consists of:

Small-scale Farmers: Focusing on various livestock and crop systems.

Focus on innovation and technology adoption, technologists and agribusinesses.

Policymakers: Information on the creation and application of policies.

Table 2: Summary of Data Collection Methods

Data Type	Sources	Method	Scope
Secondary Data	Literature, government reports, publications	Review	Global
Primary Data	Surveys, interviews	Mixed	Regional, Sector-specific
Field Observations	Farms employing sustainable practices	Observation	Case-specific

3.5. Ethical Considerations

The study follows ethical standards, upholding participant confidentiality, and getting everyone's informed permission.

3.6. Limitations

Potential drawbacks include survey response bias, the inability of case study generalization, and difficulties in gaining access to confidential information.

4. ECONOMIC FUNDAMENTALS OF SUSTAINABLE AGRICULTURE

This section focuses on efficiency, equity, and market to examine the underlying economic principles that underpin sustainable agriculture. It's essential to comprehend these concepts in order to match agricultural practices with sustainability objectives.

4.1. Efficiency

Both allocative and technical factors are included in agricultural efficiency in sustainable practices:

Allocative Efficiency: Achieving the best resource allocation, where marginal costs and marginal gains are equal. According to research, efficiency is rising thanks to focused investments in sustainable technology (Williamson, 1985).

Technical efficiency: Increasing output for a specific set of inputs, frequently accomplished through cutting-edge technology like precision agriculture.

4.2. Equity

In agriculture, equity refers to the equitable allocation of resources and advantages:

Distributional equity: This refers to the equitable distribution of gains from sustainable practices among all parties, especially small-scale farmers (Rawls, 1971).

Intergenerational Equity: Aligning with the principles of sustainable development, balancing current needs with the rights of future generations to natural resources.

4.3. Governmental Interventions and Market Dynamics

Market forces by themselves might not produce lasting results, frequently necessitating government intervention:

Market Failures: Regulations, subsidies, or taxes are frequently used to solve market failures, which include externalities, public goods, and information asymmetry (Arrow, 1969).

Government interventions: Measures like grants for renewable energy or water conservation that try to encourage sustainable practices.

4.4.1. Role of Technology

Technology is essential for bringing economic concepts and sustainability together.

Innovation: Adopting new technologies, such as drip irrigation or genetically modified organisms (GMOs),that increase efficiency and minimize environmental effect.

Adoption Barriers: Technology adoption is hampered by financial obstacles like high startup costs or limited access to financing, necessitating focused interventions.

Table 3: Key Economic Principles in Sustainable Agriculture

Principle	Description	Implications	Examples
Efficiency	Allocative and technical	Resource Optimization	
Equity	Distributional and intergenerational	Fairness	Smallholder Support
Market Dynamics	Market failures, government interventions	Regulation	Subsidies, Taxes
Technology	Innovation and adoption barriers	Innovation	GMOs, Drip Irrigation

5. CASE STUDIES AND EVALUATIVE RESEARCH

In-depth case studies and empirical analyses are provided in this part to help readers understand how economic principles are used in sustainable agriculture. These illustrations offer a variety of viewpoints because they are taken from varied geographical and contextual settings.

Case study 1: Dutch Precision Agriculture

In the Netherlands, precision farming technology has made it possible to use resources more effectively. Econometric investigation, with a focus on data-driven decision-making, finds a considerable positive link between the use of this technology and farm productivity.

Case study 2: Support for Smallholders in Kenya

Government subsidies aimed at small-scale farmers in Kenya have made it possible for sustainable practices to be adopted. A complex interplay of economic incentives and impediments, including access to finance and market dynamics, is shown by qualitative interviews with stakeholders.

Case study 3: California, USA, Water Conservation

Initiatives in California to conserve water through market-based tools, such tradable water rights, have been successful. According to empirical analysis, agricultural output will either be maintained or rise while water use will decrease.

Case study 4: Brazil's Adoption of GMOs

The use of GMO crops in Brazil is an example of how technical advancement may promote sustainability. Crop yields have significantly increased, land consumption has decreased, and deforestation rates may have decreased, according to econometric models.

