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AGRICULTURAL PRODUCTION IN UKRAINE: AN INSIGHT INTO THE IMPACT OF THE RUSSO-UKRAINIAN WAR ON LOCAL, REGIONAL AND GLOBAL FOOD SECURITY

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Abstract: The ongoing Russo-Ukrainian war is affecting Ukrainian agriculture. For example, Ukraine is no longer able to export agricultural products such as grains and cereals by sea to regional (European) and international markets, although this has been partially mitigated by the creation of a "grain corridor". As a result, food security in Ukraine, and to some extent, in the region (EU) and globally, is at some risk, especially in countries that rely heavily on agricultural imports from Ukraine. About 70% of the land in Ukraine is used for agricultural production. This paper provides an overview of Ukrainian agricultural production using statistics for 2018–2022, based on available literature, as well as FAO and official Ukrainian government statistics. Global production of the main grain crops and cereals (wheat, maize, barley, rapeseed, and sunflower), ranging between 2.9 and 6.6%, showed an upward trend in 2017–2021. Ukraine accounted for 9, 12, 12, 14, and 50% of the global trade market (import + export) in 2020/2021 for wheat, maize, barley, rapeseed, and sunflower oil, respectively. About 75% of agricultural products and services (892,852 million UAH in total) come from the crop industry, with the remainder from the livestock industry. Fertilizer export was banned in 2022.

Key words: agricultural production, economic reform, fertilizer, grains, pre-war and post-war restoration, wheat.

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Introduction

Even though an armed conflict has existed between Ukraine and the Russian Federation since at least 2014, following Euromaidan and the annexation of Crimea by the Russian Federation, as well as the break-away movements in the Donbas region (parts of Luhansk and Donetsk oblasts), this conflict developed into a full-blown war starting with the invasion of Ukraine by the Russian Federation on 24 February 2022.

Although many aspects of society and the economy have already been affected (Astrov et al., 2022; Liadze et al., 2022), the aim of this paper is to focus on how agriculture in Ukraine may be impacted by the war.

Spring is traditionally the start of the grain sowing season in Ukraine and in much of central and southern Europe, and this generally implies sowing in March and April, precisely when Ukraine was invaded, with the bombing of infrastructure and agricultural land in several oblasts. Ukraine's agricultural products, according to the UN Food and Agriculture Organization (FAO), in terms of production and export volumes, are mainly grain crops and cereals, including wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), barley (*Hordeum vulgare* L.) and rapeseed (*Brassica napus* L.), as well as sunflower (*Helianthus annuus* L.), although meat products are also an important export commodity (FAO, 2021, 2022). Agriculture, an important pillar of the Ukrainian economy, accounted for 11% of gross domestic product (GDP) in 2018–2020 (Kravchenko et al., 2020; Onegina et al., 2020) and, according to the State Statistics Service of Ukraine (SSSU), 17% of GDP in the third quarter of 2021 (SSSU, 2021a, 2022c). About 69% of land in Ukraine is used for agricultural production (SSSU, 2021a).

This paper has three objectives. First, it provides an overview of the key production and export values for some of Ukraine's main agricultural products, relying primarily on data from the FAO and the SSSU Statistical Yearbook. Second, this paper outlines developments in Ukrainian agricultural production and reform. Third, it provides a broad overview of some of the economic and structural aspects associated with Ukrainian agriculture that might be impacted by the war.

The study involved a complex of methods related to economic research, in particular: (i) the tendencies and current state of development of Ukrainian agriculture and export of agricultural products during the ongoing Russo-Ukrainian war, which was estimated by means of economic analysis and synthesis; (ii) statistical and balance methods were used to analyse the export of agricultural products; (iii) statistical groupings were used to assess the concentrations of crop production (by harvested area size under grain and leguminous crops) and livestock production (by number of farm animals) in agricultural enterprises of Ukraine; (iv) theoretical generalisation and comparison, induction and deduction were used to reveal the main areas of influence of the Russo-Ukrainian war on Ukrainian agriculture and possible impacts on national, regional and global food security, drawing conclusions.

Recent key agricultural economic indicators for Ukraine

Agricultural production patterns

According to the FAO, in 2020, Ukraine ranked seventh globally in terms of wheat production (China and India ranked first and second), producing 24.9 million tons (Mt), accounting for approximately 3.3% of global output in 2020 (FAO, 2020). Although there are no values for 2020, the FAO indicates that Ukraine ranked first in 2019 in terms of sunflower oil production (5.84 Mt) (FAO, 2019). In 2021, the greatest area of cultivated land was under cereals and leguminous crops (SSSU, 2022a).

Regarding Ukraine's role in global food production (Figure 1), we note its relative share in the output of main products. In 2021, during the pre-war period (Figure 1), Ukraine accounted for 2.9% of cereals, 4.1% of wheat, 3.3% of coarse grain (including sorghum, millet, rye, oats and other grains), 3.2% of maize, 6.6% of barley, and 3.7% of oil crops in terms of global relative production values. Ukraine's share in global production of these crops showed an upward trend in 2017–2021. The share of livestock products was not so large (Figure 1), accounting for only 0.7% of meat production (compared to global values in 2020 and 2021) and for 1.1, 1.0, and 0.9% of global milk production in 2017–2019, 2020, and 2021, respectively.

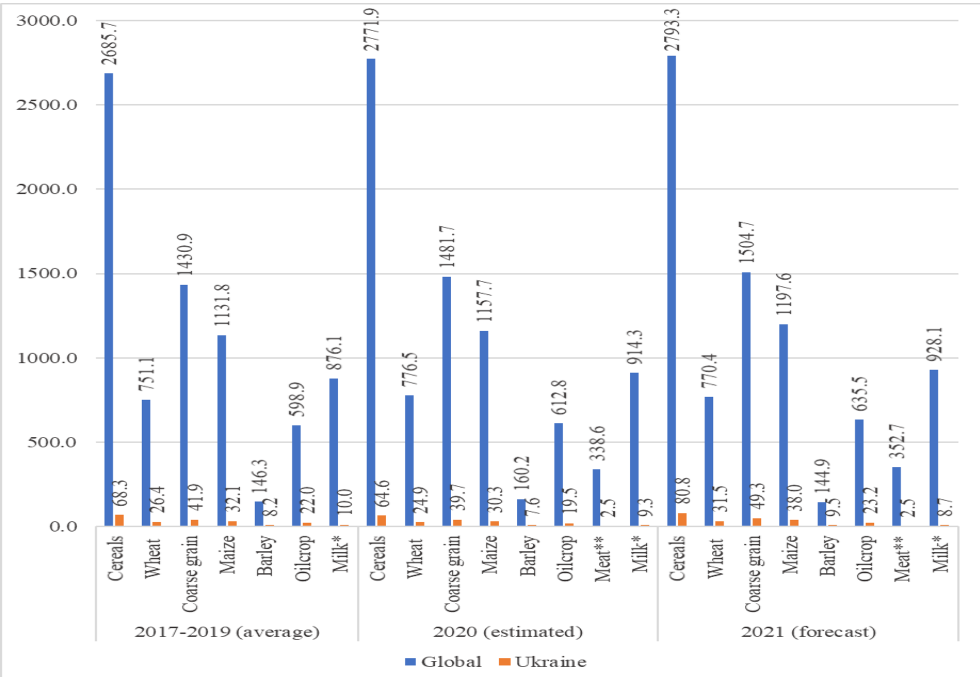
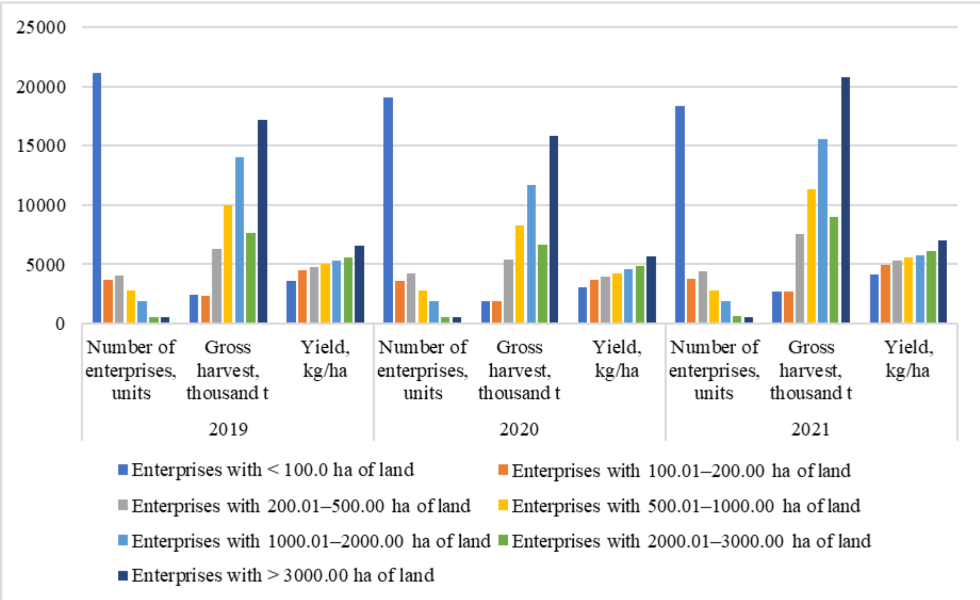


Figure 1. Agricultural production in Ukraine and globally, Mt. Source: FAO (2021).

Agriculture in Ukraine has a bipolar structure with large volumes produced by agricultural enterprises intended for export purposes, as well as multiple smaller enterprises and semi-subsistence households that produce potatoes, vegetables, fruits and berries that satisfy domestic food demand and ensure national food security (Mishenin et al., 2021; Koblianska et al., 2020). In particular, grain production in Ukraine is characterised by a high concentration of land and harvesting volumes in large enterprises, as shown by the grouping results (Figure 2).



Sources: SSSU, 2020, 2021a, 2022a; authors' compilation and visualisation.

Figure 2. Groupings of enterprises by the size of harvested area under grain and leguminous crops in Ukraine.

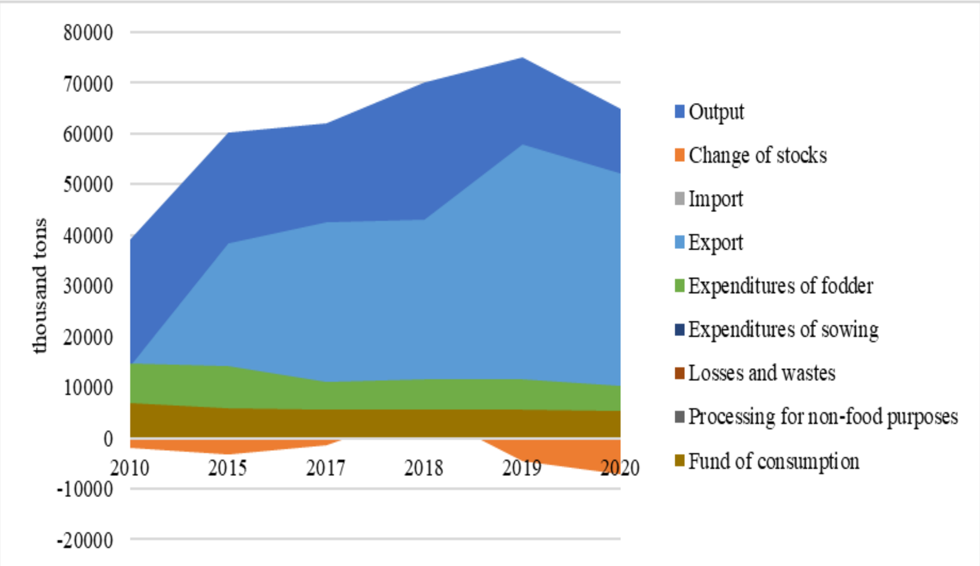
SSSU data indicates that in 2019–2021, more than 500 enterprises grew grain on an area of more than 3000 ha and produced about a third of the gross grain harvest in Ukraine. These enterprises have the highest level of intensification of grain production, which is reflected in the highest yields (for example, in 2021 it was 7.04 t ha^{-1}, which is 18.7% more than the average for Ukraine). Many of these enterprises are part of large agro-industrial formations, or agricultural holdings, which cultivate significant areas of agricultural land (SSSU, 2020, 2021a). For example, in 2021, the 10 largest agricultural holdings of Ukraine, in terms of agricultural land, cultivated 2.65 million ha, and the largest agricultural enterprise was Kernel, which cultivated 510,000 ha of agricultural land (IAMO, 2021).

Enterprises also operate in the livestock industry, and more than half of the livestock in the corporate sector is concentrated in large enterprises. Data as of 1 January 2022 indicates that 278 enterprises kept more than 1000 head of cattle (58.2% of the total), 71 enterprises kept more than 10,000 head of pigs (66.5% of the total), 75 enterprises kept more than 500 head of sheep and goats (69.5% of the total), and 33 enterprises kept more than 500,000 head of poultry (81.5% of the total) (SSSU, 2022b).

In summary, Ukraine's agriculture, primarily crop production and to a lesser extent animal production, is thus a core economic revenue generator and source of food security for Ukraine and the world (Kravchenko et al., 2020; FAO, 2022).

Ukraine in the global food trade arena

In the value structure of exports of agricultural products and provisions from Ukraine, the share of grain in 2020 accounted for 42.4%, which is 17.5% more than in 2010 (SSSU, 2021a). An analysis of the balance shows that: 1) over the past 10 years, grain production has tended to increase (from 39.3 Mt in 2010 to 64.9 Mt in 2020), as have exports (from 14.2 Mt in 2010 to 52.2 Mt in 2020); 2) Ukraine has exported three-quarters of its production; 3) domestic grain consumption accounts for only 20–25% of total production (Figure 3).

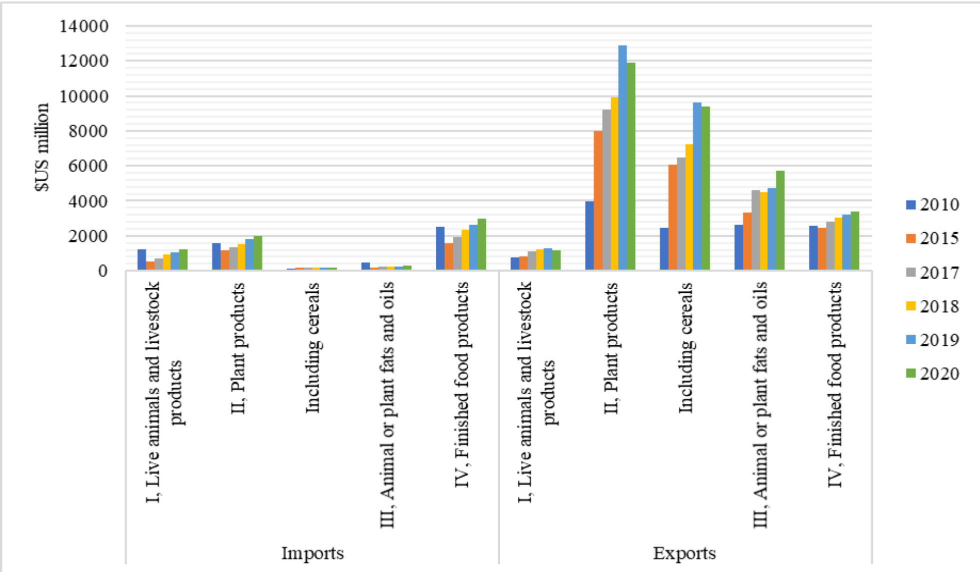


Source: SSSU (2021a); authors' calculations.

Figure 3. The balance of grain and leguminous crops (including products of grain processing counted as grain) in Ukraine.

Ukraine is one of the world's five largest grain exporters. In 2021, Ukraine was among the top five largest exporters of the following grains and their processed products (ranked first to fifth): millet, maize, barley, fresh and chilled peas, dried peas, and wheat (Dukhnytskyi, 2022). This suggests that, in terms of grain-based food security, Ukraine fed three times more people than its own population. When Ukraine was invaded by the Russian Federation in February 2022, over 400 million people around the world depended on grain supplies from Ukraine (Leshchenko, 2022a; United Nations, 2022).

The total amount of foreign exchange earnings from grain exports amounted to $US9.4 billion in 2020, which is 3.8-fold more than in 2010 (Figure 4). Revenues from agricultural exports play a key role in shaping Ukraine's foreign exchange earnings. For example, in 2021, according to the Minister of Agrarian Policy and Food of Ukraine, agriculture provided Ukraine with more than 41% of foreign exchange earnings (Leshchenko, 2022a).



Source: SSSU (2021a); authors' calculations.

Figure 4. Commodity patterns of imports and exports of agricultural products and provisions in Ukraine.

It is significant that, despite substantial grain exports, Ukraine also imports grain (Figure 4). However, the volume of these imports is insignificant since their share in the structure of total agricultural imports accounts for only 2.5–4.4% (authors' calculation based on data from Figure 4). The trend towards an increase in the volume of raw materials with an almost unchanged volume of exports of finished food products remains negative for the Ukrainian economy. At the same time, imports of processed finished food products dominate the structure of imports of agricultural products, accounting for 43.5–45.7% (SSSU, 2021a). In the context of blocking grain exports, one option is to diversify the economy through internal processing of raw materials into finished food products.

In 2021, supplies of domestic agricultural products to the European Union (EU) amounted to US$8.4 billion, a 25% increase over the previous year (US$6.7 billion). This increase is partly due to an increase in the value of most categories of goods on the world market, and partly due to an increase in shipments (Pugachov, 2022). According to scientists from the National Scientific Centre “Institute of Agrarian Economics”, the commodity structure of agricultural exports to the EU largely corresponds to the general structure of agricultural exports from Ukraine (Pugachov, 2022). More than 80% of these accounted for by exports of oils and fats, cereals and oilseeds, as well as residues from the processing industry. In 2021, all these product groups showed growth in value terms, having a decisive impact on increasing Ukrainian total agricultural exports to the EU. For several years in a row, the EU has been the main market for a number of different agri-food products from Ukraine, among which the following should be noted (the percentage of foreign sales of these types of agricultural products is provided in parentheses): fish and fish products – US$36 million (62%); egg products – US$7 million (58%); honey – US$128 million (89%); live plants and seedlings – US$5 million (63%); fruits and berries – US$315 million (86%); rapeseed – US$1303 million (77%); soybean oil – US$227 million (77%); and rapeseed oil – US$174 million (78%) (Pugachov, 2022).

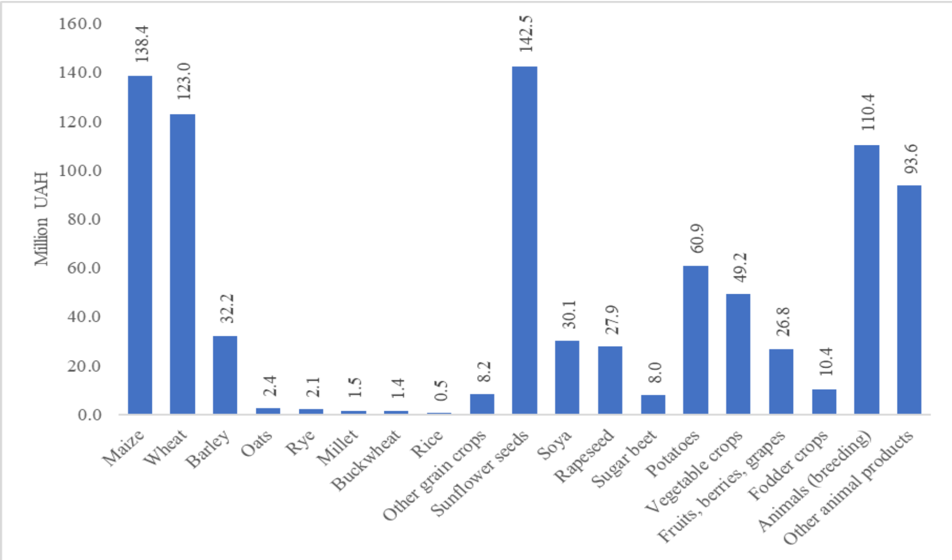
In summary, Ukraine accounted for 9, 12, 12, 14, and 50% of the 2020/2021 global trade market (import + export) for wheat, maize, barley, rapeseed, and sunflower oil, respectively (FAO, 2021).

Revenues, costs, and other notable issues

The 2021 FAO report indicates a few facts of possible relevance that are worth mentioning: 1) the Russian Federation banned the import of barley from Ukraine starting in July 2021; 2) Ukraine banned the import of sunflower oil from the Russian Federation in April 2021; 3) Ukraine set an export upper limit of 25.3 Mt of wheat for 2021/2022; 4) global freight rates (year-on-year, 26 October 2021), including heavy grains, increased between 103 and 181%, depending on the route (FAO, 2021).

In 2020, the biggest income revenue was from grain crops (309,737 million UAH), followed by industrial crops (in total). Wheat, maize and sunflower seeds were the greatest revenue generators (Figure 5). Even though the livestock industry also generated significant revenue, the crop industry, which accounts for about 75.1% of all agricultural products and services (892,852 million UAH in total) (SSSU, 2021b), is the main income source.

Total costs for all agricultural production were 441,529 million UAH, of which 13.7% went for inorganic fertilisers, 8.1% for seeds and planting materials, 7.0% for oil products, 4.8% for repair and spare parts, and 6.8% for labour (SSSU, 2021a). A total of 17.4 million ha of land employed organic or inorganic fertilisers in 2020, mainly nitrogen, phosphate and potash fertilisers, accounting for 68%, 17%, and 14% of inorganic fertiliser use, respectively (SSSU, 2021a).

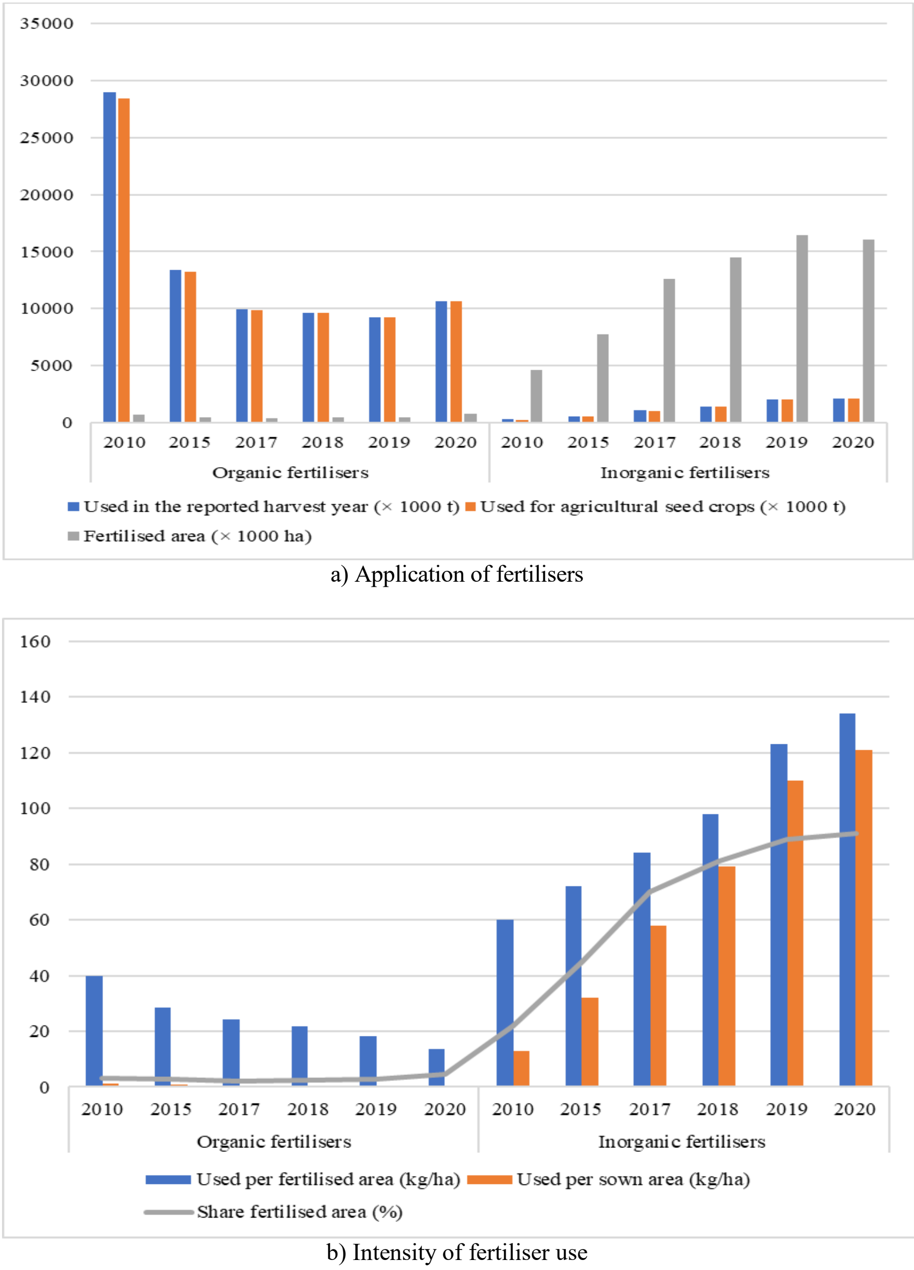


Source: SSSU (2021b); authors' calculations.

Figure 5. The income revenue of the main agricultural output in Ukraine in 2020.

Fertilisers

An analysis of the dynamics of the use of mineral fertilisers in Ukraine shows a clear trend towards an increase in the amount of inorganic fertilisers applied (Figure 6a) and the intensity of their application per unit area of land (Figure 6b). This had a positive impact on crop yields, ensuring the balance of nutrients in the soil (Mishenin et al., 2017; Ulko et al., 2022). However, this war will lead to a significant reduction in the amount of fertiliser application, which is associated with both their physical shortage and an increase in prices, and thus a high risk of not harvesting, due to hostilities. This aggravates the problem of an insufficient amount of fertilisers being applied in Ukraine (Strochenko and Koblianska, 2016; Strochenko et al., 2017; Kosovych et al., 2022), thereby threatening future yields. For example, the amount of nitrogen fertilisers applied to soils in Ukraine is 1.7-fold less than in the EU while the amount of applied organic fertilizers is 10.1-fold less (Moklyachuk et al., 2019).



Source: SSSU (2021a); authors' compilation.

Figure 6. The use of inorganic and organic fertilisers for the harvest of agricultural crops in agrarian enterprises of Ukraine.

As a consequence of the state of war, in order to maintain balance in the domestic market of mineral fertilisers, on 12 March 2022, the Ukrainian Government introduced a zero quota for their export, i.e., a de facto ban on the export of fertilisers from Ukraine (Leshchenko, 2022b). This applies to nitrogen, phosphorus, potassium and complex fertilisers. According to experts from the GMK Center, almost 45% of Ukrainian nitrogen fertiliser exports went to the EU in 2021 (Glushchenko, 2022). The biggest importers of Ukrainian nitrogen fertilisers were (in thousand t) Romania (190), Italy (138), France (104), Hungary (88), Spain (56), Bulgaria (50), and Poland (40). Consequently, EU countries will have to access and purchase nitrogen fertilisers from other countries (Glushchenko, 2022). Even though Ukrainian producers could fully meet the capacity needs of the domestic market of nitrogen fertilisers, most of the capacities for the production of these fertilisers have been closed both due to the danger of hostilities and problems with raw material supplies. On 21 March 2022, the Russian Federation fired at PJSC "Sumykhimprom", which led to an ammonia leak. According to estimates by experts from the State Ecological Inspectorate in the Sumy region, the estimated amount of damage caused to the environment due to the ammonia leak amounted to about 5.1 million UAH (State Environmental Inspectorate of Ukraine in the Sumy oblast, 2022). The Russian Federation also fired on the "Severodonetsk Azot association" (15.3% of nitrogen fertiliser production facilities in Ukraine) on 5 June 2022. It is currently closed. The "Odessa port plant" (14.4% of nitrogen fertiliser capacity) was shut down at the beginning of the war. "Rivneazot" is located in a potentially dangerous zone where rocket attacks are possible (Glushchenko, 2022).

At the same time, the production of complex fertilisers is underdeveloped in Ukraine. In particular, 1.9 Mt of complex fertilisers were imported into Ukraine in 2021 and almost a third of these fertilisers were previously imported by Ukraine from Belarus, so now there is an urgent need to replace this import volume (Glushchenko, 2022). A possible substitution could be the development of Ukrainian deposits, in particular the development of the Izymske deposit and the use of milled phosphorites in agriculture, but this part of the Ukrainian territory (i.e., Izyum district, Kharkiv oblast) is in a volatile location. Therefore, alternative fertiliser systems should be used, including green manure (Hetmanenko et al., 2021; Mishenin et al., 2022). Rising costs of organic fertilisers by about 30% (Liadze et al., 2022) have already caused rises in the costs of agricultural commodities (Shahini et al., 2022).

The state of Ukrainian agriculture during the war: a macro context

Although statistics indicate the successful development of Ukrainian agriculture and its growing role as a "food basket" globally (Mishenin et al., 2021), it is necessary to understand several aspects of the context in which Ukrainian agriculture is operating during this war.

Ukrainian crop production is developing its own trajectory, and not following the development path of Germany or the USA. After a rather long recession, due to imported technologies and production components, the agricultural sector embarked on a path of stable growth with an annual increase in wheat yields of around 0.1 t ha-1, and further development of crop production in Ukraine is likely to choose an intensive development path (Voronenko et al., 2020; Mishenin et al., 2021). However, this requires an increased use of organic and mineral fertilisers, taking into account the need for environmentally-friendly agriculture (Kosovych et al., 2022; Mishenin et al., 2022; Ulko et al., 2022). GMK experts also expect an increase in the use of fertilisers due to the introduction of a land market (Glushchenko, 2022). Grain production has always been Ukraine's most important agricultural sector, providing national food independence and security, with wheat, maize and barley being the most important cereal crops, followed by buckwheat (*Fagopyrum esculentum* Moench), millet, and rice (*Oryza sativa* L.) (Averchev and Fesenko, 2019; Mishenin et al., 2021). In 2018, the total production of buckwheat, millet and rice was 137, 81 and 69 thousand t, respectively. Zhytomyr ranked first in 2018, in terms of harvested area and yield of buckwheat, Kharkiv produced the highest yield of millet (with several oblasts having similar harvested areas, around 6000–6300 ha each), while rice cultivation was almost exclusive to the Kherson and Odessa regions along the Black Sea coast, with 7700 and 4900 ha of harvested area and production of 44,500 and 24,700 t, respectively (Averchev and Fesenko, 2019). As these are active war zones, and since Russia has annexed Kherson (Reuters, 2022a), rice will be a highly contested cereal.

Bazaluk et al. (2021) noted that the production of grain and leguminous crops amounted to 75.1 Mt in 2019, of which 38% was in the Dnieper basin (encompassing Cherkasy, Dnipropetrovsk, Kyiv, Kherson, Mykolaiv, Poltava, and Zaporizhzhia regions), while 15.3 Mt of sunflower seeds were produced in the same year, of which 41.5% originated from the Dnieper basin. The Kherson and Zaporizhzhia regions are active war zones. Bazaluk et al. (2021) have also indicated that 40% of grain is transported by rail, 24.4% by road, and about 0.5% by inland waterways, with road transport being the least energy efficient, which has implications for the transport not only of grain, but of all agricultural products, nationally and regionally, given the current fuel and energy crisis. At the beginning of the war, the Ukrainian military closed all sea ports (Reuters, 2022b), while civil and commercial airspace was also closed (Reuters, 2022c), leaving rail and road as the only currently available options to transport grain and other agricultural products. Given that the entire coast of the Azov Sea, which is directly connected to the Black Sea, is under the control of the Russian Federation, and transport to the east through Russia or to the north through Belarus is evidently not an option, this leaves only limited options to export agricultural products out of Ukraine, via Moldova, Romania, Hungary, Slovakia, or Poland, all of which are located on the western border of Ukraine. Regional (Mediterranean) importers of Ukrainian wheat, barley and maize, namely Italy, Turkey, Egypt, Cyprus, and Lebanon, will all be impacted since the ports of departure are all on the Azov Sea (Reuters, 2022b). Even though (data as of 1 February 2022) there are about 26.3 Mt of grain available (Reuters, 2022b; Rozhko, 2022), their distribution will be challenging, given that Dnipropetrovsk, Donetsk, Kherson, Kharkiv, Luhansk, Mikolayiv, Odessa, and Zaporizhzhia areas, which are under occupation or zones of active military conflict, are some of the main production centres for these crops.

Electric power and fuel costs accounted for only 1.0% and 0.4%, respectively of total agricultural production costs in 2020 (SSSU, 2021a). It will therefore be interesting to see how the relative weighting of these two factors on costs will change for the current agricultural year.

Future challenges

Deppermann et al. (2018) used models to estimate a 64% cumulative (Russia and Ukraine) increase in wheat, barley and maize yield by 2030, or 4% of global production. However, they only took into account the use of abandoned land and the application of a high-input system (presumably higher inorganic fertiliser use), but they did not consider geopolitical instability, war, or any of the limitations that both Ukraine and Russia are now experiencing as a direct result of this war. Curiously, Skrypnyk et al. (2021) noted, as a result of climate change, an increase in maize production in 2000–2018, particularly in the steppe zone, which it due to the resilience of this crop to a wider range of agro-climatic zones.

The total volume of grain and flour exports from Ukraine in the 2021/2022 market year decreased by 17.7% compared to the 2019/2020 market year, including the volume of flour exports, which decreased almost five-fold (Table 1). Although these data are the latest, they do not, of course, give a full picture of the scale of losses to be expected as a result of this war.

According to the forecast of Voronenko et al. (2020), the food security index of Ukraine is in a satisfactory state and shows a slight upward trend in the period 2020–2022, but the risks of a decline in the integral index are beyond satisfactory. This forecast of food security could be accurate if the state of the economy were to remain unchanged.

Plans to expand organic agriculture, which currently accounts for only 1.1% of all agriculture in Ukraine, as a sustainable development goal (Fedchyshyn, 2020), and to strengthen the competitive position in the EU market (Ostapenko et al., 2020), are now delayed due to the occupation of all major regions related to organic agriculture (OrganicInfo, 2022). Moreover, weak internal demand, which previously was one of the greatest obstacles inhibiting the development of organic agriculture in Ukraine (Artysh, 2018), will continue to impede further growth of this sector due to economic problems caused by the war. Provided that 40% of agricultural crop production in Ukraine uses green manure (organic fertiliser), it might be possible to use as much as 30% of the biological yield of field crop biomass for diesel biofuel (bioethanol) production (Golub et al., 2021). Such use of agricultural waste needs to be part of an integrated national resource recycling programme (Shubalyi et al., 2020; Kosovych et al., 2022; Mishenin et al., 2022). Considering the energy-dependence of Ukraine, manure-based biogas production could, with suitable technology, meet 3.2% and 2.3% of Ukraine's total electricity and natural gas demands, respectively (Wąs et al., 2020).

Table 1. Export of cereals, legumes (with processed products) and flour in the 2021/2022 market year, thousand t*.

Indicators	2019/2020 market year	2020/2021 market year	2021/2022 market year	2021/2022 in % relative to 2019/2020
Cereals and legumes, total	56627	42485	47177	83.3
Including:				
wheat	20522	16030	18578	90.5
barley	5076	4146	5686	112.0
rye	8.2	7.0	161.6	1970.7
maize	30330	21610	22445	74.0
Wheat flour	331.7	111.0	69.8	21.0
Other flour	2.5	1.1	1.6	64.0
Total flour	334.2	112.1	71.4	21.4
Total export (grain + flour)	57173	42634	47273	82.7

*Values as of 6 June 2022. Sources: SSSU (2021a); State Customs Service of Ukraine (2022).

A case study that assessed 516 enterprises in the Kharkiv oblast identified integrated animal husbandry as an effective means to intensify sustainable agriculture (Strapchuk and Mykolenko, 2021). In 2015–2017, the meat and milk security status in Ukraine was similar to that in the EU, and lower for several fruits and berries. Regional (oblast) consumption ability depends on per capita annual income, which, in 2017, was the highest in Kyiv (US$ 3064), followed by Dnipropetrovsk (US$ 2038), and the lowest in Donetsk (US$ 938) and Luhansk (US$ 619) (Vasylieva, 2019), the latter two oblasts being in the war zone. Even though several aspects of Ukrainian agricultural land use are superior to those of EU member states, many are not, so Ukrainian agriculture has the potential to be optimised for increasing yield (Petrychenko et al., 2018). Romanchuk et al. (2021), relying on SSSU data, indicated an increase in inorganic fertilisers (in kg ha^{-1}) from 79 and 96 in 2015 and 2016, respectively, to 121 and 119 in 2018 and 2019, respectively, noting that drinking water in 10 out of 15 oblasts had nitrate levels posing a high health risk to children and/or adults, as assessed by EU directives.

In Ukraine, labour productivity, and foreign investment, either economically or in the form of labour, are impacted by security and political stability (Onegina et al., 2020; Onegina and Vitkovskyi, 2020). To meet EU standards, several factors need to be considered (investments, fixed assets value, consumer price index, number of employees in the industry, quantity of goods and services sold) to ensure agricultural GDP growth (Sonko et al., 2018). Provided the war continues, or vast tracts of agricultural land are under military occupation, these areas are unlikely to attract either labour or investment. Moreover, with large numbers (about 8.0 million people) of internally displaced people (Ministry for the Reintegration of the Temporarily Occupied Territories, 2022), the equally large numbers of emigrants (about 3.5 million people) fleeing the war (Drannik, 2022), and the general mobilisation of men to fight on front lines, may have the potential to reduce labour potential if such individuals are in any ways connected to the agricultural sector.

Since 2014, the EU has opened its markets to Ukrainian agricultural products, stimulating agricultural output (e.g., for crops, 750,100 UAH income in 2016 versus 954,400 UAH in 2019) and labour productivity, but the most productive oblasts were generally concentrated in the west of Ukraine (Shmatkovska et al., 2020). In 2017, 86.9% of agricultural land owners possessed less than 1000 ha while 14 agroholdings held 3.42 million ha of land (Shvorak et al., 2020), suggesting that the agricultural land market needs to be better managed for efficient long-term development (Mohylnyi et al., 2022). The resource potential of low-income family farms, particularly family agricultural businesses, also needs reform to maximise productivity and to optimise economic activity (Strochenko et al., 2017; Zbarsky et al., 2020; Koblianska et al., 2020). Such a management programme would need to consider the weighted benefits of multiple social, economic and environmental factors (Sokil et al., 2018; Mishenin et al., 2021). Long-term socio-economic and political turmoil, and the lack of relative peace and security are not conducive to establishing a sustainable agricultural model in Ukraine (Kolesnyk et al., 2018). Without political and economic stability, consumer confidence will not be able to increase, and thus Ukraine will struggle to meet EU agricultural standards to be competitive in the market (Rogach et al., 2019).

Finally, a growth in debt burden or external creditors, reduced foreign investment, and decreasing per capita capital investment following the war might all contribute to unstable food security in Ukraine. Decreased investment will further move Ukraine from its ability to satisfy two UN Sustainable Development Goals (Plastun et al., 2021). The Ukrainian state funds only cover a third of the losses associated with natural calamities, independent of the level of agricultural insurance, i.e., low compensation efficiency. Thus, the continuation of Ukraine's agricultural insurance market reform – initiated by a special law in July 2021 (Verkhovna Rada of Ukraine, 2021) – is needed for farmers to appreciate the benefits of inclusion, as only 2% (661,000 ha) of all agricultural land in Ukraine was insured in 2017

(Agricultural Insurance Market, 2018; Prokopchuk et al., 2019).

Finally, this war has already had significant negative consequences for food security on a global scale (Ben Hassen and El Bilali, 2022).

Conclusion

The Russo-Ukrainian war, which has been ongoing since 2014, and amplified by the invasion of Ukraine on 24 February 2022, has caused not only a physical disruption of the planting season, destruction of agricultural land due to artillery strikes and bombardments, but also a considerable negative impact on distribution routes, mainly sea ports in the Azov Sea and the Black Sea, but also on land routes, via roads and railways, due to destroyed or unsafe roads and rail hubs. This affected the transport of current agricultural products in stock, such as cereal grains, although a ‘grain corridor’ was brokered by the UN at the end of July, 2022. These impacts are exacerbated by fuel and energy crises, and a rise of fertiliser costs.

The assessment of these consequences, in particular, a determination of the extent of the damage caused, and the substantiation of directions for solving the problem of guaranteeing food security at the national, regional and global levels, will require much scientific attention in the coming years.

Given the adverse social, economic, and political effects of this war that some countries are experiencing now, the long-lasting negative consequences of this war on global security are evident. Estimates of appropriate global food system losses and transformations, social and economic causes-and-effects, and suggestions on how to deal with them should be at the forefront of the global research agenda.

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POLJOPRIVREDNA PROIZVODNJA U UKRAJINI: UVID U UTICAJ RUSKO-UKRAJINSKOG RATA NA LOKALNU, REGIONALNU I GLOBALNU PREHRAMBENU SIGURNOST

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R e z i m e

Rusko-ukrajinski rat koji je u toku, utiče na ukrajinsku poljoprivredu. Na primer, Ukrajina više nije u mogućnosti da izvozi poljoprivredne proizvode kao što su zrnene kulture i žitarice morskim putem na regionalna (evropska) i međunarodna tržišta, iako je to delimično ublaženo stvaranjem „žitnog koridora". Kao rezultat toga, prehrambena sigurnost u Ukrajini, a donekle, i u regionu (EU) i globalno, izložena je određenom riziku, posebno u zemljama koje se u velikoj meri oslanjaju na uvoz poljoprivrednih proizvoda iz Ukrajine. Oko 70% zemljišta u Ukrajini se koristi za poljoprivrednu proizvodnju. Ovaj rad daje pregled ukrajinske poljoprivredne proizvodnje koristeći statističke podatke za 2018–2022, na osnovu dostupne literature, kao i statističke podatke Organizacije Ujedninjenih nacija za hranu i poljoprivredu i zvanične statističke podatke ukrajinske vlade. Globalna proizvodnja glavnih zrnenih kultura i žitarica (pšenica, kukuruz, ječam, uljana repica i suncokret), u rasponu od 2,9 do 6,6%, pokazala je trend rasta u periodu 2017–2021. Ukrajina je činila 9, 12, 12, 14 i 50% globalnog tržišta (uvoz + izvoz) u 2020/2021. godini za pšenicu, kukuruz, ječam, repicu odnosno suncokretovo ulje. Oko 75% poljoprivrednih proizvoda i usluga (ukupno 892,852 miliona UAH) dolazi iz ratarske, a ostatak iz stočarske proizvodnje. Izvoz đubriva je zabranjen 2022. godine.

Ključne reči: poljoprivredna proizvodnja, ekonomska reforma, đubrivo, zrnene kulture, predratna i posleratna obnova, pšenica.

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A COMPARATIVE STUDY ON SALT STRESS RESPONSE OF *CAMELINA SATIVA* AND *CARTHAMUS TINCTORIUS* DURING GERMINATION

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Abstract: Soil salinization is one of the most significant global problems, leading to reduced agricultural productivity potential and biodiversity. The main salt commonly found on the surface of soils and in water is NaCl, which directly impacts plant growth and land degradation. Therefore, this study was conducted to examine the morpho-physiological characteristics of two genotypes of *Camelina sativa* ('NS Slatka'; 'NS Zlatka') and two genotypes of *Carthamus tinctorius* ('NS Lana'; 'NS Una'), which potentially characterize them as salt-tolerant crops. The levels of salinity tolerance were compared under five NaCl treatments, ranging from 0 mM to 200 mM. Based on the obtained results, seeds of all four genotypes germinated at the highest salt concentration (200mM NaCl), but the germination percentage declined at all salt concentrations. Moreover, lower salt concentrations induced root elongation and reduced shoot length of seedlings of all four genotypes. Salt stress tolerance indexes showed the importance of converting the plant parameters into mathematical indexes, and the significance of comparing all the tolerance indexes according to salt stress.

Key words: NaCl, salinity, tolerance indexes.

Introduction

Agricultural areas take up 38% of the global land surface, of which one-third is used as cropland (FAO STAT, 2020). Human-induced saline and sodic soils have drastically raised the total percentage of globally salt-affected lands. The current percentage of salinated land, estimated at 50%, appears to be rising according to recent studies carried out by the United Nations Environmental Program (UNEP). This increase in salt-affected lands has both natural and human causes (Kumar, 2017; Shahid et al., 2018).

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Despite researching this globally rising problem for decades and implementing sustainable management of salt-affected soils, the issue of salinization is ubiquitous and concerning (Shrivastava and Kumar, 2015; Mukhopadhyay et al., 2021; Singh, 2022). Therefore, soil salinization is recognized as one of the most significant problems at a global level, leading to reduced agricultural productivity potential and biodiversity, which is directly connected with substantial financial losses (FAO and ITPS, 2015).

Crops are measurably affected by soil salinization. NaCl is the salt most commonly found on the soil surface and in irrigation water (Ashraf et al., 2010). Na^+ and Cl^- ions in solutions associated with other abiotic and biotic factors negatively impact plant growth and land degradation (Corwin, 2021). As a medium for seed germination – the most sensitive stage in the plant life cycle – and root growth, soil supplies plants with nutrients and water (Zuffo et al., 2020; Li et al., 2019). Soil, as a medium for seed germination, provides plants with nutrients and water. The soil surface layer is predominated by salt in saline conditions, limiting germination. Saline soil limits germination. Furthermore, plant establishment is negatively impacted by decreased soil water potential, which induces difficulties for a plant to uptake water and nutrients. Consequently, ionic imbalance and cytotoxicity occur with oxidative stress in plant cells (Hanslin and Eaggen, 2005). Salt-tolerant plants withstand high salinity through processes entrenched on cellular and tissue levels that are directed by physiological and molecular mechanisms. The primary defence mechanisms are osmotic tolerance, ionic tolerance, tissue tolerance, and cell antioxidant systems (Hasegawa et al., 2000; Wang et al., 2009).

Comparatively advantaged are crops with the capacity to accommodate salinity and adjustable crops produced on marginalized and poor-quality lands. Crops that can tolerate salinity and crops that can be grown on poor-quality lands have an advantage over other types of crops. *Camelina sativa* (false flax) and *Carthamus tinctorius* (safflower) are oil crops that belong to the Brassicaceae and Asteraceae families, respectively. Both crops have been used as a source of edible oil for centuries. Their agronomic characteristics present them as favorable cultivars, and they benefit agricultural production in terms of demand for renewable oil sources and crop rotation requirements (Ashri et al., 1974; Ekin, 2005). The short growth cycle of *C. sativa* and tolerance to cold and drought stress distinguish it as a prospective agricultural crop. *C. tinctorius* is also well known for its adaptability to varied growing conditions (Singh and Nimbkar, 2006).

The objective of this comparative study was to assess the response of two genotypes of *C. sativa* and two genotypes of *C. tinctorius* to salt stress during germination and early seedling growth stages under controlled conditions. Using different concentrations of NaCl solutions to simulate salt stress, we provided the responses of the genotypes based on germination performance and shoot and root elongation rates.

Material and Methods

The experiment was carried out at the Laboratory for Seed Testing at the Institute of Field and Vegetable Crops in Novi Sad, Serbia. The research material consisted of four genotypes obtained from the breeding program of the Institute of Field and Vegetable Crops in Novi Sad, Serbia. The two plant species tested under saline conditions were *Camelina sativa* (L.) Crantz, genotypes: 'NS Zlatka' and 'NS Slatka', as well as *Carthamus tinctorius*, genotypes: 'NS Una' and 'NS Lana'. The seeds used for this experiment were randomly taken from seed lots obtained from the crops of the same field and under the same conditions for all genotypes.

The experiment was laid out in a completely randomized design with three replications. One hundred seeds per replication were placed between filter papers in glass Petri dishes of 12 cm in diameter. Moistened filter papers were used as a growing medium. Distilled water was used as a control. Four levels of NaCl concentration were applied to induce salt stress. On the first day of the experiment, 10 ml of each treatment solution: 50, 100, 150, or 200 mM NaCl were added.

The salt stress effect on experimented seeds was investigated by a standard germination test established by ISTA (2019) for each plant species. The germination percentage (G) was determined by counting the number of seeds that produced seedlings whose radicle size was >3mm. The first count was made on the fourth day of the experiment, which was germination energy (GE). Besides seed energy and germination percentage, the length of seedlings (mm) was also determined. Shoot and root lengths (SL; RL) were measured on the sixth and tenth days of the experiment. The root/shoot ratio of the seedlings (R/S) was calculated by dividing the root and shoot lengths of the seedlings. For ease of comparison, these values were converted into root elongation rate (RER) and shoot elongation rate (SER), as explained by Channaoui et al. (2019):

$$\mathrm{RER} = \frac{(\mathrm{RLE}-\mathrm{RLS})}{(\mathrm{TE}-\mathrm{TS})} \qquad \mathrm{SER} = \frac{(\mathrm{SLE}-\mathrm{SLS})}{(\mathrm{TE}-\mathrm{TS})} \tag{1}$$

where RLE/SLE and RLS/SLS (mm) are the root and shoot lengths at the end and the start of a measurement period, respectively, and TE − TS is the time difference (d) from the start to the end of the measurement period.

Atypical seedlings (A) were also counted as undeveloped or damaged seedlings during the experiment. Germination stress tolerance index (GSTI), shoot length stress tolerance index (SLSTI), root length stress tolerance index (RLSI), and total seedling length stress tolerance index (TLSI) were calculated using the equations given by Partheeban et al. (2017):

$$\text{GSTI} = \frac{\text{Germination of stressed seeds}}{\text{Germination of control seeds}} \times 100 \quad (2)$$

$$\text{SLSTI} = \frac{\text{Shoot length of stressed plants}}{\text{Shoot length of control plants}} \times 100 \quad (3)$$

$$\text{RLSTI} = \frac{\text{Root length of stressed plants}}{\text{Root length of control plants}} \times 100 \quad (4)$$

$$\text{TLSTI} = \frac{\text{Total length of stressed plants}}{\text{Total length of control plants}} \times 100 \quad (5)$$

The recorded data were statistically analyzed, followed by two-way ANOVA using SPSS Statistic Version 25. Statistically significant differences were determined at the 0.05 probability level, and significant differences between treatments were determined using post hoc analysis – the Tukey test.

Results and Discussion

The ability of seeds to germinate and seedlings to emerge is affected by salinity as an environmental factor. These two phases of plant growth characterize different salt tolerance mechanisms essential for a plant successful establishment (Almodares et al., 2007). Therefore, it is necessary to evaluate both growth stages under stress conditions, and to understand the link between germination failures followed by seedling emergence. This is especially important for plants most sensitive at the germination stage (Hamdy et al., 1993). In this study, the results of two-way ANOVA (Table 1) showed that genotype and salt stress significantly affected the germination and R/S ratio of *Camelina* seeds. The interaction between genotype and salt stress had no significant effect on germination, indicating that the genotypes responded similarly to the stress treatments. In contrast, all sources of variation affected GE and GSTI. *Camelina* genotypes also responded differently to the stress levels for the following parameters: RL, SL, RER, and SER. When only the effect of salt stress was observed, SLSTI and TLSTI were affected, whereas A and RLSTI were affected by the interaction between salt stress and genotype. Regarding *Carthamus* seeds and according to the results of two-way ANOVA (Table 2), G, GE, and GSTI were significantly affected by all sources of variation, indicating that genotypes responded differently to stress treatments. In contrast, all other parameters (A, RL, SL, RER, SER, RLSTI, SLSTI, TLSTI and R/S) were affected only by salt stress.

The germination percentage of *Camelina* seeds was the highest in optimal conditions (0 mM NaCl) (Table 3). While ‘NS Slatka’ had a higher germination percentage when salt was lacking in the medium only in the control, ‘NS Zlatka’ showed a better germination percentage with an increasing concentration of NaCl. Germination decreased by 0.6%, 10%, 24% and 54% for ‘NS Slatka’, at 50, 100, 150 and 200 mM NaCl while for ‘NS Zlatka’ germination decreased by 2% and

31% at 150 mM and 200 mM NaCl, respectively. It should be emphasized that 'NS Zlatka' germination declined less under the highest salt treatment in comparison with 'NS Slatka', and that it was able to germinate unhindered at 150 mM NaCl.

Table 1. Results of ANOVA (sum squares) of the *Camelina* traits determined.

Camelina sativa								
	df	G	GE	A	RL	SL	RER	SER
G	1	169.00**	215.10**	0.11	2.78	0.44	0.30	0.04
conc	5	25660.00**	31849.60**	696.88**	2234.22	731.88	16.74	8.55
G x conc	5	980.70	1207.60**	84.55**	119.56**	11.55**	2.27**	0.20**
error	24	251.30	216.70	142.00	233.33	78.00	6.75	1.68
	df	RLSTI	SLSTI	GSTI	TLSTI	R/S		
G	1	83.30	17.80	1625.80**	48.50	619.26		
conc	4	38116.2**	14876.00*	36019.20**	24201.60*	219349.39*		
G x conc	4	3262.00*	314.50	433.20*	1130.20	815.76		
error	20	5158.40	3697.50	558.70	3211.20	13588..98		

*P < 0.05, **P < 0.01; GE – germination energy, G – germination percentage, A – atypical seedlings, SL – shoot length, RL – root length, SER – shoot elongation rate, RER – root elongation rate, RLSTI – root length stress tolerance index, SLSTI – shoot length stress tolerance index, GSTI – germination stress tolerance index, TLSTI – total seedling length tolerance index, R/S – root/shoot ratio.

Table 2. Results of ANOVA (sum squares) of the *Carthamus* traits determined.

Carthamus tinctorius								
	df	G	GE	A	RL	SL	RER	SER
G	1	246.50**	653.33**	56.03	38.53	4.80	4.80	0.03
Conc	4	7010.00**	8762.33**	3093.20	9949.13**	3304.87**	3304.87**	13.33**
G x conc	4	521.50**	988.33**	604.8(	175.13	23.53	23.53	0.91
error	20	354.70	312.67	791.3	1516.67	72.00	72.00	2.85
	df	RLSTI	SLSTI	GSTI	TLSTI	R/S		df
G	1	6.90	13.41	559.50**	8.60	320.79	G	1
conc	3	20710.70**	16119.47**	7079.10**	18641.80**	18015.25*	conc	3
G x conc	3	532.80	163.73	720.80**	297.30	1846.95	G x conc	3
error	16	3893.00	586.40	668.70	1637.90	346955.89	error	16

*P < 0.05, **P < 0.01; GE – germination energy, G – germination percentage, A – atypical seedlings, SL – shoot length, RL – root length, SER – shoot elongation rate, RER – root elongation rate, RLSTI – root length stress tolerance index, SLSTI – shoot length stress tolerance index, GSTI – germination stress tolerance index, TLSTI – total seedling length tolerance index, R/S – root/shoot ratio.