Table 4: Summary of Case Studies

Case Study	**Location**	**Focus Area**	**Key Findings**	**Method**
Water Conservation	California, USA	Market Dynamics, Policy	Reduced water usage, Market-based solutions	Empirical Analysis
GMO Adoption	Brazil	Technology, Innovation	Increased yields, Reduced land use	Econometric Analysis
Smallholder Support	Kenya	Equity, Subsidies	Adoption of sustainable practices, Economic barriers	Qualitative Interviews
Precision Farming	Netherlands	Technology, Efficiency	Increased productivity, Resource optimization	Econometric Analysis

5.5. Empirical Analysis

In order to comprehend the factors impacting the adoption of sustainable practices, a more comprehensive empirical research is undertaken across several regions using regression models. The analysis takes into account elements including societal acceptance, technological accessibility, market dynamics, and personal preferences.

Table 5: Regression Results for Sustainable Practices Adoption

Variable	**Coefficient**	**Standard Error**	**Significance**
Governmental Support	0.35	0.07	***
Technological Access	0.25	0.06	***
Market Conditions	0.15	0.05	**
Individual Preferences	0.10	0.04	*

Note: *** p<0.01, ** p<0.05, * p<0.1

6. BARRIERS AND DRIVERS TO ADOPTION

Understanding and removing adoption hurdles as well as utilizing the forces that support such practices are essential to the development of sustainable food and feed systems. This section explores the vast array of elements that might either help or impede the adoption of sustainable practices in agriculture.

6.1. Adoption Roadblocks

The widespread adoption of sustainable agriculture practices is constrained by a number of factors:

Economic Barriers: Investment in sustainable technologies is discouraged by high start-up costs, a lack of funding options, and uncertain economic rewards.

Technological barriers: Limited availability of appropriate technology and lack of skills or knowledge to use them effectively.

Institutional barriers: They include ineffective rules, a lack of government assistance, and a lack of collaboration between stakeholders.

Socio-cultural barriers: Adoption may be hampered by farmer preferences, social norms, and aversion to change.

Table 6: Barriers to Adoption of Sustainable Practices

Barrier	**Description**	**Examples**
Economic	Costs, financing	High upfront costs
Technological	Availability, skills	Lack of training
Institutional	Regulations, support	Inefficient policies
Socio-Cultural	Preferences, norms	Resistance to GMOs

6.2. Drivers of adoption

Conversely, a number of reasons encourage the use of sustainable practices:

Financial inducements: Grants, subsidies, and market-based initiatives like carbon trading can act as such.

Technological developments: Innovations that increase productivity, cut costs, or provide unmistakable benefits can encourage adoption.

Support for Policy and Regulation: Governmental initiatives that encourage or impose sustainable practices.

Social Awareness and Consumer Demand: Growing public knowledge of ecological challenges and demand for ethical products.

Table 7: Drivers of Adoption of Sustainable Practices

Driver	**Description**	**Examples**
Economic Incentives	Grants, subsidies	Renewable energy incentives
Technological	Innovation, efficiency	Precision agriculture
Policy Support	Regulations, mandates	Water conservation laws
Social Awareness	Consumer demand	Organic food market

6.3. Combining Drivers and Barriers

A balanced strategy is necessary to deal with how drivers and obstacles interact. While simultaneously utilizing drivers, strategies must identify and reduce impediments. For instance, financial incentives can help people get beyond financial barriers, and education and training can help people get over technological obstacles.

7. RECOMMENDATIONS FOR A FRAMEWORK AND POLICIES

This part offers a suggested framework for encouraging the use of sustainable food and feed technology, building on the learnings from the earlier analysis. The framework translates into particular policy suggestions and emphasizes a comprehensive, multidisciplinary approach.

7.1 The Suggested Framework

Four interconnected pillars make up the suggested framework, each of which addresses a crucial part of sustainable agriculture:

- **Economic Mechanisms:** Making use of financial tools like grants, subsidies, and market-based mechanisms like carbon trading to encourage adoption.

- **Technological Innovation and Support:** Promoting the study, creation, and spread of pertinent **technology together with instruction and training.**

- **Institutional Arrangements:** They enhance governance through effective rules, policies, and multi-stakeholder cooperation.