In various studies investigating the effect of salt stress on oilseed crops, increasing salinity at the germination stage reduced seed vigor. Moreover, among the four different salt types found in the soil (NaCl, Na_2SO_4, $CaCl_2$, MgCl), NaCl had the most significant negative impact on the seed germination of *Brassica sp.* (Mohammed et al., 2002; Hosseini et al., 2002; Jovičić et al., 2014).

Regarding 'NS Zlatka', with increasing salt concentration, there was no consistent decline, but germination increased by 2% and 3% at 50 mM and 100 mM NaCl stress levels, respectively. This specific result is consistent with the *Camelina* genotypes examined in the study carried out by Matthees et al. (2018). They explained that the higher the quantity of accumulated organic solutes in the seedlings, the more tolerance they showed at low salt concentrations compared to the control.

As for the *Camelina* seed, the germination percentages of *Carthamus* seeds (Table 4) in optimal conditions (0 mM NaCl) were the highest for both genotypes, and as the salt concentration increased, the germination percentage decreased. The strongest reduction of germination was recorded at the highest NaCl concentration (200 mM). The 'NS Lana' genotype had a higher germination percentage in optimal conditions than the 'NS Una' genotype, but showed a higher germination decline under the treatment solutions. Germination decreased by 13%, 9%, 30% and 41% for 'NS Una', and by 11%, 10%, 55% and 55.5% for 'NS Lana' at 50, 100, 150 and 200 mM NaCl, respectively. Soheilikhah et al. (2011) studied several safflower genotypes on this subject with the same salt concentrations and found that a concentration of NaCl decreased germination (14% and 74% at 50 and 200 mM NaCl, respectively). While their result shows 50 mM as the critical value, our results show that *Carthamus* seeds can germinate well up to 100 mM NaCl. Our findings are supported by Ghorashy et al. (1972), who found that concentrations higher than 100 mM NaCl decreased the germination of *Carthamus* seeds.

Examining the germination percentage in this study shows that the seeds of four genotypes germinated were still able to germinate at the highest concentration of NaCl (200 mM). However, they were prevented from developing their full germination potential at higher salt concentrations (150 and 200 mM). The critical value was 150 mM, except for 'NS Zlatka' – 200 mM NaCl, where there was a significant reduction in germination, indicating the high tolerance of these species to a moderate stress level.

At the highest concentration of NaCl (200 mM NaCl), atypical seedlings occurred two or three times more often than in optimal conditions (0 mM NaCl). Seedling abnormalities were reflected in the fact that some of the following structures: cotyledons, primary root, hypocotyl, and first leaves were damaged, atrophied, or absent. In addition to the fact that the highest salt level suspended the germination process, it influenced the formation of atypical seedlings, indicating the toxic effect of Na ions. Demiral and Tukan (2005) reported that seeds that remained undeveloped were a consequence of a weak antioxidant defense system and lipid peroxidation in cell membranes.

Regarding the seedling parameters (Tables 3 and 4), SL was the longest for *Camelina* and *Carthamus* seedlings in the absence of stress. Other treatments with salt ions gradually decreased the SL of seedlings. SER values were the highest within the control treatment for both 'NS Slatka' and 'NS Zlatka' and decreased with each higher salt treatment. *Carthamus* SER values for 'NS Una' were in the following order: 2.7 > 2.3 > 1.6 > 1.5 > 0.7 under the following treatments: 50, 100, 0, 150, 200 mM, and for 'NS Lana' were in the following order: 2.4 > 2.2 > 2.2 > 1.0 > 0.7 under the following treatments: 50, 0, 100, 150, 200. When observing an RL (Figure 1), the low amount of NaCl stimulated the growth of *Camelina* seedlings – both genotypes had a short length in optimal conditions, which followed the seedlings at the salt treatment of 200 mM, while a salt treatment of 50 mM NaCl induced the highest RL. RER values were the highest at 200 mM and the lowest at 100 mM NaCl. When observing the RL (Figure 2) of *Carthamus* seedlings, it was found that only the treatment of 50 mM NaCl stimulated longer root growth of both genotypes than the RL of the control in both genotypes, then the RL gradually decreased up to the highest salt conditions and shortness of RL. The RER values were the highest at 100 mM and the lowest at 200 mM of NaCl for 'NS Una', whereas the highest values of RER for 'NS Lana' were at 50 mM and the lowest at 200 mM of NaCl.

Table 3. The effect of different salinity levels on a seedling characteristic of *Camelina* genotypes.

Treatment NaCl [mM]	GE	G	A	SL	RL	SER	RER	R/S
NS Slatka								
0	87.3±3.79^{a}	88.6±3.21^{a}	5.0±3.21^{c,d}	20.3±1.53^{a}	19.3±0.58^{d}	2.3±0.19^{a,b}	1.7±0.35^{a,b,c}	0.95±0.08^{b,c}
50	86.6±3.79^{a,b}	88.0±2.65^{a}	6.3±3.06^{c,d}	20.0±2.58^{a}	43.0±3.61^{a}	1.2±0.54^{c}	1.6±0.83^{a,b,c}	2.10±0.43^{a}
100	78.3±2.89^{b,c}	79.6±4.04^{a,b}	2.3±1.53^{d}	19.0±1.00^{a}	34.6±3.79^{a,b}	1.4±0.19^{c}	0.4±0.63^{c}	1.83±0.23^{a,b}
150	63.3±2.89^{d}	66.6±2.08^{c}	10.3±2.52^{b,c}	16.0±0.00^{a,b}	34.3±3.51^{a,b}	1.5±0.10^{c}	1.8±0.44^{a,b,c}	2.15±0.22^{a}
200	19.6±1.53^{e}	40.6±4.04^{d}	20.0±3.61^{a}	11.0±1.00^{b,c}	30.0±1.00^{a,c}	1.2±0.01^{b,c}	3.0±0.17^{a}	2.74±0.16^{a}
NS Zlatka								
0	67.0±3.46^{d}	70.0±4.58^{c}	6.6±3.06^{c,d}	20.3±2.08^{d}	19.3±0.58^{d}	2.4±0.10^{a}	1.7±0.35^{a,b,c}	0.96±0.09^{b}
50	70.3±4.04^{c,d}	71.6±3.06^{b,c}	8.3±1.53^{b,c,d}	19.0±1.00^{a,b}	37.6±3.51^{a,b}	0.8±0.17^{c}	1.0±0.92^{b,c}	1.97±0.44^{a}
100	70.0±4.36^{c,d}	72.6±4.04^{b,c}	5.3±2.08^{c,d}	19.3±1.59^{a}	36.0±1.73^{a,b}	1.4±0.51^{c}	0.2±0.35^{c}	1.87±0.07^{a}
150	65.0±1.73^{d}	68.6±3.51^{c}	6.6±2.08^{c,d}	17.6±0.58^{a}	36.0±2.00^{a,b}	1.6±0.10^{b,c}	1.5±0.44^{a,b,c}	2.04±0.41^{a}
200	33.6±3.21^{e}	48.0±2.65^{d}	15.3±3.51^{a,b}	12.0±12.00^{b,c}	29.3±2.52^{b,c}	1.2±0.35^{c}	2.2±0.51^{a,b}	2.80±0.93^{a}

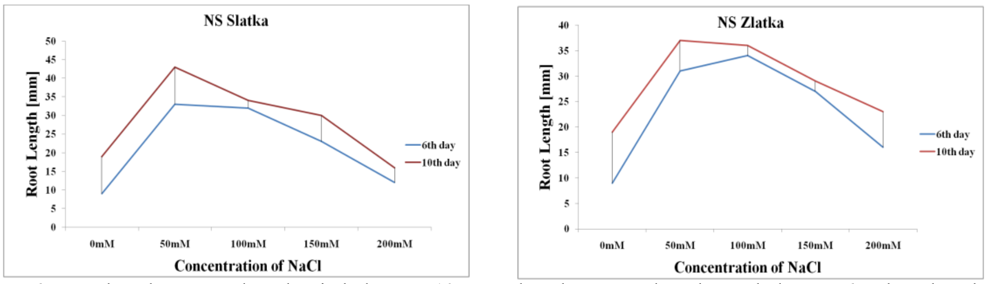
GE – germination energy; G – germination percentage; A – atypical seedlings; SL – shoot length; RL – root length; SER – shoot elongation rate; RER – root elongation rate; R/S – root/shoot ratio.

Apart from the interplay of several physiological processes, the morphological ones reflect the plant response to salinity (Julkowska and Testernik, 2015). Reducing the shoot length and lengthening the roots represent morphological adaptations to stress conditions. During salinity exposure, the energy used for plant growth is relocated to defense mechanisms, and due to decreasing photosynthesis and leaf area, the total available energy for usage is reduced (Bandehagh and Taylor, 2020). Mostafavi (2011) presented that the shoot was proportionally reduced due to the additional contact with salt stress, which was achieved through the evaporation of salt from the medium. Moreover, in the same study, in all investigated *Carthamus* genotypes, both SL and RL decreased due to salinity, unlike in our study. Ashraf et al. (2010) suggested that inhibition of cellular enzymes and hormonal imbalance reduced cell elongation. These disturbances may explain the shoot/root growth obtained in our study. In order to increase tolerance and also avoid the largest accumulation of salt on the top of the soil, plant roots elongate towards the deeper soil layer. According to Kage et al. (2004), the distribution balance of assimilates is disturbed in favor of the roots. In small-diameter seeds, such as *Camelina* seeds, increasing the total contact area of the root with the medium can be crucial for plant establishment under stress conditions. However, there is a risk of excessive elongation leading to a thin and fragile root (Sun et al., 2008). Furthermore, the R/S ratio, as a morphological marker, is a good indicator of the plant response to salinity (Agathokleous et al., 2019). The higher R/S ratio at higher salt concentration is an adaptation that allows plants to survive under salinity conditions (Munns and Tester, 2008). The results show that the R/S ratio changed in all *Camelina* and *Carthamus* genotypes as a function of concentration. The approximate values of the R/S ratio between *Camelina* genotypes indicate their adaptability to the same levels of salt stress, which does not coincide with the values of the other parameters that showed significant differences between species and genotypes.

Table 4. The effect of different salinity levels on a seedling characteristic of *Carthamus* genotypes.

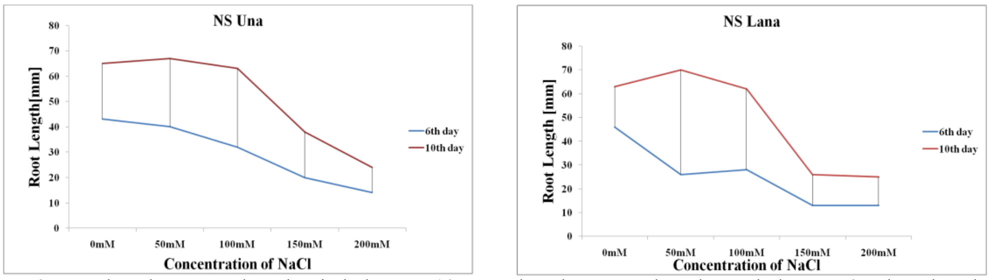
Treatment NaCl [mM]	GE	G	A	SL	RL	SER	RER	R/S
				NS Una				
0	72.3±4.93^{a,b}	79.6±5.50^{a}	19.0±4.00^{c,d}	37.0±1.73^{a}	65.3±3.51^{a}	1.6±0.28^{b,c}	3.6±0.16^{b,c}	0.95±0.08^{b,c}
50	63.3±5.03^{b,c}	68.6±5.13^{a}	20.6±3.51^{c,d}	36.3±2.52^{a}	67.3±3.79^{a}	2.7±0.63^{a}	4.5±1.41^{a,b,c}	2.10±0.43^{a}
100	66.3±4.72^{b,c}	72.0±6.24^{a}	22.6±2.08^{b,c,d}	25.3±1.15^{b}	63.0±3.43^{a,b}	2.3±0.16^{a,b}	5.1±1.75^{a,b,c}	1.83±0.23^{a,b}
150	49.6±2.08^{d,e}	55.6±4.04^{b}	33.0±4.55^{a,b,c}	15.6±2.52^{c}	38.0±3.71^{b,c}	1.5±0.33^{b,c}	2.8±2.03^{b,c}	2.15±0.22^{a}
200	40.0±5.29^{e}	46.6±3.51^{b,c}	31.6±5.03^{b,c}	10.6±1.53^{c}	24.3±3.06^{c}	0.7±0.25^{c}	1.6±0.44^{c}	2.74±0.16^{a}
				NS Lana				
0	78.0±1.00^{a}	80.0±4.35^{a}	12.3±0.057^{d}	36.6±0.58^{a}	63.0±1.73^{a,b}	2.2±0.09^{a,b}	2.7±0.91^{b,c}	0.96±0.09^{b}
50	63.0±2.64^{b,c}	70.6±2.51^{a}	19.3±3.21^{c,d}	34.0±3.61^{a}	70.0±3.00^{a}	2.4±0.78^{a,b}	7.2±0.83^{a}	1.97±0.44^{a}
100	59.0±4.00^{c,d}	71.6±2.51^{a}	18.3±5.77^{c,d}	26.0±1.73^{b}	62.0±3.41^{a,b}	2.2±0.09^{a,b}	5.6±1.74^{a,b}	1.87±0.07^{a}
150	25.0±4.35^{f}	36.0±2.64^{c}	50.3±4.50^{a}	12.3±0.58^{c}	26.6±2.31^{c}	1.0±0.19^{c}	2.1±0.33^{b,c}	2.04±0.41^{a}
200	20.0±3.00^{f}	35.6±3.78^{c}	40.3±5.50^{a,b}	12.0±0.00^{c}	25.0±3.91^{c}	0.7±0.25^{c}	1.8±0.83^{c}	2.80±0.93^{a}

GE – germination energy; G – germination percentage; A – atypical seedlings; SL – shoot length; RL – root length; SER – shoot elongation rate; RER – root elongation rate; R/S – root/shoot ratio.



RL 6 – root length measured on the sixth day; RL 10 – root length measured on the tenth day; SL 6 – shoot length measured on the sixth day; SL 10 – shoot length measured on the tenth day.

Figure 1. The root length of *Camelina* genotypes under different NaCl concentrations.



RL 6 – root length measured on the sixth day; RL 10 – root length measured on the tenth day; SL 6 – shoot length measured on the sixth day; SL 10 – shoot length measured on the tenth day.

Figure 2. The root length of *Carthamus* genotypes under different NaCl concentrations.

Based on the individual parameters of all four genotypes investigated in our study, it would be possible to predict the pattern of plant behavior in certain stages of development, which could be reflected in the yield later. Moreover, mathematical equations can precisely evaluate plant tolerance by correlating the obtained data of selected parameters of plants under non-stress and stress conditions (Jamshidi and Javanmard, 2018). To clarify the salinity tolerance mechanisms, Zuffo et al. (2020) suggested that identifying genotypes tolerant to salinity based on a single parameter or index may be ineffective. Therefore, in our study, the measured parameters were calculated as stress tolerance indexes. The stress tolerance indexes are among the most valuable tools for evaluating the plant response under stress (Živčak et al., 2008). To our knowledge, this is the first study where salt stress indexes were calculated for *Camelina* and *Carthamus*. In this way, all calculated parameters were considered, making one complex representing the plant as a whole during germination and early growth. All tolerance indexes are presented in Figure 3 for the *Camelina* genotypes and in Figure 4 for the *Carthamus* genotypes.

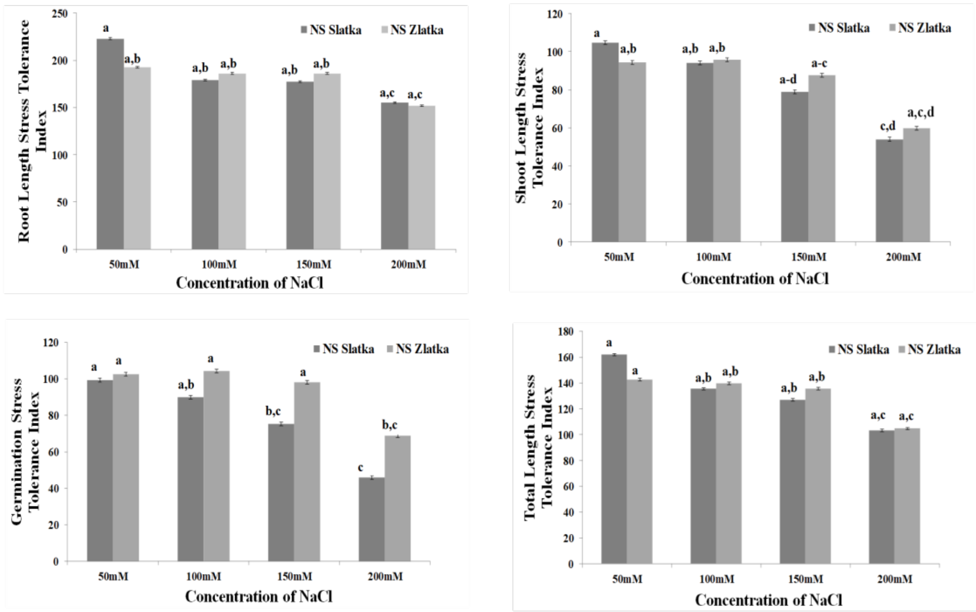


Figure 3. Stress tolerance indexes of *Camelina* genotypes.

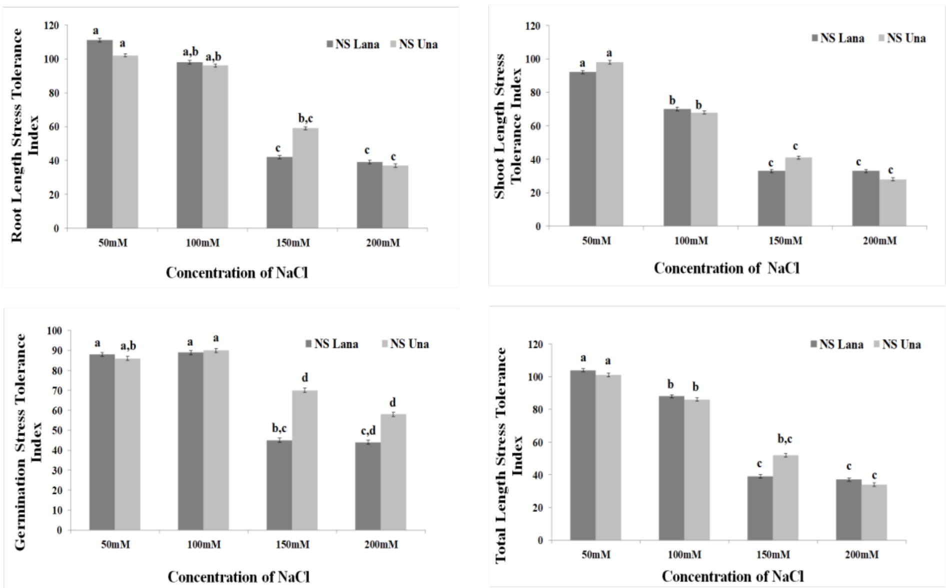


Figure 4. Stress tolerance indexes of *Carthamus* varieties.

The GSTI for *Camelina* ranged from 45 to 104%, and for *Carthamus* from 44 to 90%. The four groups were differentiated, and ‘NS Slatka’ and ‘NS Una’ had the highest tolerance indexes. The SLSTI of *Camelina* ranged from 54 to 104%, allowing differentiation into four groups, while *Carthamus* ranged from 28 to 98%, allowing differentiation into three groups. Among the genotypes, ‘NS Slatka’ and ‘NS Una’ had the highest SLSTI. Then, RLSTI ranged from 152 to 222% and from 37 to 111% for *Camelina* and *Carthamus*, respectively. The three groups were differentiated, and ‘NS Slatka’ and ‘NS Lana’ showed the highest RLSTI. When observing the TLSTI of the genotypes, the highest tolerance was detected for ‘NS Slatka’ and ‘NS Lana’ under 50 mM salinity treatment. On the other hand, the lowest TLSTI was observed in ‘NS Slatka’ and ‘NS Una’ under 200 mM salinity treatment. The obtained results indicate the difference in the tolerance to salt stress between these two plant species and between the examined genotypes. These differences occur due to various mechanisms of adaptation to a stressful environment, such as insufficient water osmotic pressure and the toxic effect of salt ions (Zuffo et al., 2020).

Conclusion

In the present study, a significant variation in salt tolerance was observed among all tested genotypes. The salt stress differentiates all genotypes by affecting germination energy, germination percentage, root length, shoot length, root elongation rate, and shoot elongation rate. The critical value of salt stress was 150 mM, except for ‘NS Zlatka’ – 200 mM NaCl, where there was a significant reduction in germination, indicating the tolerance of these species to salt stress. Moreover, seeds of all tested genotypes can be expected to germinate at 200 mM NaCl in laboratory-controlled conditions. The reduced shoot length and the elongated roots represent morphological adaptations to salinity, which can be more expected in *Camelina* genotypes. Salt stress tolerance indexes showed the importance of converting the plant parameters into mathematical indexes, and the significance of comparing all the tolerance indexes according to salt stress. Consequently, the salt stress tolerance indexes defined in this experiment might be a useful tool in selecting plant genotypes for cultivation in saline areas.

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UPOREDNI PREGLED UTICAJA STRESA SALINITETA TOKOM KLIJANJA *CAMELINA SATIVA* I *CARTHAMUS TINCTORIUS*

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R e z i m e

Zaslanjenost zemljišta kao jedan od najznačajnijih problema u svetu dovodi do smanjene poljoprivredne proizvodnje i smanjenja biodiverziteta. Najčešće zastupljena so u zemljištu i vodi je NaCl koja direktno utiče na rast biljaka i degradaciju zemljišta. Zbog navedenog problema, tokom ovog rada, ispitane su agronomske karakteristike dva genotipa *Camelina sativa* („NS Slatka”; „NS Zlatka”) i dva genotipa *Carthamus tinctorius* („NS Lana”; „NS Una”), koje ih potencijalno izdvajaju kao tolerantne useve na soni stres. Ispitano je pet tretmana NaCl od 0 mM do 200 mM. Na osnovu dobijenih rezultata seme svih ispitivanih genotipova je klijalo pri najvećem tretmanu (200 mM NaCl), međutim pri svim tretmanima zaslanjenosti procenat klijanja se smanjio. Takođe, došlo je do produžavanja korena i smanjenja dužine izdanka klijanaca kod svih ispitivanih genotipova. Korišćeni indeksi tolerancije na soni stres su pokazali značajnost preračunavanja dobijenih biljnih parametara preko matematičkih indeksa, kao i značajnost uporednog pregleda svih indeksa tolerancije na soni stres.

Ključne reči: NaCl, zaslanjenost, indeksi tolerancije.

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CORRELATION AND PATH COEFFICIENT ANALYSES OF DRY WEIGHT YIELD COMPONENTS IN THE COMMON SAINFOIN (*ONOBRYCHIS VICIIFOLIA* SCOP.)

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Abstract: Sainfoin (*Onobrychis viciifolia* Scop.) is a perennial forage crop with desirable forage properties adapted to temperate climate conditions. The purpose of this research was to study the phenotypic correlation coefficients between dry forage yield and some morphological traits, and to identify the direct and indirect effects of the associated traits. Thus, 32 ecotypes (landraces) were assessed in the randomized complete block design layout with four replications. Positive and statistically significant correlations were determined between total dry weight (TDW) and all measured traits except for internode length (IL) [$r=0.29$, $P>0.05$]. Regarding the variance inflation factor (VIF) as a multicollinearity statistic, number of nodes per main stem (VIF=1407.4) and number of internodes per main stem (VIF=1371.6) were removed from the analysis. Path coefficient analyses indicated that number of leaflets per leaf (NLL) [0.59 direct effect], height of the longest stem (HLS) [0.42 direct effect], and dry weight/fresh weight ratio (DFR) [0.27 direct effect] were influenced by TDW as a first-order trait. Five traits considered secondary or tertiary traits affected TDW – number of stems per area (NPA), number of stems per plant (NSP), number of leaves per stem (LS), length of inflorescence (LI) and stem weight/leaf weight ratio (SLR). The importance of main stem properties such as length or height, number of leaves, and number of leaflets can be used for selection in breeding programs aimed at improving common sainfoin forage yield under semi-arid conditions.

Key words: bootstrapping, dry forage yield, morphological traits, multicollinearity.

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Introduction

Common sainfoin (*Onobrychis viciifolia* Scop.) (Figure 1) is a perennial legume crop with acceptable productivity potential as a forage crop, with lower soil requirements and yields even in the poorest soils due to its high tolerance to abiotic stresses such as cold and drought (Radovic et al., 2019). It has erect or suberect hollow stems with a height of 70 cm, which can grow up to one meter tall as a cross-pollinated plant with many pink or purple flowers. It is a relatively little known forage crop compared to famous forage crops such as alfalfa or clovers, but it has attracted new interest in recent years in the world because it does not cause bloat in grazing animals, and can provide high-quality forage (Bhattarai et al., 2018). The regrowth of common sainfoin is relatively slow and it is important to give it sufficient time to replenish its root reserves to maintain its persistence and longevity (Carbonero et al., 2011). In addition, its blossoms produce large amounts of nectar, which is also attractive to pollinating insects such as honey bees.

Nowadays, common sainfoin cultivation is not widespread because its production is dependent on old, low-yielding cultivars or on local ecotypes whose future is not clear. Further expansion of common sainfoin production requires the specification of genetic resources, both for their protection and for their potential use. Common sainfoin is native to south-central Asia as a cross-pollinated crop (Burton and Curley, 1968), and the eastern Mediterranean and western Asia, especially Iran and Turkey, are considered to be the center of diversity of this species. In Iran, there are some landraces and ecotypes of common sainfoin that have been cultivated for centuries. In the northwestern and western Iran, farmers still cultivate old common sainfoin ecotypes that have good tolerance to abiotic stresses and could be an important genetic resource. Therefore, collecting and evaluating these promising ecotypes could be useful for the future breeding program.

Determining dry weight yield components will provide important benefits in common sainfoin breeding research in the future. The correlation coefficients are important in plant breeding programs because they quantify the degree of genetic and non-genetic association between two or more traits, allowing the indirect selection. However, pairwise correlation coefficients between dry weight yield and its components may not provide satisfactory results because the direct and indirect effects are not identified. In practice, selection indices based on the most important direct effects are used instead of correlation coefficients (Sharifi and Ebadi, 2018). Path analysis provides useful coefficients to construct selection indices that have been used successfully in several crops. This statistical tool is useful to identify the direct impact of one trait on another and it also separates the simple correlation coefficient into its direct and indirect effects (Takele et al., 2022). The correlation of yield performance with the other traits in common sainfoin and its partitioning into direct and indirect effects have been studied (Binek, 1983). The study of associations among traits is important for the early selection or the simultaneous selection when more than one trait is desired. However, the indirect selection using fewer complex traits with high heritability is simple and practical and may result in higher genetic progress compared to direct selection.

Figure 1. The experimental field of *Onobrychis viciifolia* Scop.

Ditterline (1973) has reported that traits such as number of stems per plant, number of branches per stem, number of florets per branch, number of seeds per branch, hundred seed weight, and seed yield are the main components in yield performance of common sainfoin. Binek (1983) has found that the number of stems has affected directly the number of florets and the number of pods in common sainfoin. Baghainiya et al. (2012) showed that dry forage yield of common sainfoin had a significant positive correlation with stem percentage, number of plants per area, and number of nodes per main stem. The utilization of such information will be of benefit in future plant breeding programs, as it may contribute to the development of genetically improved cultivars with a wide genetic base. Therefore, the aim of this study was to evaluate the association among different morphological traits of local ecotypes of common sainfoin in order to find the important traits for selection of forage yield performance useful for future breeding projects.

Material and Methods

During the 2021 regular cropping season, 32 local ecotypes of common sainfoin were studied in field experiments at the field station of University of Maragheh (37°23′21″N 46°14′15″E) under lowland conditions. Some geographical properties and annual rainfall patterns of the collection areas are shown in Table 1. The Maragheh region in northwestern Iran has a typical cool, sub-humid, temperate climate and a sandy loam soil type texture which is classified as Regosols with 1.8% organic matter (Roozitalab et al., 2018). In autumn, 30 kg ha^{-1} nitrogen and 50 kg ha^{-1} P_2O_5 fertilizers were incorporated into the soil by tillage. The experimental design was a randomized block design with four replicates, and the plots consisted of four rows, 2-m long, with a spacing of 0.25 m between rows and 0.20 m between plants. The two central rows were considered as useful harvesting area for forage yield in terms of total dry weight (TDW). In addition, number of plants per area (NPA) and stem weight/leaf weight ratio (SLR) were measured in the two central rows. Each replication was considered an observation, making up ten sample observations randomly selected from the middle row of each plot. The following traits were observed and measured: number of stems per plant (NSP), number of nodes per main stem (NMS), height of the longest stem (HLS), peduncle length (PL), length of inflorescence (LI), number of internodes per main stem (IMS), internode length (IL), number of leaves per main stem (LMS), number of leaves per stem (LS), and number of leaflets per leaf (NLL).

The dataset was tested for normality and was subjected to analysis of variance using an appropriate model with randomized block design. Simple phenotypic correlation coefficients were computed and were separated into direct and indirect effects using path analysis. A stepwise multiple regression model was performed to detect the predictor traits in first-, second- and third-order paths according to their respective contributions to the total variation in dry forage yield as well as the minimal multicollinearity. The magnitude of multicollinearity in each pathway was evaluated using the tolerance and the variance inflation factor (VIF) statistics. The tolerance statistic is the amount of variation in the selected independent trait that is not described by other independent traits ($1-R^2$), where R^2 is the coefficient of determination. The VIF statistic shows the magnitude of effects of other independent traits on the variance of the selected independent traits [$VIF = 1/(1/R^2)$]. Thus, small tolerance values (much lower than 0.1) or high VIF values (> 10) show high multicollinearity. Partial R^2 values were calculated from the path coefficients for all predictor traits. We were interested in obtaining not only a point estimate of a path coefficient, but also an estimate of its variation and a confidence interval.

Table 1. Geographical properties of collection areas of sainfoin ecotypes.

Code	Name	Coordinates	Altitude	Rainfall
G1	Bonab	37°20′N 46°03′E	1290	370
G2	Sarab	37°56′N 47°32′E	1650	285
G3	Marand	38°25′N 45°46′E	1344	526
G4	Zonuz	38°35′N 45°49′E	1700	480
G5	Varzaqan	38°30′N 46°39′E	1670	350
G6	Ahar	38°28′N 47°04′E	1341	340
G7	Azarshahr	37°45′N 45°58′E	1384	250
G8	Tabriz	38°04′N 46°18′E	1348	310
G9	Heris	38°14′N 47°06′E	1900	315
G10	Miandoab	36°58′N 46°06′E	1314	289
G11	Urmia	37°32′N 45°04′E	1332	338
G12	Silvaneh	37°25′N 44°51′E	1587	300
G13	Oshnavieh	37°02′N 45°05′E	1411	450
G14	Azna	33°27′N 49°27′E	1871	496
G15	Khorramabad	33°29′N 48°21′E	1147	412
G16	Aligudarz	33°24′N 49°41′E	2022	390
G17	Khalkhal	37°37′N 48°31′E	2243	320
G18	Garjan	38°18′N 48°12′E	1500	295
G19	Kahlaran	38°18′N 48°12′E	1500	295
G20	Meshginshahr	38°23′N 47°40′E	1400	380
G21	Sanandaj	35°18′N 46°59′E	1450	500
G22	Divandarreh	35°54′N 47°01′E	1850	275
G23	Khomeyn	33°38′N 50°04′E	1830	296
G24	Arak	34°05′N 49°41′E	1743	341
G25	Saqqez	36°14′N 46°15′E	1476	500
G26	Asadabad	34°46′N 48°07′E	1607	403
G27	Zanjan	36°40′N 48°29′E	1663	300
G28	Damavand	35°43′N 52°03′E	2051	385
G29	Faridan	32°59′N 50°24′E	2390	350
G30	Khansar	33°13′N 50°18′E	2215	453
G31	Fereydunshahr	32°56′N 50°07′E	2530	450
G32	Kabutarabad	32°29′N 51°49′E	1545	110

Resampling methods such as the bootstrap procedure provide estimates of the standard error values. Thus, the mean direct effects estimated from a set of 1,000 bootstrap samples agreed well with the observed direct effects of the various traits. To estimate the standard error of the path coefficients, the bootstrap procedure was performed. All statistical analyses were carried out using S-Plus Version 2000 (MathSoft, 1999), IBM SPSS AMOS Version 20.0 (Arbuckle, 2011), and SPSS Version 14.0 (SPSS, 2004).

Results and Discussion

The results of the analysis of variance showed significant differences in common sainfoin ecotypes for all of the measured traits (data not shown). The results of correlation coefficient analysis (Table 2) showed that there were highly positive correlations between total dry weight (TDW) and all measured traits except for internode length (IL). Therefore, to identify the most reliable pattern of the associations and to determine the magnitudes of the direct and indirect effects of the measured traits on TDW, performing a path coefficient analysis is essential. All traits were positively and significantly correlated with number of plants per area (NPA) and height of the longest stem (HLS), except for dry weight/fresh weight ratio (DFR). It is interesting that DFR had no significant positive/negative correlation with the measured traits except for TDW and stem weight/leaf weight ratio (SLR). There was a statistically significant and positive correlation between number of stems per plant (NSP) and other common sainfoin characters except for IL and DFR. The peduncle length (PL) had significant and positive correlations with length of inflorescence (LI), number of leaves per main stem (LMS), and IL. The length of inflorescence was significantly and positively correlated with number of leaves per stem (LS) and number of leaflets per leaf (NLL), IL and LMS. We also found a significant and positive correlation between IL and LMS, and between LMS with LS and NLL. The positive significant correlations were observed between LS with SLR and NLL, and between SLR and NLL.

Table 2. Correlation coefficients between 14 traits of 32 common sainfoin (*Onobrychis viciifolia* Scop.) genotypes.

	NPA*	NSP	HLS	PL	LI	IL	LMS	LS	NLL	SLR	DFR
NSP	0.679**										
HLS	0.581	0.792									
PL	0.445	0.667	0.632								
LI	0.472	0.734	0.743	0.753							
IL	0.427	0.280	0.506	0.287	0.359						
LMS	0.639	0.760	0.689	0.599	0.773	0.531					
LS	0.576	0.863	0.701	0.716	0.670	0.138	0.668				
NLL	0.468	0.505	0.484	0.198	0.372	0.169	0.466	0.498			
SLR	0.373	0.490	0.416	0.229	0.225	0.136	0.355	0.523	0.464		
DFR	0.344	0.160	0.139	-0.029	-0.004	0.135	0.206	0.078	0.195	0.635	
TDW	0.672	0.714	0.699	0.542	0.568	0.294	0.623	0.666	0.730	0.495	0.357

**Critical values of correlation $P < 0.05$ and $P < 0.01$ (D.F. 30) are 0.35 and 0.45, respectively; *Abbreviations are: number of plants per area (NPA), number of stems per plant (NSP), number of nodes per main stem (NMS), height of the longest stem (HLS), peduncle length (PL), length of inflorescence (LI), number of internodes per main stem (IMS), internode length (IL), number of leaves per main stem (LMS), number of leaves per stem (LS), number of leaflets per leaf (NLL), stem weight/leaf weight ratio (SLR) and total dry weight (TDW).

To identify the relative importance of the measured traits for the target trait (TDW), the dataset was subjected to multiple linear regression analysis, path analysis, two statistics of multicollinearity analysis, tolerance and VIF were computed (Table 3). Within the analysis, all traits were considered as first-order variables (Model I) with TDW as the response variable. The result showed high multicollinearity for number of nodes per main stem (NMS) and number of internodes per main stem (IMS). These traits show high direct effects on TDW, but their multicollinearity statistics were very high, VIF = 1407.4 for NMS and 1371.6 for IMS, thus, these traits were removed from the analysis. The estimation of direct effects by path analysis was considered by removing the NMS and IMS traits (Model II), and the analysis of multicollinearity showed a better understanding of the associations among the measured traits and their relative contribution to TDW. The results of the tolerance and VIF values for the predictor traits did not show any remarkable reduction in the VIF values in Model II compared with Model I.

Table 3. Direct effects of first-order predictor variables on the dry forage yield of 32 common sainfoin (*Onobrychis viciifolia* Scop.) genotypes and two measures of collinearity in path analysis; Model I (all predictor traits used as first-order variables) and Model II (the traits with high collinearity were removed).

Traits	Model I			Model II		
	Direct effect	Tolerance	VIF*	Direct effect	Tolerance	VIF
NPA	0.145	0.354	2.8	0.128	0.369	2.7
NSP	0.086	0.136	7.4	0.114	0.141	7.1
NMS	2.120	0.001	1407.4			
HLS	-0.059	0.103	9.7	0.228	0.224	4.5
PL	0.128	0.183	5.4	0.300	0.292	3.4
LI	0.028	0.154	6.5	-0.086	0.208	4.8
IMS	-1.769	0.001	1371.6			
IL	0.023	0.363	2.8	-0.046	0.409	2.4
LMS	-0.131	0.187	5.3	-0.046	0.205	4.9
LS	0.053	0.140	7.1	0.020	0.142	7.1
NLL	0.561	0.498	2.0	0.512	0.550	1.8
SLR	-0.169	0.289	3.5	-0.160	0.293	3.4
DFR	0.291	0.374	2.7	0.287	0.384	2.6

*VIF: variance inflation factor; **Abbreviations are: number of plants per area (NPA), number of stems per plant (NSP), number of nodes per main stem (NMS), height of the longest stem (HLS), peduncle length (PL), length of inflorescence (LI), number of internodes per main stem (IMS), internode length (IL), number of leaves per main stem (LMS), number of leaves per stem (LS), number of leaflets per leaf (NLL), stem weight/leaf weight ratio (SLR) and total dry weight (TDW).

The adjusted coefficient of determination (R^2 = 73.3) indicates the influence of the NLL, PL, and DFR traits as first-order traits that contribute to exploring the total variation of TDW (Table 4). Of the three traits influencing TDW, the NLL had the greater direct effect (0.594) than PL and DFR. The PL had the greater direct effect (0.418) than DFR on TDW. The indirect effect of NLL via PL and DFR was relatively low and positive (Table 5). For a better understanding of the association among the traits, a graphical representation of the results can be useful, thus, the diagram of path analysis (Figure 2) was generated. The results of the path analysis, when the first-order traits were used as response traits, showed that NSP positively influenced NLL and accounted for more than 50% of the observed variation while LI and LS positively influenced the PL and accounted for more than 62% of the observed variation (Table 4). The indirect effect of LI on PL via LS and the indirect effect of LS on PL via LI were relatively moderate. Finally, the last first-order trait (DFR) was influenced positively by SLR and NPA while it was influenced negatively by LS, and more than 53% of its total variation was explained by these second-order traits. The indirect effect of SLR on DFR via LS was moderate and negative, whereas the indirect effect of SLR on DFR via NPA was relatively low and positive. The indirect effect of LS on DFR via SLR was relatively high and positive, while the indirect effect of LS on DFR via NPA was relatively moderate and positive. The indirect effect of NPA on DFR via SLR and LS was relatively high and positive.

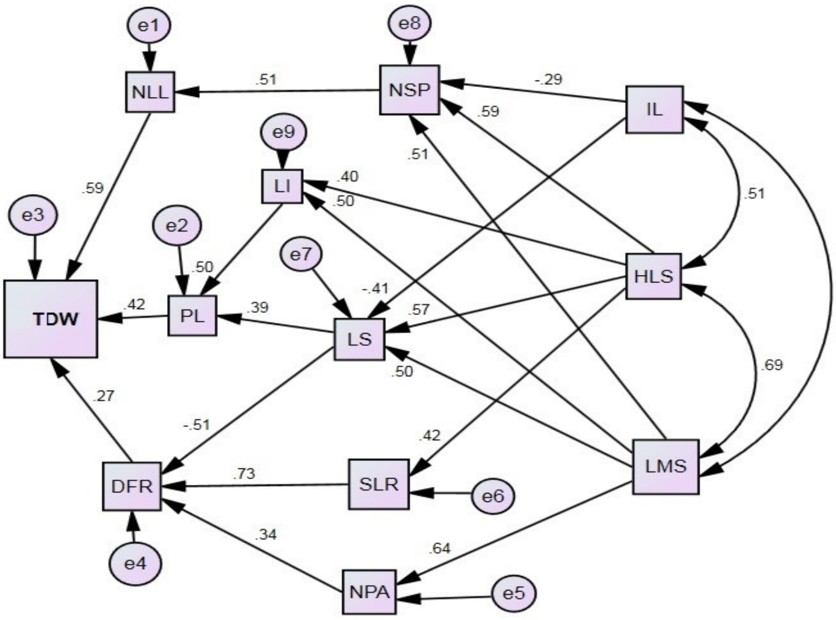

Figure 2. Path analysis diagram illustrating the associations among morphological traits contributing to dry forage yield.

Abbreviations are: number of plants per area (NPA), number of stems per plant (NSP), height of the longest stem (HLS), peduncle length (PL), length of inflorescence (LI),), internode length (IL), number of leaves per main stem (LMS), number of leaves per stem (LS), number of leaflets per leaf (NLL), stem weight/leaf weight ratio (SLR) and total dry weight (TDW).

Table 4. The estimation of coefficients of determination, direct effects, collinearity statistics and standard error values of path coefficients.

Response	Predictor	Path analysis coefficients		Collinearity statistics		Bootstrap statistics		
Trait	Trait	R^2*	Direct effect	Tolerance	VIF	Mean	Bias	SE
TDW**	NLL	51.7	0.594	0.921	1.1	0.593	-0.001	0.1
	PL	67.6	0.418	0.956	1.0	0.420	0.001	0.1
	DFR	73.3	0.273	0.957	1.0	0.272	-0.001	0.1
NLL	NSP	23.0	0.505	1.000	1.0	0.506	0.001	0.2
PL	LI	55.3	0.497	0.552	1.8	0.504	0.008	0.1
	LS	62.5	0.386	0.552	1.8	0.384	-0.001	0.1
DFR	SLR	38.3	0.732	0.718	1.4	0.745	0.014	0.2
	LS	45.7	-0.511	0.558	1.8	-0.512	-0.001	0.2
	NPA	53.4	0.344	0.661	1.5	0.327	-0.017	0.2
NSP	HLS	61.5	0.588	0.497	2.0	0.654	0.066	0.2
	LMS	69.5	0.507	0.480	2.1	0.497	-0.010	0.1
	IL	74.5	-0.286	0.680	1.5	-0.436	-0.150	0.3
LI	LMS	58.4	0.497	0.525	1.9	0.502	0.005	0.1
	HLS	65.9	0.401	0.525	1.9	0.399	-0.002	0.2
LS	HLS	47.5	0.568	0.497	2.0	0.562	-0.006	0.1
	LMS	52.6	0.496	0.480	2.1	0.503	0.007	0.1
	IL	63.8	-0.414	0.680	1.5	-0.397	0.017	0.2
SLR	HLS	14.6	0.416	1.000	1.0	0.404	-0.012	0.2

*R^2, coefficient of determination; **Abbreviations are: number of plants per area (NPA), number of stems per plant (NSP), height of the longest stem (HLS), peduncle length (PL), length of inflorescence (LI), internode length (IL), number of leaves per main stem (LMS), number of leaves per stem (LS), number of leaflets per leaf (NLL), stem weight/leaf weight ratio (SLR) and total dry weight (TDW).

To identify the third-order traits as predictors, the second-order traits were adopted separately as response traits. The results showed that IL negatively influenced NSP, whereas HLS and LMS positively influenced NSP and accounted for about 75% of the observed variation. The indirect effect of HLS on NSP via LMS was relatively high and positive, whereas the indirect effect of HLS on NSP via IL was relatively low and negative (Table 5). The indirect effect of LMS on NSP via HLS was relatively high and positive, whereas the indirect effect of LMS on NSP via IL was relatively moderate and negative. The indirect effect of IL on NSP via HLS and LMS was relatively high and positive. LMS and HLS also positively influenced LI and accounted for about 66% of the variation, whereas SLR was positively influenced by HLS (Table 4). The indirect effect of LMS on LI via HLS and the indirect effect of HLS on LI via LMS were relatively high and positive (Table 5). Finally, HLS and LMS positively influenced LS, whereas IL negatively influenced LS, and together these traits accounted for about 64% of observed variability. The indirect effect of LI on PL via LS and the indirect effect of LS on PL via LI were relatively high and positive (Table 5).

Table 5. Direct and indirect effects for the predictor traits in the path analysis divided into first-, second- and third-order traits.

TDW*	NLL	PL	DFR	DFR	SLR	LS	NPA
NLL	0.594	0.083	0.053	SLR	0.732	-0.267	0.128
PL	0.117	0.418	-0.008	LS	0.383	-0.511	0.198
DFR	0.116	-0.012	0.273	NPA	0.273	-0.294	0.344
NSP	HLS	LMS	IL	LS	HLS	LMS	IL
HLS	0.588	0.349	-0.145	HLS	0.568	0.342	-0.209
LMS	0.405	0.507	-0.152	LMS	0.392	0.496	-0.220
IL	0.298	0.269	-0.286	IL	0.288	0.264	-0.414
PL	LI	LS		LI	LMS	HLS	
LI	0.497	0.258		LMS	0.497	0.276	
LS	0.333	0.386		HLS	0.342	0.401	

*Abbreviations are: number of plants per area (NPA), number of stems per plant (NSP), height of the longest stem (HLS), peduncle length (PL), length of inflorescence (LI),), internode length (IL), number of leaves per main stem (LMS), number of leaves per stem (LS), number of leaflets per leaf (NLL), stem weight/leaf weight ratio (SLR) and total dry weight (TDW).

Morphological traits have been used to explain the variability of different crop landraces, and no comprehensive studies have been conducted for common sainfoin (*Onobrychis viciifolia* Scop.), with the exception of Binek (1983). The results of these studies indicate a high variation in measured traits among accessions and ecotypes of various geographical regions (Mohajer et al., 2013; Bhattarai et al., 2018) and we found relatively high variation in our plant materials and measured traits. A total of fourteen traits were used to assess thirty-two common sainfoin landraces, highlighting the remarkable potential to improve this species by breeding programs. As for common sainfoin breeding and selection of the most favorable individuals, it is important to reveal the variation available for the crop pattern and yield components. A better understanding of how forage yield components influence forage yield formation can be determined by path analysis, which indicates the direct and indirect effects of primary, secondary, and tertiary traits on forage yield formation. In addition, the path analysis shows how traits indirectly influence the yield performance through other traits and it provides more information on the relationship between traits than simple correlation coefficients (Kozak and Kang, 2006). A significant and positive correlation between forage yield (TDW) of common sainfoin and number of stems per plant (NSP), number of branches per stem, and number of leaflets per branch was reported by Hasanzadeh-Gorttapeh et al. (2014). In addition, Bhattarai et al. (2018) found a positive and significant correlation among TDW, NSP and HLS in common sainfoin, and

Mohajer et al. (2013) found similar results in terms of correlations between NSP and PL with other important traits such as TDW, HLS, LMS and NLL in common sainfoin. Some authors have reported similar results about the highly positive and significant correlation of number of stems per plant and number of stems per area with forage yield of common sainfoin (Veisipoor et al., 2012; Hasanzadeh-Gorttapeh et al., 2014; Bhattarai et al., 2018), while in this research, these traits did not show any direct effects as primary variables on forage yield, but had indirect effects as secondary variables on forage yield formation. Veisipoor et al. (2012) reported number of stems per plant and dry matter percent as the main variables in forage yield determination of common sainfoin, while Najafipoor and Majidi (2017) found number of stems per plant and number of seeds per inflorescences as the main traits in seed yield performance. Zarabiyan et al. (2015) also found that number of leaves per stem and number of stems leaves plant played a role in the path analysis of common sainfoin.

The direct effects estimated from a set of 1,000 bootstrap samples and the results indicated that the standard error values as well as the bias amounts for all the direct effects were low (Table 3), demonstrating the good robustness of Model II in path analysis. The path analysis might result in a multicollinearity of the traits. To avoid this problem, we removed the highly multicollinearized traits similar to other researchers who have employed this strategy in different crops: Mohammadi et al. (2003) in maize, Asghari-Zakaria et al. (2007) in potato, and Sabaghnia et al. (2010) in rapeseed. Our results indicate that there were three primary traits in forage yield formation, namely, number of leaflets per leaf (NLL), peduncle length (PL) and dry weight/fresh weight ratio (DFR), whereas Binek (1983) has reported only the number of inflorescences as the most important trait for yield performance. However, the role of NLL as one of the yield components in forage yield formation could not be neglected, whereas the role of PL and DFR traits in common sainfoin yield is logical. Similarly, Veisipoor et al. (2012) found peduncle length and dry weight/fresh weight ratio as the primary traits in forage yield. In contrast, Zarabiyan et al. (2015) reported plant height, number of leaves per stem, number of stems per plant and stem diameter as the variables directly influencing path analysis of common sainfoin, while we detected these traits as secondary or tertiary traits. This method of evaluating the association of different traits and regression analysis was used by Sabaghnia et al. (2010) in rapeseed, Janmohammadi et al. (2014) in bread wheat and Nayebi-Aghbolag et al. (2019) in rye.

In the next step of path analysis, we found five traits as secondary or tertiary traits, namely, number of stems per area (NPA), number of stems per plant (NSP), number of leaves per stem (LS), length of inflorescence (LI) and stem weight/leaf weight ratio. Similarly, Veisipoor et al. (2012) and Zarabiyan et al. (2015) found NPA and NSP as the traits determining forage yield, while Dadkhah et al. (2011)

reported NPA, NSP and LI as primary traits for seed yield performance. Thus, it seems that number of stems per plant or area is an important trait in common sainfoin and must be used in selection indices for genetic improvement programs. Regarding both primary and secondary traits, NSP→NLL path had the great impact on forage yield, followed by NPA→DFR path. Also, SLR→ DFR path and LI→PL path had a relatively remarkable impact on forage yield, but LS showed no such effect, having a positive effect on PL, but a negative effect on DFR. Thus, using number of leaves per stem in breeding programs must be done with caution due to its relatively complex role on forage yield formation. Finally, the remaining traits were identified as quaternary traits, including internode length (IL), number of leaves per main stem (LMS), and height of the longest stem (HLS). Similarly, Dadkhah et al. (2011) and Zarabiyan et al. (2015) found that plant height was the variable affecting forage yield. Also, Davazdahemami et al. (2019) reported number of leaves per plant as the contributing variable in common sainfoin forage yield. Thus, despite the number of leaves per stem (LS), number of leaves per main stem (LMS) had a remarkable impact on the forage yield. Regarding all primary, secondary, and tertiary traits, the sum of all paths of HLS had the great impact on forage yield, followed by the sum of all paths of LMS, but IL showed no such effect because the sum of its positive and negative effects was not high due to relatively equal positive and negative effects. Also, the relatively low magnitudes of the standard error of all the direct effects as well as the low bias amounts in the bootstrap procedure showed the robustness of our path analysis results. The T-test of significance using standard error values obtained through bootstrap resampling showed that all the direct effects were significant (data not shown). The used path analysis method in this study minimized the collinearity statistics (tolerance and VIF) of all traits facilitating the identification of the actual contribution of each predictor traits in the different paths, with negligible and confounding effects and interference. The advantage of this method in decreasing collinearity challenges and detecting real partnerships for each trait in different paths is similar to those reported in other crop studies (maize: Mohammadi et al., 2003; potato: Asghari-Zakaria et al., 2007 and rapeseed: Sabaghnia et al., 2010), indicating that it should be very useful in obtaining reliable result.

Conclusion

Generally, the correlation coefficients, regular path coefficients, and bootstrapping procedures in this study showed very close associations between forage yield performance and other morphological traits, with NLL, PL and DFR being the first-order variables, and with NSP, LI, LS, SLR, LS and NPA being the second-order variables. Finally, HLS, LMS and IL were the third-order variables associated with forage yield performance. The importance of main stem properties such as length or height, number of leaves and number of leaflets can be used for selection in breeding programs, with the aim of improving common sainfoin forage yield under semi-arid conditions.

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ANALIZE KOEFICIJENATA KORELACIJE I PAT KOEFICIJENTA KOMPONENTI PRINOSA SUVE MASE KOD ESPARZETE (*ONOBRYCHIS VICIIFOLIA* SCOP.)

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R e z i m e

Esparzeta (*Onobrychis viciifolia* Scop.) je višegodišnja krmna kultura sa poželjnim krmnim svojstvima prilagođenim uslovima umerene klime. Cilj ovog istraživanja bio je da se ispitaju koeficijenti fenotipske korelacije između prinosa suve krme i nekih morfoloških osobina, kao i da se prepoznaju direktni i indirektni uticaji pridruženih osobina. Stoga su procenjena 32 ekotipa (sorte) u potpuno slučajnom blok dizajnu sa četiri ponavljanja. Utvrđene su pozitivne i statistički značajne korelacije između ukupne suve mase (USM) i svih merenih osobina osim dužine internodije (DI) [r=0,29, P>0,05]. Uzimajući u obzir faktor inflacije varijanse (FIV) kao statistički pokazatelj multikolinearnosti, broj nodija po glavnoj stabljici (FIV=1407,4) i broj internodija po glavnoj stablljici (FIV=1371,6) uklonjeni su iz analize. Analiza koeficijenata putanje pokazala je da je na broj listića po listu (BLL) [0,59 direktni uticaj], visinu najduže stabljike (VNS) [0,42 direktni uticaj], i odnos suve mase/sveže mase (OSS) [0,27 direktni uticaj] uticala USM kao osobina prvog reda. Pet osobina koje se smatraju sekundarnim ili tercijarnim osobinama uticale su na USM – broj stabljika po površini (BSP), broj stabljika po biljci (BSB), broj listova po stabljici (LS), dužina cvasti (DC) i odnos mase stabljike/mase lista (OSL). Važnost osobina glavne stabljike kao što su dužina ili visina, broj listova i broj listića može se koristiti za selekciju u programima oplemenjivanja koji imaju za cilj poboljšanje prinosa krme esparzete u polusušnim uslovima.

Ključne reči: butstraping, prinos suve krme, morfološke osobine, multikolinearnost.