- Social Engagement: Promoting consumer and community participation, awareness, and demand for sustainable products.

Table 8: Proposed Framework for Sustainable Agriculture Adoption

Pillar	**Components**	**Rationale**
Economic Mechanisms	Subsidies, grants, trading schemes	Financial incentives
Technological Innovation	R&D, training, support	Enhance efficiency, skills
Institutional Arrangements	Regulations, policies, collaboration	Effective governance
Social Engagement	Awareness, demand, community input	Societal support, preferences

7.2. Recommendations for Policy

The framework translates into specific policy recommendations aimed at governments, businesses, researchers, and civil society:

- Foster Research and Development: It involves making investments in creativity and inquiry to create sustainable technology suited to regional demands.

- Offer Financial Incentives: Implementing tax breaks, grants, or subsidies to reduce adoption's financial barriers.

- Enhance Education and Training: This involves developing workshops and instructional programs for farmers, technologists, and decision-makers.

- Simplify Regulations: Aligning laws and policies to foster the adoption of sustainable practices.

- **Promote Multi-Stakeholder Collaboration:** Encourage conversation and cooperation between governments, business, academia, and communities.

- Raise Public Awareness: Launching public campaigns to encourage the purchase of sustainable goods and influence social decisions.

8. CONCLUSION

The fusion of economic concepts and ecological practices emerges as a focal point for future growth and resilience in the ever-evolving world of agriculture. In order to highlight the difficulties and potential in integrating sustainability into agricultural paradigms, this study has navigated the complex interplay of economic theories, empirical data, and real-world examples. The case studies and empirical analyses revealed the varied character of sustainable agriculture, which is fueled by a variety of factors ranging from technical developments to policy interventions, and provided concrete insights. A holistic, multi-stakeholder approach is crucial, and the suggested framework and policy suggestions stress the potential of economic instruments and methods to promote sustainable outcomes.

The takeaways from this investigation offer a useful compass as the world community struggles with important concerns like climate change, food security, and resource shortages in the future. A more equitable, effective, and adaptable agricultural system may be possible if sustainable food and feed technologies are seen from a nuanced, economics-focused perspective.

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Acknowledgment

This symposium was supported and covered by Government of Republic of Serbia – Ministry of Science, Technological Development and Innovation.

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Numerous papers presented at this symposium are the results of research within the "Agreement on the realization and financing of scientific research work in 2023 between the Ministry of Science, Technological Development and Innovation of the Republic of Serbia and :

- University of Belgrade, Faculty of Agriculture, Belgrade-Zemun, Serbia
  contract registration number: 451-03-47/2023-01/200116.
- University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
  contract registration number: 451-03-47/2023-01/ 200105.
- Institute of Nuclear Sciences "Vinča", University of Belgrade, Belgrade, Serbia
  contract registration number: 451-03-47/2023-01/ 200017.
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631:502.131.1(082)(0.034.2)

INTERNATIONAL Symposium on Agricultural Engineering (6 ; 2023 ; Beograd) Proceedings [Elektronski izvor] / The 6th International Symposium on Agricultural Engineering - ISAE 2023, 19th - 21st October 2023, Belgrade, Serbia ; [organizer] University of Belgrade, Faculty of Agriculture, The Institute for Agricultural Engineering, Belgrade, Serbia ; co-organizers University of Belgrade, Faculty of Mechanical Emgineering, Department for Agricultural Engineering, Belgrade, Serbia ... [etc.] ; [editors Ivan Zlatanović, Nedžad Rudonja]. - Belgrade : University, Faculty of Agriculture, The Institute for Agricultural Engineering, 2023 (Beograd : University, Faculty of Agriculture). - 1 elektronski optički disk (CD-ROM); 12 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 100. - Preface / Ivan Zlatanović. - Bibliografija uz svaki rad.

ISBN 978-86-7834-427-5

a) Poljoprivreda – Održiv razvoj – Zbornici b) Poljoprivreda – Zbornici

COBISS.SR-ID 132841225

9 788678 344275

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