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EFFECT OF COMPOST WITH BANANA PEEL AND MORINGA LEAF POWDERS ON SEED YIELD AND YIELD COMPONENTS OF GREEN GRAM (*VIGNA RADIATA* L. WILCZEK)

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Abstract: The one-factor experiment was carried out in 2019–2020 at the University farm, Faculty of Agriculture, Eastern University, Sri Lanka to study the effect of compost with banana peel and *Moringa* leaf powders on seed yield and crop residue of green gram (*Vigna radiata* L. Wilczek). It was laid out in a complete randomized design with eight replicates and the following treatments: T1 – control (100 g of compost alone), T2 – 100 g of compost + 9 g of banana peel, T3 – 100 g of compost + 6 g of banana peel + 3 g of *Moringa* leaf, T4 – 100 g of compost + 4.5 g of banana peel + 4.5 g of *Moringa* leaf, T5 – 100 g of compost + 3 g of banana peel + 6 g of *Moringa* leaf and T6 – 100 g of compost + 9 g *Moringa* of leaf powder per polybag (0.07 m^2). The results showed that the application of compost with 4.5 g of banana peel and 4.5 g of *Moringa* leaf powders (T4) produced remarkable changes in the number of pods per plant, pod weight per plant, seed weight per plant, pod yield and seed yield than the other treatments. At the harvest, treatment T4 had the highest value (1,587.1 kg/ha) of seed yield, and treatment T1 gave the lowest value (906.1 kg/ha). The present study suggests that the application of 100 g (equivalent to 14.3 t/ha) of compost with 9 g (equivalent to 1.3 t/ha) of banana peel and *Moringa* leaf powders at a 1:1 (w/w) ratio would result in optimum seed yield of green gram in sandy regosol. The combined application of locally available banana peel and *Moringa* leaf powders could be used with compost for increasing the seed yield of green gram with less environmental impact.

Key words: banana peel, compost, green gram, *Moringa* leaf, seed yield.

Introduction

Green gram (*Vigna radiata* L. Wilczek) belongs to the Fabaceae family, and it is one of the most important grain legumes. The food legume is a significant crop globally, and pulses are the second most important group after cereals (Dash and

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Rautaray, 2017). Green gram grain is an excellent source of easily digestible protein and specific essential amino acids such as tryptophan and lysine in vegetarian diets (Pandiyan et al., 2012). Residues of green gram plants, especially leaves and stems, are used as organic manure in crop cultivation. The crop can fix atmospheric nitrogen in its root nodules and can be grown in various soils and climatic conditions due to its drought tolerance (Malik et al., 2006). Green gram is cultivated in the dry and intermediate zones of Sri Lanka. It can grow successfully in sandy loam soils (Seran and Krishanthy, 2009) when appropriate cultural practices are used.

In pulse crop cultivation, proper nutrient management is a significant factor for increasing the seed yield of grain legumes. A leguminous crop like green gram has a high potassium requirement (Singh et al., 2016) for its plant growth. Deore et al. (2010) stated that the balanced use of NPK fertilizer could not maintain the higher yields over the years due to micronutrient deficiencies and the decline of soil physical properties. Deficiencies of essential nutrient elements cause crop yield losses (Kumar and Babel, 2011). Moreover, excessive and continuous use of NPK chemical fertilizers decreases crop productivity and soil and environmental quality (Nasab et al., 2015). Thus, applying proper fertilizers with macro and micronutrients is necessary to increase growth and yield and decrease the negative impact on the environment (Magen, 2008). Primary and secondary nutrients and micronutrients are available in organic fertilizers to improve crop growth and development. Organic manure can replace inorganic fertilizers to increase soil nutrients and organic matter content (Gayathri and Seran, 2020). Animal waste, crop residues and other locally available plant materials are used as organic manures, increasing soil fertility to produce better crop yield (Seran, 2016; Priyadharshini and Seran, 2009; Nadeeka and Seran, 2020).

The organic material is used as a soil amendment to enhance crop growth and productivity with less environmental impact. Many people in the world consume ripe banana fruits, and their peels are solid waste, accounting for about 18–33% of the whole fruit weight (Wolfe et al., 2003). This waste increases soil fertility decreases environmental pollution (Panwar, 2015) and increases crop growth and yield (Mercy et al., 2014). Banana peels contain phosphorus and potassium, but relatively abundant potassium is available in its peel (Gayathri and Seran, 2020). Similarly, leaves of *Moringa oleifera* contain high levels of potassium, calcium, carotenoids, phenols, and vitamin E, zeatin (Asaolou et al., 2012). A sufficient amount of potassium is required for improving the crop yield due to its effect on photosynthesis, water use efficiency and plant tolerance to diseases, drought and cold (Singh, 2017). Furthermore, *Moringa* leaves consist of essential amino acids such as methionine, cysteine, tryptophan, and lysine (Makkar and Becker, 1996), and various antioxidant compounds such as ascorbic acid, flavonoids, phenolic compounds and carotenoids (Anwar et al., 2005). The addition of *Moringa* leaves to the soil enhances both micro and macro nutrients for plant uptake. Also, it can act as a scavenger of certain nutrients such as calcium, potassium, and sodium (Anyaegbu, 2014).

Banana peel and *Moringa* leaf powders are bioorganic substances locally available in Sri Lanka. Compost is a rich source of nutrients, and it has a high content of organic matter. Therefore, this experiment was aimed to study the effect of applying compost with banana peel and *Moringa* leaf powders on seed yield and yield components of green gram (*Vigna radiata* L.) and to determine the suitable quantity of banana peel and/*Moringa* leaf powder/s to obtain an optimum yield of green gram in sandy regosol.

Material and Methods

The one-factor experiment was conducted in 2019–2020 at the University farm, Faculty of Agriculture, Eastern University, Sri Lanka to study the effect of applying compost containing banana peel and *Moringa* leaf powders (BMP) on crop residue and seed yield of green gram and also to select the suitable combination of banana peel and *Moringa* leaf powders for obtaining an optimum yield of green gram. The experimental site is located between latitude 70 43’ and longitude 810 42’ in the eastern region of Sri Lanka at an elevation of 75 m above mean sea level. The temperature was 30±2℃ and the relative humidity was 60–70%. This pot experiment was carried out in a completely randomized design (CRD) with six treatments and eight replicates. They were as follows:

T1: 100 g of compost (control);

T2: 100 g of compost with 9 g of banana peel powder (ratio of 1:0 BMP);

T3: 100 g of compost with 6 g of banana peel + 3 g of *Moringa* leaf powder (ratio of 2:1 BMP);

T4: 100 g of compost with 4.5 g of banana peel + 4.5 g of *Moringa* leaf powder (ratio of 1:1 BMP);

T5: 100 g of compost with 3 g of banana peel + 6 g of *Moringa* leaf powder (ratio of 1:2 BMP);

T6: 100 g of compost with 9 g of *Moringa* leaf powder (ratio of 0:1 BMP).

Banana peels and *Moringa* leaves were collected from the market and the crop farm, respectively, in the eastern region of Sri Lanka. The collected banana peel and *Moringa* leaves were cleaned and then air dried separately for four days. Subsequently, the banana peels and *Moringa* leaves were powdered using a grinder (Magic Bullet blender, USA) and sieved separately using a 500-μm mesh sieve as described by Shiriki et al. (2015) and then kept at room temperature until used in this experiment. Subsequently, 3 g, 4.5 g, 6 g and 9 g of the banana peel powder were measured separately using an electronic analytical balance. After that, these were packed in polythene and sealed airtight. Moreover, 3 g, 4.5 g, 6 g and 9 g of

Moringa leaf powders were measured separately and sealed airtight to be applied to each polybag as fertilizer along with compost in this experiment.

A black polybag (0.07 m^2) was used in this experiment. The nutrient contents of the soil were nitrogen (10.0 μg/g), phosphorus as P_2O_5 (40.0 μg/g), and potassium as K_2O (0.25 meq/100 g), which were obtained from the previous research work done by Seran and Imthiyas (2016). The bags were filled with soil, leaving about a ¼th of the space between the soil and the top of the polybag. Holes were made at the bottom of the bags to remove excess water. All the polybags were placed 30 cm apart between rows. Organic fertilizer was applied according to the treatments in which 100 g (equivalent to 14.3 t/ha) of compost (0.56% N, 0.48% P2O5, 0.62% K2O) with 0–9 g of different rates of banana peel and *Moringa* leaf powders (BMP) were added to the soil in each polybag. In this experiment, seeds of the green gram variety *Harsha* were used. They were soaked in water for about 12 hours and then three seeds were sown at a depth of 2 cm in each bag three days after fertilizer application. No chemical fertilizers were applied in this experiment. Irrigation was done twice a day in the early morning and late evening from sowing to germination and once a day in the evening from germination to pod formation and once in two days in the evening after the pod formation by using the watering can. Weeding in the pots and on the experimental plot was done manually at two-week intervals.

Harvesting was done after eight weeks from seeding. The number of pods per plant, pod length, single pod weight, number of seeds per pod, seed weight per pod, 100-seed weight, pod weight per plant, seed weight per plant were recorded, and shelling percentage, as well as pod yield, were calculated. Further, the weights of the stem, leaves and roots were measured at the harvesting stage of the plants. The collected data were analyzed using the statistical software (SAS 9.1 version), and the treatment means were compared using the Tukey's honestly significant difference test at a 5% significance level.

Results and Discussion

Number of pods

The statistically analyzed data in Table 1 show that the application of compost containing banana peel and *Moringa* leaf powder (BMP) played a remarkable role in the number of pods per plant at harvest. There were significant differences ($P<0.01$) in the number of pods. Treatment T4 (compost containing 9 g BMP in a 1:1 ratio) remarkably differed from the other treatments except for T2 and T3. The highest average number (12.1) of pods was recorded in T4, followed by T3, whereas the lowest number of pods per plant was noted in T1 (6.8). The application of the banana peel (T2) or *Moringa* leaf powder (T6) alone resulted in lower values than the combined application of both powders. It was also noted that the number of pods was higher in the BMP treated plants than in the untreated plants (control treatment). The findings are supported by Sakpere et al. (2019), who have confirmed that a combination of *Moringa* extracts and fruit peels result in a synergistic effect that boosts the plant growth of *Solanum scabrum.* It may be due to the enriched plant nutrients in BMP for pod formation. Banana peel contains high levels of potassium and phosphorus (Gayathri and Seran, 2020). As a result, plants treated with 9 g of banana peel (T2) had a relatively higher number of pods than the control treatment (T1). The result is consistent with Mazed et al. (2015), who also noted that the number of pods was the highest in potassium treated mung bean plants compared to the control treatment. Qader (2019) also further proved that the phosphorus introduced into the soil through banana peel treatment resulted in the highest number of pods per pea plant.

Table 1. The number of pods per plant, pod length and number of seeds per pod of green gram as influenced by compost containing banana peel and Moringa leaf powders at harvest.

Treatments (compost 100 g with *BMP per polybag)	Treatment codes	Number of pods per plant	Pod length (cm)	Number of seeds per pod
0:0 BMP	T1	6.8 ± 0.4^{b}	7.03±0.28	8.4±0.4
1:0 BMP (9 g+0 g)	T2	8.4 ± 0.9^{ab}	6.97±0.18	7.8±0.3
2:1 BMP (6 g+3 g)	T3	9.3 ± 1.1^{ab}	7.47±0.12	8.2±0.5
1:1 BMP (4.5 g+4.5 g)	T4	12.1 ± 1.3^{a}	7.39±0.13	8.9±0.1
1:2 BMP (3 g+6 g)	T5	8.1 ± 0.8^{b}	7.03±0.31	8.1±0.1

*BMP – Banana peel and *Moringa* leaf powders. Values represented are means ± standard errors of eight replicates. F test – ns: not significant; ** P<0.01. Means followed by the same letter are not significantly different from each other at a 5% significance level according to the Turkey's honestly significant difference test.

Pod length

The BMP application on the green gram plant did not substantially affect (P>0.05) the average pod length (Table 1). The greatest pod length was attained in T3 (7.47), followed by T4 (7.39 cm). Treatment T6 had a lesser pod length (6.62 cm) compared to other treatments. Colpan et al. (2013) have mentioned that the fruits are small at a low potassium level while fruits were too large at a high potassium level. The pod length of snap bean plants was increased by spraying with *Moringa* leaf extract compared to control plants sprayed with distilled water (Emongor, 2015). The application of organic manures improves soil properties (Seran, 2016; Nadeeka and Seran, 2020). Thus, the availability of nutrients in the soil after adding the compost with BMP, particularly banana peel, influenced the pod length.

Number of seeds per pod

The effect of compost with BMP application on the number of seeds per pod is presented in Table 1. The number of seeds per pod was notably similar between the treatments (P>0.05). However, the highest mean number of seeds per pod was obtained in T4 (8.9), while the lowest number of seeds per pod was recorded in T6 (7.3). Moreover, the number of seeds per pod was slightly higher in T1 (compost alone as control) than in T2, where plants were treated with compost and banana peel. Banana peel (Gayathri and Seran, 2020) and *Moringa* leaves (Asaolou et al., 2012) are rich in potassium. It showed that the high nutrient availability in the soil amended with banana peel and *Moringa* leaves, particularly potassium, may affect the seed formation. It might reduce the uptake of the other essential nutrients, particularly nitrogen, calcium, and magnesium. As a result, the addition of BMP at a 1:1 ratio showed a better response to the seed formation than the other treatments. Based on this fact, the mixture of both powders also provides the important primary and secondary macronutrients to the plants in this study in addition to the micronutrients. Moyo et al. (2011) have stated that dried *M. oleifera* leaf powder has a higher content of macro and micronutrients such as calcium (3.65%), potassium (1.5%), phosphorus (0.3%) and magnesium (0.5%). Potassium and magnesium are key contributors to the process of photosynthesis and the subsequent transport of photo assimilates (Tränknera et al., 2018).

Pod weight

The analyzed data presented in Table 2 show that there was an insignificant variation (P>0.05) in single pod weight with different ratios of BMP application. The highest mean pod weight (0.581 g) was obtained in T3, and the lowest pod weight (0.525 g) was recorded in T6. At the same time, the pod weight in T4 was 0.575 g. Fruit peels comprise sugar, protein, and nutritional components, especially potassium, which are required for crop growth and yield (Bakry et al., 2016). Fruit peel is a natural fertilizer for increasing plant yield (Mercy et al., 2014). *Moringa* leaves as a soil amendment may help to reduce the pest and disease incidence in crop production and its storage as they consist of various types of antioxidant compounds (Anwar et al., 2005).

Seed weight per pod

Seed weight per pod is an important parameter directly connected with the total seed yield. The seed weight per pod was statistically the same in all the treatments. Application of compost with BMP did not substantially influence (P>0.05) the seed weight per pod (Table 2). Among the treatments, T3 gave the highest seed weight per pod (0.415 g), and T6 showed the lowest seed weight per pod (0.372 g). This is in accordance with Sakpere et al. (2019), who stated that *Moringa oleifera* leaves applied alone did not produce a positive response in most growth parameters measured. An increase in plant growth ultimately increases crop yield (Qader, 2019). Moreover, it was also observed that seed weight per pod was slightly higher in plants treated with the compost and banana peel than with the compost and *Moringa* leaf powder. Banana peel contains essential nutrients, particularly potassium and phosphorus (Gayathri and Seran, 2020), which are responsible for physiological processes to increase seed weight.

Table 2. Single pod weight, seed weight per pod and 100-seed weight of green gram as affected by compost containing banana peel and *Moringa* leaf powders.

Treatments	Pod weight (g)	Seed weight (g) per pod	100 seeds weight (g)
T1	0.570±0.03	0.398±0.02	5.11±1.52
T2	0.567±0.02	0.405±0.02	5.24±1.50
T3	0.581±0.04	0.415±0.02	5.45±0.93
T4	0.575±0.02	0.407±0.01	5.54±3.53
T5	0.539±0.04	0.380±0.04	5.39±2.03
T6	0.525±0.05	0.372±0.04	5.12±1.61
F test	ns	ns	ns

Values represented are means ± standard errors of eight replicates. F test – ns: not significant. The means followed by the same letter are not significantly different from each other at a 5% significance level according to the Turkey's honestly significant difference test.

100-seed weight

The effect of compost with different ratios of BMP application on 100-seed weight is given in Table 2. Regarding the 100-seed weight of green gram, no significant differences were observed (P>0.05) among tested treatments at harvest. The highest 100-seed weight was obtained in T4 (5.54 g), followed by T3 (5.45 g) and T5 (5.39 g). Simultaneously, the lowest 100-seed weight was attained in T1 (5.11 g), the control treatment. The plants treated with BMP had relatively higher values of 100-seed weight values than the untreated plants with BMP (T1). This may indicate that the accumulation of seed reserves is more a result of BMP application to the soil. The findings are in conformity with Bakry et al. (2016), who corroborated that foliar application of banana peel extract considerably increased the 1000-seed weight of quinoa plants compared to the untreated plants. Zare et al. (2014) also stated that 1000-seed weight was significantly increased using the potassium effect. Both banana peel and *Moringa* leaf are rich in potassium and other essential nutrients related to dry matter accumulation.

Pod weight per plant

The data relating to pod weight per plant are a significant part of ultimate crop yield. The pod weight per plant was significantly ($P<0.05$) varied among the treatments (Table 3). The remarkably higher value (6.76 g) of pod weight per plant was achieved ($P>0.05$) in T4 (1:1 BMP treatment) than in T1 (control treatment) and T6 (*Moringa* leaf powder alone). Compared with the other treatments, the lowest values (3.87 g and 3.97 g) were recorded in T1 and T6, respectively. Furthermore, both treatments gave notably ($P>0.05$) similar results in pod weight per plant. In addition, the result showed that the lower values of pod weight were achieved in the banana peel and *Moringa* leaf applied separately than in the combined use of BMP. Hence, the plant nutrients from both organic materials contribute to the increase in pod weight per plant. Organic fertilizer increases the availability of N, P, K and other essential nutrients that play an important role in plant growth and development (Palm et al., 2001).

Table 3. The weights of pods, seeds, and crop residue per plant of green gram as affected by compost containing banana peel and *Moringa* leaf powders.

Treatments	Pod weight (g) per plant	Seed weight (g) per plant	*Crop residue weight (g) per plant
T1	3.87 ± 0.33^{b}	2.75 ± 0.24^{b}	5.55±0.30
T2	4.75 ± 0.50^{ab}	3.34 ± 0.36^{ab}	6.62±1.01
T3	5.44 ± 0.78^{ab}	3.88 ± 0.55^{ab}	6.90±1.11
T4	6.76 ± 0.58^{a}	4.81 ± 0.43^{a}	7.94±1.31
T5	4.45 ± 0.60^{ab}	3.16 ± 0.47^{ab}	7.07±0.92
T6	3.97 ± 0.61^{b}	2.84 ± 0.47^{b}	5.78±0.25
F test	*	*	ns

Values represented are means ± standard errors of eight replicates. F test - ns: not significant*$P<0.05$. Means followed by the same letter are not significantly different from each other at a 5% significance level according to the Turkey's honestly significant difference test.

Seed weight per plant

The impact of different ratios of BMP application on seed weight per plant of green gram is presented in Table 3. The seed weight per plant was substantially influenced by applying banana peel and *Moringa* leaf powder on the green gram. Significant differences ($P<0.05$) were observed among the treatments. The highest seed weight per plant was obtained in T4 (4.81 g), followed by T3 (3.88 g) and T2 (3.34 g), whereas the lowest seed weight per plant was noted in T1 (2.75 g). The highest seed weight in T4 may result from the necessary plant nutrients released from the organic fertilizer applied. T4 considerably varied ($P<0.05$) from T1 and T6 in terms of seed weight per plant. Lee et al. (2010) have stated that banana peel extract is high in natural phenolic compounds, vitamins, flavonoids, and K elements required for plant growth and yield.

Dry weight of plant parts

No remarkable differences (P>0.05) were noted in air - dried weight of stem, leaves and roots of green gram among the treatments (Figure 1). However, the amount of an increase in each plant part varied due to the application of compost containing banana peel and *Moringa* leaf powders. These results may be due to plant nutrients and growth-promoting substances in both powders that enhanced shoot growth. This is supported by Anhwange (2008), who has found that fruit peel consists of substantial amounts of Na, K, Ca, Fe and Mg. Asaolou et al. (2012) have also stated that *Moringa* leaf is rich in K, Ca, carotenoids, phenols, naturally occurring cytokinin, ascorbates, vitamin E and zeatin for plant growth. As a result, the dry weight of stems and leaves were higher in plants treated with compost containing banana peel and *Moringa* leaf powders than in the control treatment.

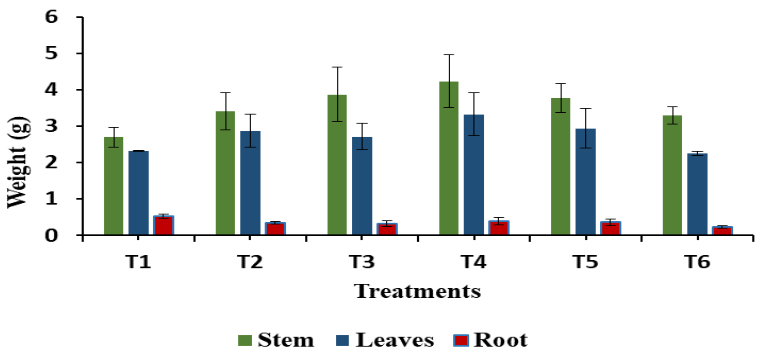

Figure 1. Air - dried weights of leaves, stem, and root of green gram plant as influenced by compost containing banana peel and Moringa leaf powders.

Treatment T4 showed the highest dry weight (4.23 g) of stem per plant, followed by T3 (3.87 g), whereas T1 had the lowest dry weight (2.69 g) of the stem. This is in agreement with Bakry et al. (2016), who reported that the application of banana peel extract increased the dry shoot weight of quinoa plants compared to the untreated plants. It was further noted that the dry weight of leaves was higher in T4 (3.32 g), and the lowest dry weight (2.25 g) was noted in T6. This could be in agreement with the statement of Makinde and Ayoola (2010), who reported that the dry matter in leaves was low due to the slow release of nutrients by organic fertilizers. Yeh et al. (2000) have also found that phosphorus-deficient plants grow slowly and have fewer leaves. Kadir et al. (2016) have stated that banana peels are rich in phosphorus. Accordingly, the nutrients that plants need may be supplied at different times and in different amounts through the combined application of banana peel and *Moringa* leaf powders for better leaf growth. Moreover, it was observed that the dry weight of roots was high in T1 (0.53 g), and the lowest value was noted in T6 (0.23 g). Consequently, essential nutrients may be available for root growth to the plants by the application of compost alone. On the other hand, Bakry et al. (2016) have reported that the percentage increase in banana peel extract is the response to dry weight of roots compared to untreated control. Phosphorus promotes rooting and fruit set, and potassium is essential for stem and root growth (Wazir et al., 2018).

Crop residues

The effect of organic fertilizer application on crop residue weight as the total air - dried weight of leaves, stems and roots is presented in Table 3. T4 had the highest weight (7.94 g) of crop residue per plant, while T1 showed the lowest weight (5.55 g) of crop residue per plant. No significant difference ($P>0.05$) was noted among the treatments, but positive effects on crop residue were observed among treatments. This may be attributed to the macro and micronutrients present in both *Moringa* leaf and banana peel powders according to available information (Moyo et al., 2011; Gayathri and Seran, 2020). Cakmak (2008) has stated that zinc increases biomass production in plants. *Moringa* leaf extract gave a non-significant increase in both shoot and root dry mass (Emongor, 2015).

Pod yield

There was a noteworthy difference ($P<0.05$) in pod yield by the application of compost with BMP on the green gram (Table 4). The highest pod yield was obtained in T4 (2231 kg/ha), followed by T3 (1793.8 kg/ha), T2 (1565.9 kg/ha), while the lowest value was obtained in T1 (1276.2 kg/ha). According to the results, plants treated with compost and a 1:1 ratio of banana peel and *Moringa* leaf powders (T4) showed significantly ($P<0.05$) higher pod yield as compared to plants treated with compost alone (T1) or compost containing *Moringa* leaf plants (T6). Even though T1 was equal to T6 in terms of pod yield, T6 gave a higher value than T1. It is in conformity with Thomas and Howarth (2000), who reported that *Moringa* leaf extract enhanced the number of leaves, which increases the photosynthesis and photo assimilates, resulting in high yield. Further, an insignificant difference ($P>0.05$) in pod yield of green gram was noted among the 1:0, 2:1, 1:1 and 1:2 ratios when banana peel and *Moringa* leaf powders were applied. Bakry et al. (2016) stated that the foliar application of banana peel extract significantly increased the yield of quinoa plants. Gayathri and Seran (2020) have found that banana peel has significant effects on various biological aspects in plants.

Table 4. The effect of compost with banana peel and *Moringa* leaf powders on pod and seed yield of green gram.

Treatments	Pod yield (kg/ha)	Seed yield (kg/ha)
T1	1276.2±10.8[b]	906.1±7.8[b]
T2	1565.9±16.3[ab]	1101.6±11.8[ab]
T3	1793.8±25.7[ab]	1279.8±18.1[ab]
T4	2231.0±19.3[a]	1587.1±14.3[a]
T5	1468.5±20.0[ab]	1041.6±15.7[ab]
T6	1308.4±20.3[b]	936.4±15.6[b]
F test	*	*

Values represented are means ± standard errors of eight replicates. F test - *: P<0.05. Means followed by the same letter are not significantly different from each other at a 5% significance level according to the Turkey's honestly significant difference test.

Shelling %

Shelling % is an imperative economic feature and indicates the percentage of the kernel weight on the pod (unshelled) weight. A slight change was observed in the shelling % of green gram by compost with BMP (Figure 2). T3 (compost with 2:1 BMP) gave the highest shelling % (71.51%), and T5 showed the lowest shelling % (69.67%). Among the treatments, an insignificant difference (P>0.05) was noticed in shelling %. It was further observed that T1 and T4 had the same values in the shelling percentage of green gram. More or less equal percentage of shelling may be due to the organic fertilizers used in this study; as a by-product, shells cannot be used efficiently and economically (Zhao et al., 2012).

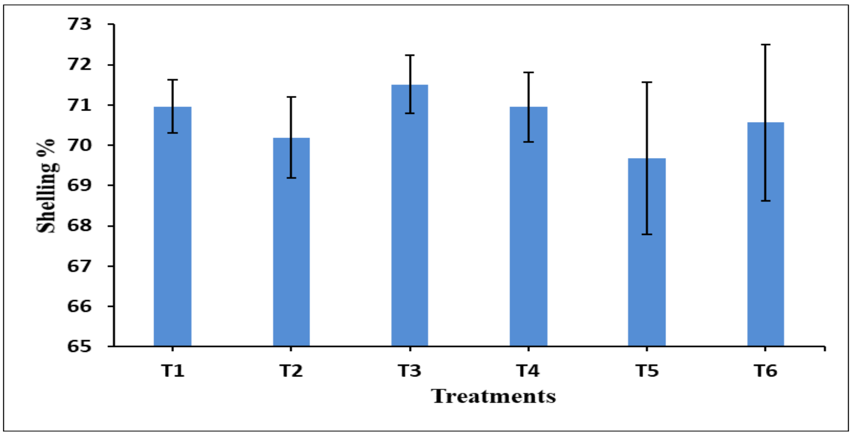

Figure 2. Shelling % of green gram plant as influenced by compost containing banana peel and *Moringa* leaf powders.

Seed yield

A significant difference ($P<0.05$) was observed in the seed yield of green gram among the treatments (Table 4). The result showed the lowest value of seed yield in T1 (906.1 kg/ha), where plants were treated with the compost alone (control treatment). However, the plants treated with compost and BMP had an effect on seed yield, and the highest value was obtained in T4 (1587.1 kg/ha) followed by T3 (1279.8 kg/ha). It was further noted that T4 remarkably ($P<0.05$) produced a higher seed yield than T1 and T6. The seed yield of T1 (compost alone) was statistically ($P>0.5$) equal to that of T6 (compost with *Moringa* leaf powder only). Sakpere et al. (2019) confirmed that *Moringa oleifera* leaves applied alone did not show a positive effect on crop yield. In the present study, plants treated with banana peel powder alone (T2) or in combination with *Moringa* leaf powder (T3, T4 and T5) gave higher yields than T1 (control) and T2 (*Moringa* leaf powder alone).

Conclusion

In the present study, the application of compost with different ratios of banana peel and *Moringa* leaf powders (BMP) had positive effects on the yield components and seed yield of green gram in sandy regosol. The results showed significant differences ($P<0.05$) in the number of pods per plant, pod weight per plant, seed weight per plant, pod yield and seed yield at harvest. It was further noted that there were no significant differences ($P>0.05$) in pod length, number of seeds per pod, single pod weight, seed weight per pod, 100-seed weight, shelling percentage, stem dry weight, leaf dry weight, root dry weight and crop residue weight per plant. However, the compost containing 4.5 g of banana peel and 4.5 g of *Moringa* leaf powders (T4) as organic fertilizer substantially increased the number of pods per plant, pod weight per plant, seed weight per plant, pod yield and seed yield compared to the control treatment at harvest. The highest value of seed yield of green gram was obtained in T4 (1,587.1 kg/ha), and the lowest value was obtained in T1 (906.1 kg/ha). According to the results, T4, which included the application of 100 g of compost with 4.5 g of banana peel and 4.5 g of *Moringa* leaf powders (1:1 ratio of BMP), was the best application in sandy regosol. Banana peel and *Moringa* leaf are locally available materials that could be used as organic fertilizer in crop production.

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UTICAJ KOMPOSTA SA KOROM BANANE I LISTOM MORINGE U PRAHU NA PRINOS SEMENA I KOMPONENTE PRINOSA MUNGO PASULJA (*VIGNA RADIATA* L. WILCZEK)

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R e z i m e

Jednofaktorski eksperiment je sproveden u 2019–2020. godini na univerzitetskom dobru Poljoprivrednog fakulteta Istočnog univerziteta u Šri Lanci kako bi se ispitao uticaj komposta sa korom banane (*Musa paradisiaca* L.) i listom biljke moringa (*Moringa oleifera* L.) u prahu na prinos semena i ostatke useva mungo pasulja (*Vigna radiata* L. Wilczek). Eksperiment je postavljen u potpuno slučajnom dizajnu sa osam ponavljanja i u okviru sledećih tretmana: T1 – kontrola (100 g kompost), T2 – 100 g komposta + 9 g kore banane, T3 – 100 g komposta + 6 g kore banane + 3 g lista moringe, T4 – 100 komposta + 4,5 g kore banane + 4,5 g lista moringe, T5 – 100 g komposta + 3 g kore banane + 6 g lista moringe i T6 – 100 g komposta + 9 g lista biljke moringe u prahu po polietilenskoj vreći (0,07 m^2). Rezultati su pokazali da primena komposta sa 4,5 g kore banane i 4,5 g lista moringe u prahu (T4) dovode do značajnih promena u broju mahuna po biljci, masi mahuna po biljci, masi semena po biljci, prinosu mahuna i prinosu semena nego ostali tretmani. Najveći prinos semena zabeležen je na tretmanu T4 (1.587,1 kg/ha), dok je na tretmanu T1 prinos semena bio najmanji (906,1 kg/ha). Ovom studijom se sugeriše da bi primena 100 g (ekvivalentno 14,3 t/ha) komposta sa 9 g (ekvivalentno 1,3 t/ha) kore banane i lista moringe u prahu u odnosu 1:1 (m/m) mogla dovesti do optimalnog prinosa semena mungo pasulja u peskovitom regosolu. Kombinovana upotreba kore banane i lista moringe u prahu, koji su lokalno dostupni, može se koristiti sa kompostom za povećanje prinosa semena mungo pasulja uz manji uticaj na životnu sredinu.

Ključne reči: kora banane, kompost, mungo pasulj, list moringe, prinos semena.

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INHERITANCE OF YIELD-RELATED MORPHOLOGICAL CHARACTERISTICS IN F_1 TOBACCO HYBRIDS

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Abstract: The aim of this work was to study the mode of inheritance of the number of leaves per stalk and the length, width and area of the leaves from the middle part of the stalk – traits directly related to the yield in the offspring of the first generation. The studies were made with four mother parent tobacco varieties of different types (three of the Prilep type: P-23, П 18-50/4, П 76/86 and one of the Basmak type – MC 8/1), one pollen donor parent Burley B-1-91, and their four F_1 hybrids. The crosses were made in 2018, 2019 and 2020, and the experiment with the parent genotypes and their hybrids was set up in 2019, 2020 and 2021, on a field trial at the Scientific Tobacco Institute – Prilep in a randomized block design with four replications. All appropriate cultural practices were applied during the growing season. The research data indicates that there was no heterosis in the hybrids for the studied traits. The partially dominant mode of inheritance is an indicator of good successive selection of individuals in future generations and quick fixation and stabilization of the traits. The hybrids MS 8/1 x B-1/91 and P 18-50/4 x B-1/91 represent very interesting material for future tobacco breeding activities.

Key words: *Nicotiana tabacum* L., tobacco crosses, hereditary traits, intermediance, dominance, heterosis.

Introduction

One of the most important places in the economy of the Republic of North Macedonia belongs to the production of Oriental aromatic tobacco. The largest part of the tobacco raw material is intended for foreign markets, which shows the importance of this agricultural crop for the country. The participation of our tobacco in the highest quality cigarette brands is a proof of its first-class quality and outstanding pleasant aroma.

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Taking into account the above, studies on tobacco genetics and selection are of great importance. Using the methods of these sciences, breeders try to create more productive and higher quality varieties, better in many traits than the existing ones.

The introduction of new superior varieties in tobacco production will mean an increase in the economic effect of this crop, which will result in an improvement in the standard of producers, as well as an increase in the flow of funds in the country.

The aim of this paper is to study the variability and mode of inheritance of the number of leaves per stalk and the dimensions of the leaves from the middle part of the stalk – traits, directly related to the yield of tobacco, in the F_1 progeny of different tobacco varieties, to reveal a possible heterotic effect, as well as to provide material for further successive tobacco breeding activities.

The inheritance of the number and dimension of tobacco leaves has been studied by many authors, because the value of this trait correlates with the yield. Partial dominance in the inheritance of leaf number per stalk was found in the following studies: Korubin – Aleksoska (2000), in the crosses of three Oriental varieties, Korubin – Aleksoska (2001), in ten Oriental genotypes, Gixhari and Sulovari (2010), in a one-way diallel of eight Oriental genotypes. A different way of inheritance and a weak heterotic effect were found by Aleksoski (2010), in a one-way diallel of three Oriental varieties and one Burley variety. Dyulgerski and Radoukova (2019) found dominance of the parents with a greater number of leaves in seven hybrids of the Burlay type in the F_1 and F_2 generations. Heterosis with a positive heterotic effect on the trait was found in the following studies: Butorac et al. (1999), in F_1 offspring of four Burley varieties, Lalitha et al. (2006), in crosses of six lines and six testers, Dimanov and Dyulgerski (2012), in ten crosses of local and introduced Burley varieties (high heterotic effect is detected), Aleksoski et al. (2013), in hybrids obtained from four parent genotypes of tobacco of different types (the heterosis had a weak heterotic effect), Ramachandra et al. (2015), in hybrids obtained from six lines of different types of tobacco and eight testers.

The partial-dominant and intermediate way of inheriting of the length and width of the leaves from the middle part of the stalk is most common in the studies of: Lee and Chang (1984), in crosses of Korean and Oriental varieties, Legg (1991), in crosses of Burley varieties, Gixhari and Sulovari (2010), in a diallel of eight Oriental genotypes, Dyulgerski and Radoukova (2015), in seven Burley-type crosses and seven Virginia-type crosses, in the creation of parental genotypes of local and introduced origin, etc. The heterotic effect in inheriting the length and width of the leaves was obtained in the following studies: Lalitha et al. (2006), in 36 F_1 hybrids obtained by crossing six lines and six testers (the resulting heterosis had a moderate heterotic effect in both directions), Dyulgerski and Dimanov (2012), in ten crosses of Burley varieties (the best heterotic effect was obtained by the width of the seventh and eighth leaves, which makes heterosis economically more important). Dyulgerski and Radoukova (2015), in seven Burley-type crosses and seven Virginia-type crosses, of parental genotypes of local and introduced origin (heterosis had no economic significance), Ramachandra et al. (2015), in crosses with six lines of different types of tobacco and eight testers (hybrids had the longest leaf length).

The most common way of inheritance for the area of the leaves is partially dominant and intermediate. Similar results were obtained by: Aleksoski (2010), in a one-way diallel of four parental genotypes of Oriental and Burley origin, Gixhari and Sulovari (2010), in a one-way diallel of eight Oriental genotypes, Aleksoski et al. (2013), in a diallel of four parent genotypes of tobacco of different types, Aleksoski (2018), in a diallel of four Oriental varieties, etc. Positive heterosis in inheriting of leaf area was achieved in the following studies: Korubin – Aleksoska (2000), in diallel of three Oriental and one semi-Oriental variety (a positive heterotic effect appeared in two crosses where one parent was the introduced variety Pobeda-2), Lalitha et al. (2006), in hybrids of six lines and six testers (the resulting heterotic effect was low to moderate in both directions), Aleksoski (2010), in a one-way diallel of four parental genotypes – three Oriental and one Burley (the weak heterotic effect was not economically justified), Gixhari and Sulovari (2010), in a diallel of eight parent Oriental genotypes, Aleksoski et al. (2013), in six diallel crosses of four parent tobacco genotypes of different types, Aleksoski (2018), in hybrids of four Oriental varieties.

Material and Methods

As working material, we chose five genotypes from the gene bank of the Science Tobacco Institute - Prilep: Prilep P-23, Prilep P 18-50/4, Prilep P 76/86, Basmak MS 8/1 and Burley B-1/91. As a father, we used the broadleaf variety B-1/91, so with its pollen in 2018, 2019 and 2020 we produced four F_1 hybrids: P-23 x B-1/91 (Photo 6), P 18-50/4 x B-1/91 (Photo 7), P 76/86 x B-1/91 (Photo 8) and MS 8/1 x B-1/91 (Photo 9). The parental varieties and their F_1 hybrids were planted in a randomized block system in four replications, in an experimental field at STI-Prilep, in 2019, 2020 and 2021, on a working area of about 291.6 m^2 or a total area of 655.2 m^2 (working surface and paths). The broadleaf variety and F_1 hybrids were planted at a planting distance of 90 cm (between rows) x 50 cm (between plants in a row), while the Oriental varieties were planted at a planting distance of 45 cm (between rows) x 15 cm (between plants in the row). The number of leaves per stalk and the dimensions of the leaves of the middle band of the stalk (length, width and area) were determined at the full development stage of the plant at the beginning of flowering.

The mode of inheritance of the components was determined by the test-significance of the F_1 generation in relation to the average of both parents, according to Borojevic (1981). Intermediate mode of inheritance (i) occurs when the mean value of one trait in the hybrid is equal to the parental average. Partial-dominant mode (pd) occurs when the mean value of hybrid offspring approaches one of the parental varieties. Dominance in inheritance (d), positive or negative, occurs when the mean value of the hybrid matches the mean value of one of the parents (+d – when a parent with a higher mean value dominates, -d – when a parent with a lower mean value dominates). Positive heterosis (+h) occurs in a hybrid with a significantly higher value than that of the parent with a higher mean value, while negative heterosis (-h) occurs in a hybrid with a significantly lower value than that of the parent with a lower mean value.

Parental genotypes

Prilep P-23 – Kosta Nikoloski and Milan Mitreski are the authors of this variety. It belongs to the Oriental sun-cured tobacco type Prilep. It is characterized by fir-habitus, a stem 65 cm high, 45–50 seated leaves 20 cm long and 10.5 cm wide (Photo 1), and a semi-spherical, compacted inflorescence with pink flowers. The dried leaves have a golden yellow to light orange color, with an elastic and compact leaf plate. They have a strong, pleasant aroma. The dry leaf mass yield is 2000–2500 kg/ha (Korubin – Aleksoska, 2004).

Prilep P 18-50/4 – creation by Ana Korubin – Aleksoska. The variety belongs to the group of Oriental sun-cured tobacco of the type Prilep. It is characterized by a cylindrical to elongated-elliptical habitus, the height of the stalk with the inflorescence is 85–90 cm. There are about 45 sitting leaves, which are light green with curly edges. The length of the largest leaf is 20–23 cm, and the width is 11–12.5 cm (Photo 2). The inflorescence is spherical with bright pink flowers. The dried leaves are golden yellow to orange, with a moderately pronounced main rib and a thin weakly expressed secondary leaf veins. The yield of dry leaf mass is 2700–2900 kg/ha.

Photo 1. Prilep P-23.

Photo 2. Prilep P 18-50/4.

Prilep P-76/86 is an Oriental sun-cured variety of the Prilep type, created by Dimche Chavkaroski and his collaborators. It is characterized by an elliptic-conical habit. The average height of the stem is 90 cm. This variety has, on average, 60 sessile leaves, the largest of which is 23 cm long and 11.5 cm wide (Photo 3). There are dense hemispherical flower clusters with white to pale pink flowers. It is characterized by a long growing season (from planting to flowering – 85–95 days). The lower dry leaves are yellow, the middle ones are orange, and the upper ones are reddish-orange, with a specific pleasant aroma. The dry mass yield is 3500–4000 kg/ha (Korubin – Aleksoska, 2004).

Basmak MS 8/1 – created by a group of authors, headed by Dusko Boceski. It belongs to the Basmak sun-cured type, which was created from the Jakali type from Greece. The habit is cylindrical to elongated-elliptical with a height of about 110 cm. This variety has an average of 42 leaves with a length of about 21 cm and a width of about 12 cm (Photo 4). The color of the dry leaves is from yellow-orange to red-orange, with a specific pleasant aroma. The dry mass yield is 3500–4000 kg/ha (Korubin – Aleksoska and Ayaz Ahmad, 2016).

Photo 3. Prilep P-76/86.

Photo 4. Basmak MS 8/1.

Burley B-1-9 – Dimche Cavkaroski and his collaborators are the authors of this variety. It belongs to the group of broadleaf air-cured tobacco varieties. It is characterized by a conical habit, a tall stem (185 cm), 30–33 sessile leaves, the largest of which is 60 cm long and 35 cm wide (Photo 5). The flowers are scattered in a panicle with pale pink flowers. Dry leaves have a shiny brown color and a thin texture. The dry mass yield is 3500–4000 kg/ha (Korubin – Aleksoska, 2004).

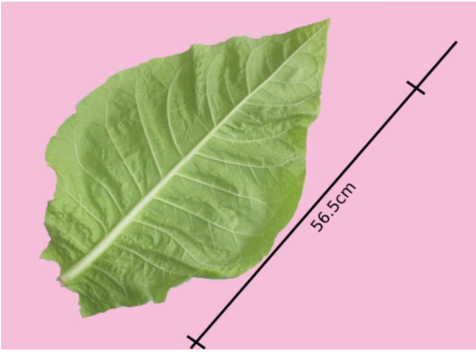

Photo 5. Burley B-1/91.

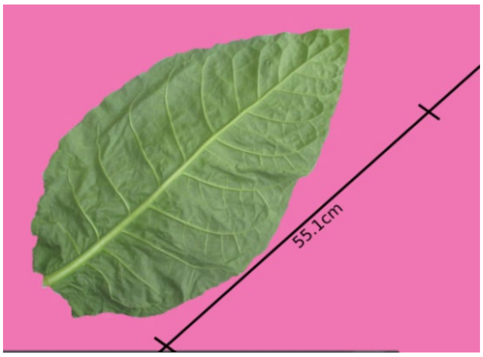

Photo 6. P-23 x B-1/91 (F_1).

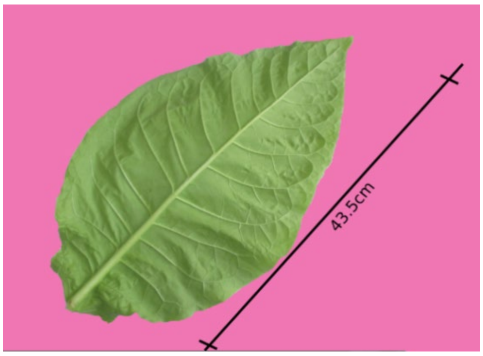

Photo 7. P 18-50/4 x B-1/91 (F_1).

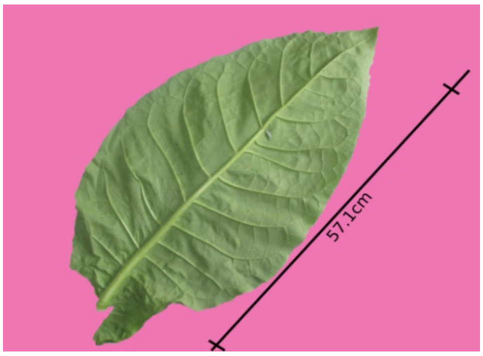

Photo 8. P-76/86 x B-1/91 (F_1).

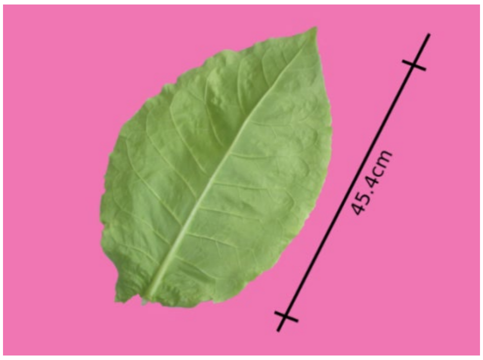

Photo 9. MS 8/1 x B-1/91 (F_1).

Climatic and soil conditions in the study area

As with all plants, environmental factors make changes in a large number of quantitative and qualitative traits in tobacco. However, these changes are differently limited, depending on the type of trait and the degree of its heredity. Therefore, during scientific research on morphological traits from the aspect of selection and genetics, it is necessary to take into account the environmental conditions in which the studies were conducted.

From the data in Table 1, it can be seen that the climate parameters were very close in 2019 and 2020, while they differed drastically in 2021. Basically, in 2021, the temperature was lower from May to September, the humidity was lower, and there was about 43% less rainfall.

Table 1. Weather conditions (by month and averages) – Prilep: 2019, 2020, 2021.

Year	Climatic parameters	May	June	July	August	September	$\bar{x}$
2019	Avg. temp. (°C)	15.77	22.77	24.26	27.39	21.97	22.43
	Min. temp. (°C)	8.00	16.00	14.00	22.00	14.00	14.80
	Max. temp. (°C)	20.00	28.00	29.00	32.00	27.00	27.20
	Humidity (%)	71.30	67.17	59.42	42.61	53.00	58.70
	Precipitation/ rainfall (mm)	124.10	139.90	91.80	9.50	39.50	∑ = 404.80
2020	Avg. temp. (°C)	16.97	20.3	24.77	25.48	23.23	22.15
	Min. temp. (°C)	9.00	14.00	20.00	20.00	15.00	15.60
	Max. temp. (°C)	25.00	27.00	31.00	31.00	30.00	28.80
	Humidity (%)	69.80	70.40	59.20	56.70	49.80	61.20
	Precipitation/ rainfall (mm)	64.90	73.00	97.40	133.90	32.40	∑ = 400.60
2021	Avg. temp. (°C)	14.50	19.00	22.00	22.20	16.80	18.90
	Min. temp. (°C)	8.80	13.00	15.90	16.20	11.60	13.10
	Max. temp. (°C)	19.60	24.20	27.30	27.50	21.90	24.10
	Humidity (%)	61.00	53.00	46.00	45.00	56.00	52.20
	Precipitation/ rainfall (mm)	57.00	34.00	26.00	22.00	35.00	∑ = 174.00

https://en.climate-data.org/europe/macedonia/prilep/prilep-37313/.

Our research was conducted in the experimental field of the Scientific Tobacco Institute in Prilep on a deluvial (colluvial) soil type, without carbonates, characterized by low humus and total nitrogen content, moderately acidic to neutral reaction, low to extremely low security with readily available phosphorus and medium to good potassium supply.

Results and Discussion

Number of leaves per stalk

The study of the number of leaves in tobacco is always present in programs for the creation of new varieties and breeding of existing ones, because it represents an important quantitative characteristic due to its direct connection with the increase in yield.

The lowest number of leaves among the parents was noted in B-1/91 (31.2), and the highest in P-76/86 (54.8), while in hybrids, the lowest number of leaves was observed in P-23 x B-1/91 (31.3), and the highest in P 18-50/4 x B-1/91 (35.6). The standard deviation ranged from 1.2 (P 18-50/4 and P-76/86 x B-1/91) to 2 (B-1/91). The coefficient of variability ranged from 2.2% (P-76/86 x B-1/91) to 4.5 (B-1/91). The fact that the coefficient of variability is low, despite the different environmental conditions of the years, indicates that this trait is highly heritable and it is a varietal characteristic. This coefficient had a value of less than 10, which means that the tested variants are stable and uniform.

The mode of inheritance of this trait was negatively dominant (there was partial dominance only in P 18-50/4 x B-1/91). There was no heterosis.

No heterosis in crosses of Oriental tobacco was found by: Korubin – Aleksoska (2000, 2001), Gixhari and Sulovari (2010).

Table 2 shows the mean values, mode of inheritance, standard deviation, and coefficient of variability for the number of leaves per stalk in parents and F_1 hybrids.

Table 2. Mean values, variability and mode of inheritance of the number of leaves per stalk in parents and F_1 hybrids.

S. No.	Parents and F_1 hybrids		Number of leaves per stalk					
			Years of research			$\overline{x}$	σ (±)	CV (%)
			2019	2020	2021			
			x	x	x			
1.	P-23	P1 (♀)	43.2	45.4	44.8	44.5	1.4	3.5
2.	P 18-50/4	P1 (♀)	45.5	46.3	47.4	46.4	1.2	3.6
3.	P-76/86	P1 (♀)	53.7	54.5	56.2	54.8	1.5	3.6
4.	MS 8/1	P1 (♀)	41.3	40.8	41.3	41.1	1.5	4.1
5.	B-1/91	P2 (♂)	30.4	32.2	30.9	31.2	2.0	4.5
6.	P-23 x B-1/91	F_1	29.5^{-d}	31.5^{-d}	32.2^{-d}	31.3^{-d}	1.5	2.4
7.	P 18-50/4 x B-1/91	F_1	35.0^{pd}	36.2^{pd}	35.5^{pd}	35.6^{pd}	1.5	2.3
8.	P-76/86 x B-1/91	F_1	31.5^{-d}	33.0^{-d}	33.8^{-d}	32.8^{-d}	1.2	2.2
9.	MS 8/1 x B-1/91	F_1	32.1^{pd}	34.5^{pd}	31.5^{-d}	32.7^{-d}	1.7	3.2

Legend: -d – negative dominance, pd – partial dominance.

Length of leaves from the middle part of the stalk

The shape of the leaves is a trait of the variety, but the dimensions are highly variable depending on the environmental factors and the applied agrotechnics.

Among the parental genotypes, the shortest length of the leaves from the middle part of the plant was noted in the variety P 18-50/4 (22.4 cm) and the largest was observed in B-1/91 (56.5 cm). As for hybrids, the shortest leaf length was found in P 18-50/4 x B-1/91 (43.5 cm), and the largest was observed in P-76/86 x B-1/91 (57.1 cm). The standard deviation ranged from 1.8 (P-23 and P 18-50/4 x B-1/91) to 5.4 (B-1/91). The coefficient of variability ranged from 2.8% (P-76/86 x B-1/91) to 9.1% (P-76/86). The coefficient of variability of the hybrids was lower than that of parental genotypes. CV-value was lower than 10, which attests to the stability and uniformity of the variants.

The mode of inheritance of this trait was intermediate, partially dominant and positively dominant. There was no heterosis.

Table 3 shows the mean values, mode of inheritance, standard deviation and coefficient of variability for the leaf length of the middle part of the stalk in parents and F_1 hybrids.

Table 3. Mean values, variability and mode of inheritance of length of the leaves from the middle part of the stalk in parents and F_1 hybrids.

S. No.	Parents and F_1 hybrids		Length of the leaves from the middle part of the stalk					
			Years of research			$\overline{x}$ (cm)	σ (±)	CV (%)
			2019	2020	2021			
			x (cm)	x (cm)	x (cm)			
1.	P-23	P1 (♀)	23.0	23.5	23.2	23.2	1.8	7.3
2.	P 18-50/4	P1 (♀)	23.1	22.2	21.8	22.4	2.0	8.3
3.	P-76/86	P1 (♀)	23.2	24.6	23.4	23.7	2.1	9.1
4.	MS 8/1	P1 (♀)	25.4	24.9	25.3	25.2	2.2	7.1
5.	B-1/91	P2 (♂)	57.5	55.4	56.7	56.5	5.4	6.5
6.	P-23 x B-1/91	F_1	55.3^{+d}	55.8^{+d}	54.2^{+d}	55.1^{+d}	2.7	3.5
7.	P 18-50/4 x B-1/91	F_1	44.3^{i}	43.9^{pd}	42.2^{i}	43.5^{i}	1.8	3.3
8.	P-76/86 x B-1/91	F_1	57.1^{+d}	56.8^{+d}	57.4^{+d}	57.1^{+d}	1.9	2.8
9.	MS 8/1 x B-1/91	F_1	45.2^{i}	46.2^{pd}	44.9^{i}	45.4^{pd}	2.7	2.9

Legend: +d – positive dominance, pd – partial dominance , i – intermediate.

Width of the leaves from the middle part of the stalk

The width of the leaf is a trait of the tobacco variety, on which environmental factors have a limited impact.

The smallest width of the leaves from the middle part of the stalk among the parental genotypes was noted in the variety P-76/86 (11.7 cm), and the largest was observed in B-1/91 (33.6 cm). As for F_1 hybrids, the smallest leaf width was found in MS 8/1 x B-1/91 (29.8 cm), and the largest was noted in P-76/86 x B-1/91 (33.6 cm). The standard deviation ranged from 0.7 (P-23 x B-1/91) to 1.9 (P-23 and P-76/86). The coefficient of variability ranged from 3.3% (P-23 x B-1/91) to 9.5% (P 18-50/4). This coefficient was lower in the hybrids than that in the parental genotypes. In all variants, the CV-value was lower than 10, which is an indicator of uniformity and stability of the studied variants (Table 4).

The mode of inheritance of a trait was partially dominant and positively dominant and no heterotic effect was observed.

The absence of heterosis was found in these studies: Fan and Aucock (1974), in crosses of Meryland varieties, Espino and Gil (1980), in diallel in eight varieties of light tobacco, Lee and Chang (1984), in crosses of Korean and Oriental varieties, Legg (1991), in crosses of Burley varieties, Dyulgerski and Radoukova (2015), in seven Burley crosses and seven Virginia crosses, etc.

Table 4. Mean values, variability and mode of inheritance of the width of the leaves from the middle part of the stalk in the parents and F_1 hybrids.

S. No.	Parents and F_1 hybrids		Width of the leaves from the middle part of the stalk					
			Years of research			$\overline{x}$ (cm)	σ (±)	CV (%)
			2019	2020	2021			
			x (cm)	x (cm)	x (cm)			
1.	P-23	P1 (♀)	11.9	12.3	11.7	12	1.9	7.5
2.	P 18-50/4	P1 (♀)	11.5	12.5	12.3	12.1	1.4	9.5
3.	P-76/86	P1 (♀)	11.3	12.2	11.7	11.7	1.9	8.2
4.	MS 8/1	P1 (♀)	12.4	12.8	12.6	12.6	0.9	7.3
5.	B-1/91	P2 (♂)	33.1	34	33.8	33.6	1.7	5.8
6.	P-23 x B-1/91	F_1	29.6^{pd}	30.7^{pd}	31.4^{+d}	30.6^{pd}	0.7	3.3
7.	P 18-50/4 x B-1/91	F_1	30.6^{+d}	33.6^{+d}	34.2^{+d}	32.8^{+d}	1.2	4.6
8.	P-76/86 x B-1/91	F_1	30.8^{+d}	34.5^{+d}	35.5^{+d}	33.6^{+d}	1.0	4.5
9.	MS 8/1 x B-1/91	F_1	28.1^{pd}	30.4^{pd}	28.1^{pd}	29.8^{pd}	1.1	5.4

Legend: +d – positive dominance, pd – partial dominance.

Leaf area of the middle part of the stalk

The smallest leaf area from the middle part of the stalk in the parental genotypes was found in the variety P 18-50/4 (170.38 cm^2), and the largest in B-1/91 (1210.54 cm^2), while in F_1 hybrids the smallest leaf area was noted in MS 8/1 x B-1/91 (801.68 cm^2), and the largest in P-76/86 x B-1/91 (1294.75 cm^2). The standard deviation and the coefficient of variability were not calculated for this trait, because the values were obtained by applying the formula for the area, where the mean values of the length and width of the leaves by repetitions were entered.

The mode of inheritance of this trait was intermediate, partially dominant and positively dominant. There was no heterosis.

Table 5 shows the mean values and mode of inheritance for the leaf area of the middle part of the stalk in the parents and F_1 hybrids.

Table 5. Inheritance of the leaf area from the middle part of the stalk in F1 hybrids.

S. No.	Parents and F_1 hybrids		Leaf area from the middle part of the stalk			
			Years of research			$\bar{x}$ (cm²)
			2019	2020	2021	
			x (cm²)	x (cm²)	x (cm²)	
1.	P-23	P1 (♀)	173.909	183.662	172.473	175.421
2.	P 18-50/4	P1 (♀)	168.794	176.324	170.376	163.679
3.	P-76/86	P1 (♀)	166.576	190.696	173.96	170.166
4.	MS 8/1	P1 (♀)	200.126	202.515	202.553	198.55
5.	B-1/91	P2 (♂)	1209.33	1196.84	1210.54	1206.24
6.	P-23 x B-1/91	F_1	1040.07^{pd}	1088.48^{+d}	1081.37^{+d}	1071.32^{pd}
7.	P 18-50/4 x B-1/91	F_1	861.34^{pd}	937.24^{pd}	917.03^{pd}	906.59^{pd}
8.	P-76/86 x B-1/91	F_1	1117.46^{+d}	1245.13^{+d}	1294.75^{+d}	1219.05^{+d}
9.	MS 8/1 x B-1/91	F_1	807.03^{i}	892.41^{pd}	801.68^{i}	859.65^{pd}

Legend: +d – positive dominance, pd – partial dominance , i – intermediate.

Conclusion

Regarding our studies on the parental genotypes and their F_1 hybrids, as well as the mode of inheritance of the number of leaves per stalk and the leaf sizes from the middle part, we have drawn the following conclusions:

- The varieties that are the subject of these studies were characterized by a high degree of stability and uniformity, as a result of their homozygosity. The parents in the role of mothers and the parent in the role of father differed significantly in the investigated traits.
- The inheritance of the number of leaves per stalk was negatively dominant (it was only partially dominant in P 18-50/4 x B-1/91).
- Intermediance, partial dominance and positive dominance were found in the inheriting of the length of the leaves from the middle part of the stalk.
- There was partial dominance and positive dominance in the inheriting of the width of the leaves from the middle part of the stalk.
- The leaf area of the middle part of the stalk was inherited by intermediance, partial dominance and positive dominance.

- There was no occurrence of a heterotic effect in the F_1 population in all studied morphological traits in the three years of study.
- Within these investigations, we obtained F_1 hybrid offspring that will serve as material for further breeding activities.
- The results obtained within these studies are useful achievements in the genetics and tobacco breeding, and they are of utmost importance for science and practice in the process of creating new superior varieties.

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NASLEĐIVANJE MORFOLOŠKIH KARAKTERISTIKA KOJE SE ODNOSE NA PRINOS KOD F_1 HIBRIDA DUVANA

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R e z i m e

Cilj rada je bio proučavanje načina nasleđivanja broja listova po stabljici i dužine, širine i površine listova srednjeg pojasa – morfološke osobine direktno vezane za prinos kod potomaka F_1 generacije. Istraživanja su obavljena sa četiri sorte duvana u ulozi majke različitih vrsta (tri sorte vrste prilep: P-23, P 18-50/4, P 76/86 i jedna sorta vrste basmak – MS 8/1), jednim donorom polena – berlej B-1-91, i njihova četiri F_1 hibrida. Ukrštanja su rađena 2018, 2019. i 2020. godine, a terenski ogledi sa roditeljskim genotipovima i njihovim ukrštanjima postavljeni su 2019, 2020. i 2021 godine, na oglednom polju u Naučnom institutu za duvan – Prilep, prema randomizovanom blok sistemu u četiri ponavljanja. Tokom vegetacionog perioda primenjivane su sve uobičajene agrotehničke mere. Podaci istraživanja ukazuju na to da kod hibrida nema pojave heterozisa za proučavana svojstva. Parcijalno dominantan način nasleđivanja pokazatelj je dobre sukcesivne selekcije jedinki u budućim generacijama i brzog fiksiranja i stabilizacije osobina. Hibridi: MS 8/1 x B-1/91 i P 18-50/4 x B-1/91 predstavljaju veoma zanimljiv materijal za buduće aktivnosti selekcije duvana.

Ključne reči: *Nicotiana tabacum* L., hibridi duvana, nasledne osobine, intermedijarnost, dominantnost, heterozis.

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COMPARISON OF FIELD PERFORMANCE AND FRUIT QUALITY AMONG NEWLY RELEASED ITALIAN JUNE-BEARING STRAWBERRY CULTIVARS

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Abstract: The aim of this study was to compare newly released June-bearing strawberry cultivars (‘Quicky’, ‘Sandra’, ‘Lofty’, ‘Nadja’ and ‘Aprica’) in terms of their phenology, vegetative growth, productivity and fruit quality to identify their potential for wider cultivation. A field study was conducted in a strawberry plantation established in July 2020 in double rows on beds covered with black polyethylene foil (Šid, Serbia). The cultivars were evaluated in 2021–2022 for their flowering and ripening time, productivity, plant growth, biometrical and nutritional fruit traits (soluble solids content – SSC, total acids – TAs, vitamin C, total anthocyanins – TACY, total phenolics – TPC and total antioxidant capacity – TAC). The cultivar ‘Quicky’ started to ripen earliest, while ‘Aprica’ was the latest in both experimental years. The number of branch crowns per plant was significantly higher in ‘Sandra’ and ‘Lofty’, whereby ‘Sandra’ had also the highest number of leaves per rosette (41.5) in comparison with the other tested cultivars. The cultivar ‘Aprica’ was superior in terms of productivity (1061 g/plant and 4.67 kg/m^2), fruit weight (29.9 g) and fruit shape index (1.15). Contrary to this, ‘Nadja’ was the least productive cultivar (608 g/plant and 2.68 kg/m^2). The cultivars ‘Lofty’ and ‘Sandra’ showed the highest SSC values and were also characterized by a considerably high level of TPC (1.29 mg GAE eq g^{-1} FW) and TACY (24.4 mg pg-3-g eq 100 g^{-1} FW), respectively. Variability among the tested cultivars could serve as an important criterion for the selection of new high-performing cultivars for a given growing region.

Key words: strawberry, cultivar, plant growth, ripening time, productivity, fruit quality.

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Introduction

Strawberry (*Fragaria* × *ananassa* Duch.) is an economically important fruit crop worldwide, whose production has increased steadily in recent decades (Milivojević et al., 2021; Milosavljević et al., 2021; Fotirić Akšić et al., 2019a). With an annual production of 22,427 t, Serbia is grouped among countries with low-intensive production. One of the important factors of highly intensive strawberry production is the introduction of new, promising cultivars well adapted to certain growing regions that are not only highly productive but also possess consistently high external (size, shape, color) and internal fruit quality traits (texture, taste, nutritional and health-promoting compounds). In recent years, public and private breeding activities have intensified greatly to provide growers with new cultivars that meet market needs (Simpson, 2014). The ultimate goal of numerous breeding programs in the world is to integrate new scientific knowledge from genetic, agronomic and biomedical studies (Mezzetti et al., 2016). These programs are expected to release new cultivars that are adapted to local conditions, have resistance to pathogens, and offer high productivity and fruit quality in terms of sweetness, flesh firmness, attractive appearance and long shelf-life (Meulenbroek et al., 2015; Martinez-Ferri et al.*,* 2014). Plant growth, phenological phases, productivity, fruit size and content of phytochemicals vary among strawberry genotypes, but also these traits can be affected by environment, cultivation techniques and postharvest conditions (Vittori et al., 2018; Tomić et al., 2018; Krüger et al., 2012).

On the other hand, producers still do not recognize the benefits of growing new strawberry cultivars selected for their bioactive potential. A huge number of scientific studies confirm the nutritional and health-promoting values of strawberry fruits based on a higher concentration of particularly potent phenolic compounds, which mainly include anthocyanins, flavonols, flavanols, phenolic acids (hydroxybenzoic/hydroxycinnamic acids) and ellagitannins (Milosavljević et al., 2021; Fotirić Akšić et al., 2019b; Manganaris et al., 2014; Milivojević et al., 2013; Giampieri et al., 2012; Panico et al., 2009). Their assessment is important for discovering new sources of natural antioxidants, and cultivars with abundant quantities of phenolic compounds should be promoted and consumed more frequently due to their health-promoting properties.

This study aimed to compare five newly released June-bearing strawberry cultivars bred in Italy (‘Quicky’, ‘Sandra’, ‘Lofty’, ‘Nadja’ and ‘Aprica’) to determine their vegetative growth, flowering and ripening time, yield potential, biometrical and nutritional/antioxidant fruit traits. The knowledge of the inter-cultivar variation of evaluated parameters could be used at a commercial level as an important criterion for the selection of new high-performing cultivars for certain growing conditions.

Material and Methods

The field study was conducted in the strawberry plantation located in the municipality of Šid (45°07' N, 19°13' E, 113 m a.s.l.) in 2021–2022. The temperate continental climate, with a mean annual air temperature of 10.7°C and a mean annual precipitation of 650 mm, is characteristic of the region. The soil consisted of a fine sandy loam, and had a pH of 6.8 and medium levels of all nutrients (10 mg P_2O_5 and 22 mg K_2O 100 g^{-1} of the soil). Cold stored plants of Italian June-bearing strawberry cultivars ('Quicky', 'Sandra', 'Lofty', 'Nadja' and 'Aprica') were planted on raised double beds covered with black polyethylene foil in July 2020 with a planting density of 44,440 plants per ha. Drip irrigation was used with two laterals per raised bed and emitters were spaced at a 10-cm distance. Plants were fertigated in accordance with crop requirements as previously reported by Tomić et al. (2018).

The trial was set up in a completely randomized design with 3 replications and 20 plants per replication for each cultivar. According to the UPOV Code for strawberries (2012), the following phenological properties were studied: beginning of flowering – 10% of flowers are open; end of flowering – when the petals have fallen from 90% of flowers; beginning of ripening – 10% of fruits are ripe and can be easily removed from the plant; end of ripening – date of the last harvest.

Vegetative traits were studied by measuring the number of branch crowns per plant, plant height (cm) and the number of leaves per rosette in both studied years using counting and standard morphometric methods.

Yield components, such as the number of inflorescences and fruits per plant, as well as yield per plant (g) were determined by counting inflorescences and fruits and weighing the harvested fruits from each plant. Yield per m^2 (kg) was calculated as the product of the number of plants per m^2 (4.4) and the yield obtained per plant.

Fruits were harvested in triplicate in the first (2021) and the second year (2022) after planting and evaluated for biometrical and chemical traits. At the second harvest, 20 fruits per replication (60 fruits per cultivar) were picked at the commercial maturity stage. The fruit fresh weight was measured by a technical scale with a sensitivity of ± 0.01 g (Acom JW-1, Korea). Two linear dimensions, height and width (in mm) of each fruit were measured using a digital caliper Prowin (China), while the ratio of the maximum height and width was presented as a fruit shape index. Previously frozen fruits of each replication were homogenized by liquid nitrogen to analyze soluble solids content (SSC), total acids (TAs), and vitamin C content, or further extracted in 80% methanol at a ratio of 1:3 (w/v) to determine total anthocyanins (TACY), total phenolic content (TPC), and total antioxidant capacity (TAC).

SSC was read by a digital refractometer (Pocket PAL-1, Atago, Japan) and the results were expressed as a percentage of dissolved solids in the fruit extract. Total acids in the samples were analyzed using a digital burette for titration of 0.1 M NaOH to the endpoint and the acidity was expressed as a percentage of malic acid equivalents. Vitamin C was measured by a reflectometer set (Merck RQflex, Merck KGaA, Germany) as described by Pantelidis et al. (2007) and the results were expressed as mg ascorbic acid per 100 g of fresh weight (mg 100 g^{-1} FW).

Spectrophotometric analyses of TACY, TPC and TAC were performed on Multiscan® Spectrum (Thermo Electron Corporation, Vantaa, Finland) using supernatants obtained by centrifugation at 10000×*g* for 10 min at 4°C. The modified pH differential absorbance method (Cheng and Breen, 1991) was used for TACY measurement with 0.025 M potassium chloride buffer at pH 1.0 and 0.4 M sodium acetate buffer at pH 4.5. The absorbance was read at 510 and 700 nm, and the results were expressed as micrograms of pelargonidin-3-glucoside (ε=17330 $L·mol^{-1}·cm^{-1}$) equivalents per 100 g of fresh weight (μg pg-3-g eq 100 g^{-1} FW).

TPC was determined using gallic acid (GA) as a standard solution (0 to 340 μg of GA mL^{-1}) for the calibration curve (Dragišić Maksimović and Živanović, 2012). Standards and samples were combined with 0.25 N Folin-Ciocalteu reagent and after 3 min of incubation at 22°C, 0.2 M sodium carbonate was added and additionally incubated for 60 min at 22°C. The absorbance was recorded at 724 nm and the results were expressed as milligrams of GA equivalent per gram of fresh weight (mg GA eq g^{-1} FW).

The TAC was measured by the ABTS method of Arnao et al. (1999). The results were expressed as milligrams of ascorbic acid equivalent per gram of fresh weight (mg AsA eq g^{-1} FW).

Statistical analysis

The data were processed by the Fisher model of variance analysis (ANOVA, F test) using the statistics software package STATISTICA version 8.0 (StatSoft, Inc., Tulsa, OK, USA). The analyses were performed in three replications per year and the obtained values were expressed as the means ± standard error. The significance of differences between factor levels was determined using the LSD test at the lowest significance level of $P \leq 0.05$.

Results and Discussion

Phenology of newly released June-bearing strawberry cultivars

The earliest flowering in 2021 was recorded for ‘Sandra’ (April 11), which also had the longest flowering period (32 days). Contrary to this, ‘Aprica’ began to flower the latest (April 25) with a duration of 28 days (Table 1). In the second year of trial, a similar beginning of flowering was observed among tested cultivars ranging from April 14 (‘Quicky’, ‘Sandra’ and ‘Nadja’) to April 15 (‘Lofty’ and

‘Aprica’). The shortest flowering period was observed for ‘Lofty’ (30 days), while the longest was for ‘Aprica’ (33 days), which also ended this phase the latest (May 17). Although the temperature is the primary factor determining strawberry phenology, day length often modifies temperature responses, and this effect can be taken into account to explain asynchronous flower production in two consecutive years (Li et al., 2018).

Table 1. Flowering and ripening time of newly released June-bearing strawberry cultivars in two consecutive years.

Cultivar	Year	Flowering time			Ripening time		
		Beginning	End	Duration (days)	Beginning	End	Duration (days)
Quicky	2021	April 12	May 12	31	May 15	June 10	27
	2022	April 14	May 14	31	May 13	June 1	20
Sandra	2021	April 11	May 12	32	May 15	June 8	25
	2022	April 14	May 14	31	May 14	June 3	21
Lofty	2021	April 18	May 14	27	May 17	June 8	23
	2022	April 15	May 14	30	May 14	June 3	21
Nadja	2021	April 12	May 8	27	May 18	June 12	26
	2022	April 14	May 14	31	May 15	June 3	20
Aprica	2021	April 25	May 22	28	May 20	June 16	28
	2022	April 15	May 17	33	May 19	June 8	21

The harvest in 2021 began early for ‘Quicky’ and ‘Sandra’ (May 15), while ‘Aprica’ started to ripen the latest (May 20). The ripening season lasted from 23 days (‘Lofty’) to 28 days (‘Aprica’). Some earlier beginning of harvest for one to three days was observed in the second year of the trial when ‘Quicky’ started to ripen earliest (May 13) and ‘Aprica’ was the latest (May 19). The duration of the ripening season was shorter, ranging from 20 days (‘Quicky’ and ‘Nadja’) to 21 days (‘Sandra’, ‘Lofty’ and ‘Aprica’). The accelerated ripening can be explained by the influence of higher temperatures during fruit maturation in 2022.

The vegetative potential of newly released June-bearing strawberry cultivars

In strawberry plants, a crown is a primary stem in which leaves, roots and runners are cyclically formed. Crowns consist of a variable number of internodes and terminate with an inflorescence (Savini et al., 2005). Branch crowns (secondary crowns) originate from the axillary meristem or lateral buds. After winter dormancy, several branch crowns per plant may develop from latent buds depending on climatic conditions and cultural practices (Sugiyama et al., 2004). Our study shows that the number of branch crowns per plant differed among the tested cultivars, whereby ‘Sandra’ and ‘Lofty’ expressed significantly higher values along with ‘Aprica’ in comparison with the other tested cultivars (Table 2). An increase in the number of branch crowns per plant was significant only for ‘Quicky’ and ‘Aprica’ in the second year of the trial ($P \leq 0.05$). Cultivars did not differ in terms of plant height, but this parameter was significantly affected by year ($P \leq 0.001$) and cultivar × year interaction ($P \leq 0.01$).

Table 2. The vegetative potential of newly released June-bearing strawberry cultivars in two consecutive years.

Factor			Number of branch crowns per plant	Plant height (cm)	Number of leaves per rosette
Cultivar (A)	Quicky		3.62±0.26b	33.2±2.84	28.0±2.27d
	Sandra		4.65±0.24a	34.2±2.07	41.5±4.18a
	Lofty		4.55±0.22a	34.1±1.31	33.2±1.86c
	Nadja		3.87±0.19b	34.6±1.45	33.8±2.38c
	Aprica		4.62±0.45a	33.6±0.83	37.5±1.89b
Year (B)	2021		3.84±0.14	30.5±0.60b	29.2±4.62
	2022		4.68±0.20	37.4±0.59a	26.7±1.70
A×B	Quicky	2021	3.13±0.30e	27.0±1.01d	29.2±4.62de
		2022	4.10±0.10cd	39.5±0.62a	26.7±1.70e
	Sandra	2021	4.30±0.00bcd	29.8±0.62cd	50.5±2.11a
		2022	5.00±0.40abc	38.6±1.20a	32.6±1.72bcde
	Lofty	2021	4.23±0.23bcd	31.5±0.39c	34.0±3.61bcde
		2022	4.87±0.30abc	36.7±1.33ab	32.3±1.88bcde
	Nadja	2021	3.87±0.30de	32.1±1.33c	37.6±3.64ab
		2022	3.87±0.30de	37.0±1.66ab	30.1±0.95cde
	Aprica	2021	3.67±0.20de	31.9±0.57c	35.1±1.44abc
		2022	5.57±0.30a	35.3±0.40b	39.8±3.21b
F test	Cultivar		**	ns	**
	Year		ns	***	ns
	Cultivar × year		*	**	**

Values within each column followed by the same letter are not significantly different at $P \leq 0.05$ (LSD test). *, **, ***Significant at P ≤ 0.05, 0.01 and 0.001, respectively; ns – not significant.

The number of leaves per rosette significantly varied among the cultivars, ranging from 28.0 (‘Quicky’) to 41.5 (‘Sandra’). This parameter was also significantly affected by the cultivar × year interaction, showing a significant decrease in the number of leaves per rosette only in ‘Sandra’ and ‘Nadja’ in the second year of the trial ($P \leq 0.01$). Leaves are one of the main organs for absorbing sunlight and influencing photosynthetic rates and growth. Recent studies have also highlighted that the number of leaves is strongly affected by genotype and environment; however, many other factors including the application of growth retardants and different fertilizers may also contribute to leaf development (Molano et al., 2021; Min Kim et al., 2019; Tomić et al., 2018).

Yield potential of newly released June-bearing strawberry cultivars

Productivity is usually an important trait that a producer takes into consideration when deciding to grow some new cultivars. Vittori et al. (2018) reported that plant yield is the amount of harvested commercial fruits for each production cycle. In our study, the number of inflorescences and fruits per plant was significantly higher in ‘Sandra’ (7.15 and 43.3, respectively), whereas the cultivar ‘Nadja’ had the lowest values regarding all parameters of yield potential (Table 3). On the contrary, the cultivar ‘Aprica’ was characterized by the highest productivity (1061 g/plant and 4.67 kg/m^2, respectively). As opposed to the obtained results, Capocasa et al. (2017) noted a much lower yield per plant for the cultivar ‘Aprica’ (652 g/plant) grown organically under a plastic tunnel in the Marche region of Italy, probably due to different climatic conditions and cultivation methods employed.

Table 3. Yield components of newly released June-bearing strawberry cultivars in two consecutive years.

Factor			Number of inflorescences per plant	Number of fruits per plant	Yield per plant (g)	Yield per m^2 (kg)
Cultivar (A)	Quicky		4.50±0.22c	27.1±0.98d	633±83.17c	2.78±0.50c
	Sandra		7.15±0.16a	43.3±1.85a	850±40.93b	3.74±0.25b
	Lofty		5.35±0.15b	31.6±2.48c	710±28.35c	3.12±0.17c
	Nadja		4.20±0.19c	22.3±1.51e	608±38.10c	2.68±0.23c
	Aprica		5.90±0.26b	38.9±2.53b	1061±52.69a	4.67±0.36a
Year (B)	2021		5.52±0.28	29.9±2.20b	801±48.1	3.53±0.31
	2022		5.32±0.33	35.3±2.28a	744±59.2	3.27±0.35
A×B	Quicky	2021	4.93±0.18	28.0±0.60d	808±42.05cd	3.56±0.25cd
		2022	4.07±0.13	26.1±1.88d	459±50.04g	2.02±0.29g
	Sandra	2021	7.13±0.29	41.6±3.33ab	926±40.57bc	4.07±0.24bc
		2022	7.17±0.20	44.9±1.80a	774±30.86cde	3.40±0.18cde
	Lofty	2021	5.40±0.31	26.3±0.41d	669±20.47def	2.94±0.13def
		2022	5.30±0.15	36.9±1.62bc	751±44.08de	3.30±0.26de
	Nadja	2021	4.40±0.35	19.2±0.92e	581±70.93fg	2.56±0.42g
		2022	4.00±0.12	25.4±0.95d	636±38.21ef	2.80±0.23ef
	Aprica	2021	5.73±0.52	34.6±3.52c	1023±81.37ab	4.50±0.65ab
		2022	6.07±0.18	43.2±1.10a	1099±76.16a	4.84±0.46a
F test	Cultivar		***	***	***	***
	Year		ns	***	ns	ns
	Cultivar × year		ns	*	**	**

Values within each column followed by the same letter are not significantly different at $P \leq 0.05$ (LSD test). *, **, ***Significant at P ≤ 0.05, 0.01 and 0.001, respectively; ns – not significant.

The number of fruits per plant in our study was significantly affected by year ($P \leq 0.001$) and cultivar × year interaction ($P \leq 0.05$), with higher values obtained for three strawberry cultivars (‘Lofty’, ‘Nadja’ and ‘Aprica’) in 2022. Apart from the differences in some yield potential parameters, most of the tested cultivars showed yield stability between two consecutive growing seasons which is in accordance with the findings reported by Choi et al. (2014). Unfortunately, there is a lack of information on how these newly released strawberry cultivars perform in terms of yield potential under field conditions.

Fruit quality traits of newly released June-bearing strawberry cultivars

Besides the agronomic performance of the strawberry cultivars, the biometrical and chemical fruit traits are also considered to be important factors generally related to consumers’ perception of fruit quality. Since fruit size has been considered one of the main components of the yield, larger fruits are preferred for the fresh market and they improve hand-harvesting efficiency.

In the present study, ‘Aprica’ and ‘Nadja’ were found to have significantly higher fruit weight (29.9 g and 27.8 g, respectively) than the other cultivars, among which ‘Sandra’ had the lowest value (20.3 g). This is the expected result, since this cultivar produced the highest number of fruits per plant and was the second most productive cultivar belonging to the group of small-fruited cultivars. Regarding all tested cultivars, the fruit shape index ranged from 1.15 (‘Aprica’) to 1.42 (‘Quicky’), corresponding to a conical and long conical shape, respectively. Fruit height did not differ between two consecutive years. However, significantly higher values for fruit weight and width accompanied by fruit shape index were registered in the first year of the trial ($P \leq 0.001$). Fruit weight and fruit height were not affected by the cultivar × year interaction, whereas the fruit shape index was significantly increased in the second year of the trial (Table 4).

Consumer acceptance of strawberries is highly dependent on sweetness, which is often correlated with a high SSC. A minimum of 7% SSC is considered the recommended standard for acceptable taste (Dragišić Maksimović et al., 2015). Among evaluated cultivars, ‘Lofty’ and ‘Sandra’ surpassed the SSC values of all other cultivars, whereas ‘Aprica’ had the lowest content (Table 5). Capocasa et al. (2017) also reported a very low SSC value (5.8%) for ‘Aprica’, grown organically under protected conditions in the Marche region of Italy.

In our study, significantly higher SSC values were found in 2021 in all cultivars except for ‘Aprica’, which showed the opposite trend. This cultivar also had the lowest total acid content (0.58%), which is in line with the recently published data of Capocasa et al. (2017). On the other hand, ‘Quicky’ was the predominant cultivar in terms of total acid content (0.62%), which was below the recommended maximum value of 0.8% for exceptional taste (Dragišić Maksimović et al., 2015).

Table 4. Biometrical fruit traits of newly released June-bearing strawberry cultivars in two consecutive years.

Factor			Fruit weight (g)	Fruit height (mm)	Fruit width (mm)	Fruit shape index
Cultivar (A)	Quicky		23.5±2.49b	47.7±0.66ab	33.9±1.30cd	1.42±0.06a
	Sandra		20.3±1.51c	41.9±0.77b	32.9±0.44d	1.27±0.02c
	Lofty		23.0±1.16b	47.0±0.74ab	35.0±0.79c	1.35±0.02b
	Nadja		27.8±1.46a	49.2±0.70a	37.9±0.59b	1.30±0.01bc
	Aprica		29.9±1.37a	47.0±0.95ab	41.2±0.85a	1.15±0.01d
Year (B)	2021		27.8±1.08a	46.9±0.87	37.7±0.84a	1.25±0.02b
	2022		22.0±1.16b	46.2±0.72	34.6±0.88b	1.35±0.03a
A×B	Quicky	2021	28.8±1.33	47.4±0.79	36.7±0.47c	1.30±0.03c
		2022	18.2±1.01	47.9±1.22	31.0±0.38e	1.55±0.02a
	Sandra	2021	22.6±2.14	41.0±0.38	33.5±0.22d	1.23±0.01d
		2022	17.9±1.23	42.7±1.46	32.3±0.79de	1.32±0.01c
	Lofty	2021	25.5±0.44	48.0±1.02	36.6±0.52c	1.31±0.03c
		2022	20.4±0.47	45.9±0.81	33.3±0.17d	1.38±0.03b
	Nadja	2021	30.0±2.24	49.2±1.52	38.8±0.88 b	1.28±0.02cd
		2022	25.5±0.71	49.1±0.35	36.9±0.23c	1.33±0.00c
	Aprica	2021	31.9±1.37	48.6±0.55	42.6±0.82a	1.14±0.01e
		2022	27.9±1.92	45.5±1.32	39.7±0.91b	1.16±0.02e
F test	Cultivar		***	***	***	***
	Year		***	ns	***	***
	Cultivar × year		ns	ns	*	***

Values within each column followed by the same letter are not significantly different at $P \leq 0.05$ (LSD test). *, *** Significant at $P \leq 0.05$ and 0.001, respectively; ns – not significant.

The nutritional value of strawberry fruit is also influenced by the content of vitamin C (Milosavljević et al., 2021; Milivojević et al., 2013; Capocasa et al., 2008). Significantly higher vitamin C content was recorded in ‘Sandra’ and ‘Aprica’ (36.0 and 36.4 mg 100 g-1 FW, respectively) in comparison to the other cultivars analyzed. These results confirm a previous finding of Milosavljević et al. (2021), who determined the range of vitamin C content from 32.27 to 56.32 mg100 g-1 FW in various strawberry cultivars.

The red color of the fruits can be attributed to high content of anthocyanins, which also have a strong antioxidant capacity (Milosavljević et al., 2021; Milivojević et al., 2013; Scalzo et al., 2005; Wang et al., 1997). The highest quantity of total anthocyanins (TACY) in this study was found in ‘Sandra’ with a value of 24.4 mg pg-3-g eq 100 g-1 FW, followed by ‘Quicky’ (21.5 mg pg-3-g eq 100 g-1 FW), whereas significantly lower TACY content was recorded in ‘Aprica’ (13.8 mg pg-3-g eq 100 g-1 FW). The anthocyanin concentrations obtained herein were similar to those previously reported by Milosavljević et al.

(2020). However, TACY was significantly affected by year and cultivar × year interaction contributing to a greater accumulation of TACY in the second year of the study for all cultivars tested. Kalt et al. (1999) also confirmed that the anthocyanin content of a single cultivar may differ by 30% between two seasons. In addition to the genetic background and its interaction with climatic factors, cultivation techniques and the site can also strongly influence anthocyanin content in strawberries (Vittori et al., 2018).

Table 5. Chemical fruit traits of newly released June-bearing strawberry cultivars in two consecutive years.

Factor			Soluble solids (%)	Total acids (%)	Vitamin C (mg 100 g^{-1} FW)	TPC (mg GAE eqg^{-1} FW)	TACY (mg pg-3-g eq 100 g^{-1} FW)
Cultivar (A)	Quicky		9.00±0.15c	0.62±0.01a	34.1±1.02b	1.20±0.08ab	21.5±1.81b
	Sandra		9.80±0.07a	0.59±0.02c	36.0±0.34a	1.04±0.06d	24.4±2.32a
	Lofty		9.87±0.10a	0.60±0.02bc	33.2±0.47b	1.29±0.15a	19.5±2.23bc
	Nadja		9.22±0.09b	0.61±0.01b	34.0±0.43b	1.16±0.18cd	18.2±1.43c
	Aprica		8.40±0.30d	0.58±0.01d	36.4±0.74a	1.10±0.19cd	13.8±0.70d
Year (B)	2021		9.29±0.22	0.62±0.01a	35.7±0.45a	0.88±0.04b	22.4±1.58a
	2022		9.22±0.11	0.58±0.00b	33.7±0.42b	1.44±0.05a	16.6±0.61b
A×B	Quicky	2021	9.33±0.09c	0.65±0.00a	36.3±0.38	1.02±0.05cd	24.2±2.89b
		2022	8.67±0.03e	0.59±0.00c	31.9±0.50	1.38±0.04b	18.7±0.69cd
	Sandra	2021	9.93±0.03a	0.63±0.00ab	36.6±0.43	0.94±0.05de	29.3±1.26a
		2022	9.67±0.07	0.56±0.01d	35.4±0.17	1.14±0.08c	19.5±0.90c
	Lofty	2021	10.07±0.09a	0.64±0.00b	33.9±0.63	0.97±0.01cd	24.3±1.30b
		2022	9.67±0.03b	0.57±0.00d	32.5±0.39	1.61±0.10a	14.70.52±e
	Nadja	2021	9.40±0.00c	0.63±0.00b	34.6±0.60	0.77±0.06ef	21.3±0.83bc
		2022	9.03±0.09d	0.59±0.01c	33.4±0.43	1.54±0.04ab	15.1±0.13de
	Aprica	2021	7.73±0.07f	0.58±0.00c	37.4±1.33	0.70±0.06f	12.7±0.85e
		2022	9.07±0.03d	0.57±0.01d	35.5±0.30	1.51±0.09ab	14.8±0.80e
F test	Cultivar		***	***	***	**	***
	Year		ns	***	***	***	***
	Cultivar × year		***	***	ns	**	***

Values within each column followed by the same letter are not significantly different at $P \leq 0.05$ (LSD test). **, *** Significant at $P \leq 0.01$ and 0.001, respectively; ns – not significant.

Among the tested cultivars, 'Lofty' was dominant in total phenolic content (1.29 mg GAE eq g^{-1} FW). In general, TPC values were much higher than those previously reported by Milosavljević et al. (2021). Mean TPC values differed between two consecutive years with a significant increase in the first year as opposed to the trend observed for TACY content. In this context, Dragišić Maksimović et al. (2015) explained that anthocyanin concentrations are more susceptible to changes than the phenolics during fruit storage mainly due to their degradation.

Strawberries are known to possess a high total antioxidant capacity (TAC), with wide variability among different cultivars (Milosavljević et al., 2021). A significant variation in TAC values among the tested cultivars was found only in the second year of our study, where 'Aprica' dominated (1.68 mg AsA eq g^{-1} FW) (Figure 1), probably due to the contribution of vitamin C (Table 5).

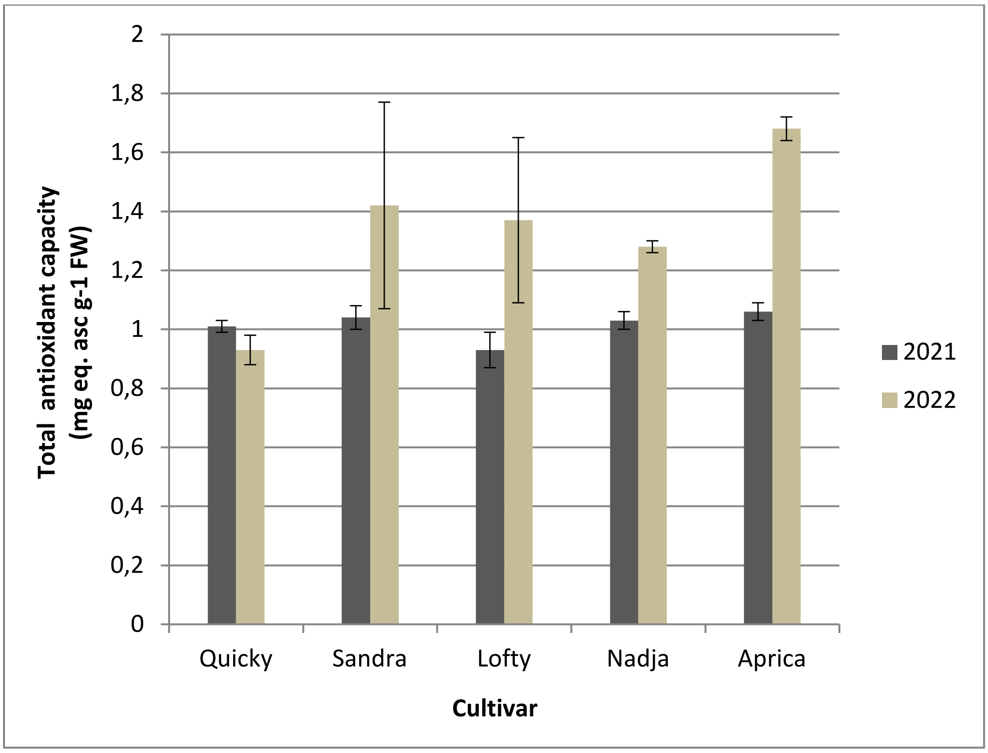

Figure 1. Comparison of total antioxidant capacity among newly released June-bearing strawberry cultivars in two consecutive years.

Slightly lower TAC values were registered in 'Sandra' and 'Lofty' (1.42 and 1.37 mg AsA eq g^{-1} FW, respectively). As previously reported, the range of TAC values in most of the tested cultivars appeared to be lower than the values previously published by Milosavljević et al. (2021), except for 'Aprica', which showed up to three-fold higher antioxidant activity in our study. This discrepancy may be attributed to the adaptability of these cultivars to various climatic conditions among the years of study, locations and production cycles.

Conclusion

A comparative study of five newly released June-bearing strawberry cultivars reveals great variability in agronomic and nutritional fruit properties, reflected in the earlier ripening time of ‘Quicky’ and ‘Sandra’, the higher productivity and larger fruits rich in vitamin C in ‘Aprica’, as well as in the superior nutritional quality of ‘Lofty’ and ‘Sandra’. The latter cultivar had significantly lower average fruit weight (20.3 g) in comparison with the other cultivars, which is the expected result since it produced the highest number of fruits per plant and was therefore the second most productive, classified in the group of small-fruited cultivars. Contrary to this, ‘Nadja’ had the lowest values regarding all yield potential parameters. Most of the tested cultivars showed yield stability between two consecutive growing seasons, except for ‘Quicky’ which had an almost twice lower yield in the second experimental year (459 g/plant). Fruit weight and fruit height were not affected by the cultivar × year interaction, whereas the fruit shape index was significantly increased in the second year of the trial. The cultivars ‘Lofty’ and ‘Sandra’ surpassed the SSC found in all other cultivars (9.87 and 9.80%, respectively), while ‘Quicky’ was the predominant cultivar in terms of total acids (0.62%). The highest quantity of TACY was found in ‘Sandra’ (24.4 mg pg-3-g eq 100 g^{-1} FW), followed by ‘Quicky’ (21.5 mg pg-3-g eq 100 g^{-1} FW), whereas ‘Lofty’ was dominant in TPC (1.29 mg GAE eq g^{-1} FW). Mean TPC values significantly increased in the first year as opposed to the trend observed for TACY content indicating that anthocyanin concentrations were more susceptible to changes than those of other phenolics due to the specific influence of climatic factors between the years. The comprehensive knowledge of the referred variability among the tested cultivars could serve as an important criterion for the selection of new high-performing cultivars for certain growing conditions.

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POREĐENJE PROIZVODNIH PERFORMANSI I KVALITETA PLODA IZMEĐU NOVOSTVORENIH ITALIJANSKIH JEDNORODNIH SORTI JAGODE

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R e z i m e

Ovaj rad prikazuje rezultate ispitivanja fenologije, produktivnosti i kvaliteta ploda novostvorenih jednorodnih sorti jagode („kviki", „sandra", „lofti", „nadja" i „aprika") poreklom iz Italije sa ciljem prepoznavanja njihovog potencijala za širi uzgoj. Istraživanja su izvedena u plantažnom zasadu jagode koji je podignut u julu 2020. godine u blizini Šida (Srbija). Primenjen je dvoredni sistem gajenja na gredicama prekrivenim crnom polietilenskom folijom. Tokom perioda 2021–2022. godina, ispitivani su: vreme cvetanja i zrenja, komponente prinosa, vegetativni rast, kao i biometrijska i nutritivna svojstva ploda (sadržaj rastvorljive suve materije, ukupnih kiselina, vitamina C, ukupnih antocijana, ukupnih fenola i antioksidativni kapacitet ploda). Najraniji početak zrenja imala je sorta „kviki", dok je najkasniji registrovan kod sorte „aprika" u obe eksperimentalne godine. Broj krunica po bokoru je bio značajno veći kod sorti „sandra" i „lofti", pri čemu je sorta „sandra" takođe imala i najveći broj listova u rozeti (41,5) u poređenju sa ostalim ispitivanim sortama. Sorta „aprika" je imala najveću produktivnost (1061 g/biljci i 4,67 kg/m^2), krupnoću ploda (29,9 g) i indeks oblika ploda (1,15). Suprotno tome, najniži rodni potencijal utvrđen je kod sorte „nadja" (608 g/biljci i 2,68 kg/m^2). U pogledu sadržaja rastvorljive suve materije najviše rangirane su bile sorte „lofti" i „sandra", koje su se karakterisale i značajno višim sadržajem ukupnih fenola (1,29 mg ekv. galne kis. g^{-1} sveže mase ploda) i ukupnih antocijana (24,4 mg ekv. pg-3-g 100 g^{-1} sveže mase ploda). Ustanovljena variabilnost među ispitivanim sortama bi mogla biti korišćena kao važan kriterijum za odabir novih sorti visokih performansi za određene uslove gajenja.

Ključne reči: jagoda, sorta, vegetativni rast, vreme zrenja, produktivnost, kvalitet ploda.

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THE WAY SERBIAN RAKIJA DISTILLERS EVALUATE THE QUALITY AND MARKET POSITION OF THEIR SPIRITS

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Abstract: This research aims to answer questions regarding how Serbian distillers evaluate the quality of their products and their chances on the market. The author also intends to determine the number of market segments for rakija, the Serbian national spirit. As this is the first known study of distillers and the economics of rakija production in Serbia, this research will be exploratory in nature. A quantitative survey of professional and hobbyist rakija distillers (N = 104) was conducted online in October 2021, which means that at the 95% probability level, the sampling error is below 10%. Rakija distillers rated the quality of their rakija as relatively high – 7.88 out of 10, while, conversely, they rated the market situation as relatively low – 2.67 out of 7. They are very enthusiastic about their future market prospects – 4.19 out of 7, but with current business approaches and their outdated production methods, their future does not look bright. It has been found that the rakija market in Serbia has three segments in terms of price: low-priced (up to 500 dinars), mid-priced (between 501 and 1000 dinars), and high-priced (1001 dinars and above). The median, or medium price of all rakija in our sample, was 750 dinars. Finally, a feasible strategy for the rakija market was synthesized by the SWOT/TOWS analysis. The research findings will be useful not only for distillers, but also important for agricultural policymakers as stricter standards need to be introduced to ensure rakija quality.

Key words: rakija, spirits, product quality, market position, segmentation, distillers.

Introduction

Rakija (also known as rakia or schnapps) is a spirit-based beverage. Article 6 of the Serbian Law on Rakija and Other Alcoholic Beverages, *Official Gazette of RS*, No. 41/09, defines rakija as an alcoholic beverage produced by distilling fermented crushed fruit, pressed fruit, pomace or fruit marc, grapes, edible forest fruits, and other raw materials of agricultural origin with a minimal ethanol content

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of 15% v/v and with preserved specific sensory properties derived from the raw material from which it was produced. It is considered to be a traditional (Nikićević, 2021) and culturally endorsed national Serbian beverage, especially šljivovica (also known as slivovitz), which is a plum spirit or plum brandy, although other types of fruit spirits are also regularly distilled. Other southern and eastern European countries also produce spirits and consider them part of the national culture. Moreover, consumers continue to value regional origin (Schamel, 2009). Almost every culture has a long history of using and producing alcoholic drinks (McGovern, 2009). The harmful use of alcohol is increasingly recognized by public health authorities as a global public health problem of major concern. The harmful use of alcohol is responsible for an estimated 3 million or 5.3% of all deaths worldwide (World Health Organization, 2020). An estimated 95,000 fatalities in the United States are caused by excessive alcohol consumption each year, making it a leading cause of preventable death (Esser et al., 2020). However, in Serbia, the impact of alcohol abuse on life expectancy does not appear to be significant. Eliminating alcohol mortality resulted in only 0.63 years for men and only 0.15 years for women in Serbia (Marinković, 2020). The cultural pattern of alcohol consumption does not confirm that this mortality factor represents a significant burden amongst the general Serbian population.

The alcoholic consumption pattern in Serbia has a southern European or Mediterranean alcoholic consumption origin. It entails frequent but moderate alcohol consumption, which is nearly always limited to mealtimes and enjoyed among family and friends. These patterns of alcohol consumption have long been linked to a low risk of alcohol abuse (Agnoli et al., 2018). Serbs consume rakija either with meze, a selection of small dishes served as appetizers, or immediately prior to the main meal. The Mediterranean style of consuming wine and fruit spirit along with food is often held up as an example of responsible alcohol consumption, in contrast to the harmful habits of alcohol consumption more prevalent in northern Europe, where such drinks as beer and vodka are typically consumed without food. Unfortunately, this harmful style of alcoholic consumption is prevalent throughout the world, because vodka is the most commonly consumed drink worldwide. Despite competition from alternative alcoholic beverages such as beer and local cultural drink specialties, as well as competitive pressures within the industry, vodka remains the best-selling alcoholic spirit in the world (Musonera and Hemley, 2008). The United States alone consumes half of all vodka distilled.

Over the past four decades, the alcoholic beverage sector has undergone two significant changes (Mosher, 2012). Between 1970 and 1997, beer became the most popular beverage. Young people were mainly responsible for the beginning of this trend. In the late 1990s, young people’s taste in beverages changed again, the growth of beer leveled out, and the distilled spirits business exploded. Youth marketing innovation was causal to this shift in the distilled spirits industry.

Furthermore, according to a study (Carew et al., 2017), the alcoholic beverage market is segmented into numerous price categories. The findings reveal two red wine segments and three white wine segments.

However, it seems that marketing creativity and innovations in the distilled spirits industry are not adequately supported by academic research. There are just a handful of respected journals that cover the marketing strategies used by the alcoholic beverage industry. Most academic papers focus on wine marketing (Lockshin and Corsi, 2012). A considerable amount of the associated research has employed unrepresentative and small samples. Simultaneously, other studies addressed the same or similar issues in different countries, regions, or time periods. Martinho (2021) examined the scientific literature on wine marketing. In the Web of Science, 87 studies were found, while 127 studies were found in Scopus (with 34 papers duplicated).

We have noticed that only a handful of academic papers have been published relating to the market challenges of the Serbian national alcoholic spirit rakija, and that among them, to the best of our knowledge, there is not a single quantitative study on rakija distillers and their market position and prospects. With this work, we fill this perceived gap, which is especially important considering that the UNESCO World Heritage List has recently been expanded. Namely, at the end of 2022, the Serbian plum rakija šljivovica was added to the list of intangible cultural heritage UNESCO under the name "Social practices and knowledge related to the production and use of traditional plum brandy – šljivovica". In this contribution, for the first time, one can learn about the strength of the rakija that is put on the market. We found its achieved average price, as well as the unenviable position of distillers who have significant surpluses of goods, but also unrealistic expectations of their rakija business. We assume that the prestigious UNESCO status of the Serbian national alcoholic beverage and our contribution to this field will stimulate further research on this neglected national treasure, which is highly valued emotionally in Serbia but neglected commercially.

The distilled spirits industry in Serbia

In 2019, the global whiskey market was worth $62 billion (Facts and Factors, 2020). With an estimated market growth of 6.5% (Facts and Factors, 2020), the market will be worth over $100 billion by 2027. It is estimated that about 50 million liters of rakija are produced in Serbia (Agroklub, 2019), and that about 80% of the market is illegal (Business and Finances, 2021). Over 600 producers are officially registered (Politika Online, 2019), and 2,823 tons of spirits worth $14.5 million are exported (and even more imported) (Info Press, 2020); this is a trivial 0.000000000233 (2.33×10^{-10}) value of the whiskey market. Moreover, the value of imports of alcoholic beverages is higher than the value of exports.

The cause of the poor position of rakija producers in the market is the "I do the same as my grandfather" attitude, who did not sell rakija but mostly drank it himself and gave it to friends; the grandfathers distilled superior plum varieties for rakija than those distilled today and did not use sugar in the production, only fruit (Adžić, 2021). The only thing that is similar today is that such producers who produce poor-quality rakija cannot surpass their grandfathers, and also make such products that basically no one will buy. The average retail price of rakija in Serbia is 586,66 dinars (Statistical Office of the Republic of Serbia, 2020), and industrial rakija made from ethanol and blended with artificial flavors rather than fruit dominates the market. In comparison, according to the same official statistics, the average prices per liter in dinars for other alcoholic beverages are 108.82 for lager beer, 261.76 for wine, and 832.49 for rakija, distilled from wine. Josif Vacić (2016) and the Ethnographic Museum organized the exhibition "Make and drink rakija". The exhibition materials describe very realistically the history of rakija in Serbia. It is obvious that, historically, there has been no "golden" period for rakija in Serbia. Until the appearance of phylloxera in the 1890s, grapes were mostly grown and wine was consumed in Serbia. With the extinction of vineyards, Serbs reoriented to plum, which is still the most common fruit in Serbia. They also made rakija from plums, but it did not look like today's beverages. It was drunk from larger glasses than wine, and had a lower alcohol percentage than wine (Vacić, 2016). Drinking a distilled drink with a lower percentage of alcohol was common throughout the region as protection against cholera due to contaminated water. Plums were not commonly used for rakija, but there were more profitable ways to earn money from the former. At the beginning of the 20th century, they were exported as jam in barrels, and then as prunes. The foreign market and consumers were looking for pitted prunes, but Serbia did not supply them. The unwillingness to change established patterns of behavior and adopt successful business methods has led to the plum rakija. This is, therefore, the third reserve, an obvious urgent choice that did not contribute to an increase in plantings, and the export results were far from the previous ones. When Alembic distillation was widely used worldwide, so-called peasant pots made of mud and wood were used in Serbia, and the rakija produced was far from what might be considered "good quality". In addition, rakija was distilled in winter when there was no work in the countryside. The fermented fruit mash for rakija, which stood for a long time, did not contribute to the quality; on the contrary, it harmed it. Although Serbia became a part of the former Yugoslavia after the First World War, it remained impossible for such a low-quality rakija to succeed in the then larger market. The use of the Alembic method spread across Serbia after the Second World War, but the socialist system stifled any private initiative. Today, in addition to the 600 registered distilleries in the country, there are tens of thousands of distillation pot stills operated by small producers. It is obvious that rakija has never been a profitable business in Serbia.

Even today, when Serbia is among the top five countries in plum production, Serbian exports of plums and plum products are essentially insignificant (Matković, 2015). It is perhaps not surprising, therefore, that the areas under plum cultivation in Serbia are decreasing (Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia, 2019).

Finally, there are a number of questions to answer: what is Serbian plum rakija, what plum varieties is it made from, is there a standardized production procedure, yeast, pot still, is it stored in a barrel or a glass balloon, and how long is it typically aged? There are no standards in the industry and, significantly, no legislation. It is well known what cognac is made from, not only what grape variety, but also where the grapes were harvested. Plum rakija is a drink made from plums by a Serb, even if that Serb happens to live in Australia, and it seems completely irrelevant from which plums and by what method. This is neither a guarantee of quality nor a basis for building a brand. Today, in Serbia, consumable plum varieties, which are not suitable for rakija production, predominate. Požegača, the most famous Serbian plum variety with ideal distillation potential, has almost become extinct in the country (Matković, 2015). The plum rakija made by small producers also contains certain unwanted chemicals, of which methanol is of particular concern (Nikićević and Tešević, 2005). Šljivovica of undefined quality has no chance of being suitable for export, which is why Adžić (2021) suggests that producers turn to quince. There are many quality plants, and rakija has a better price. Quince is an industrial fruit for which there are not many alternative uses.

Kentucky, the home of bourbon, has almost ten times fewer distilleries (73) than Serbia, and produces two barrels of finished product per capita (Louisville Business First, 2018), that is 20 times more than the amount of rakija produced in Serbia. Can Serbia catch up with at least half, or even a quarter of bourbon production?

Material and Methods

The aim of this research is to answer the questions of how Serbian distillers might evaluate the quality of their products and what chances they have to sell them on the market. The quantitative part of the research was conducted in October 2021 in two Facebook groups, "Rakija i Rakijaši – original" and "Rakija i Rakijaši". The goal of these groups is to gather hobbyists and professionals in a joint effort to produce top-quality rakija by combining traditional and modern technical-technological procedures. Accordingly, the sample was intentional and was formed by those who distill rakija, whether professionally or as hobbyists. These groups, together, have about 50,000 members. The responses were collected electronically via a questionnaire created using Google Forms. The questionnaire consisted of 70 questions. The length of the questionnaire was conditioned by the fact that this is the first research to be conducted on this topic in Serbia. Participation in the study was voluntary and anonymous. The pilot survey was conducted in October 2021. The pilot survey showed that it was necessary to significantly simplify the questions in order to be understood by potential respondents, who were mostly rural farmers unfamiliar with technical terms. In the main study, responses were collected from 104 respondents (N = 104). The data were analyzed using IBM SPSS Statistics (Version 25).

Being the first research on distillers and, indeed, the first research on the rakija market in Serbia, this research effort was exploratory in nature. The following research question was posed: What can we conclude from the perception of Serbian rakija producers about the quality of their spirits and their market position and perspective? Another intention was to determine the number of market segments for rakija in terms of price, based on the results of previous surveys, official statistics and the results of this survey.

Results and Discussion

The answers were given by 104 respondents, which means that at the 95% probability level, the sampling error is 10%. This means that in the group of brandies, the results will be valid for 95 out of 100 brandies, and that the accuracy of the results may vary by 10% (more precisely, 9.6%) according to the formulas for determining the sample size for research activities (Israel, 2013; Krejcie and Morgan, 1970). There was only one female respondent in the sample. Furthermore, 79.8% of the respondents are employed. The majority of distillers have completed high school (34.6%) and are between 40 and 49 years old (34.6%). Every year, the respondents make rakija, most of them alone (59 respondents). In addition, 45% of distillers use only their own fruit as raw material, while 35% supplement the missing quantities with purchased fruit. Only one fifth of the distillers buy the entire amount of fruit as raw material on the market. Moreover, 77, or three-quarters, of the respondents own a pot still. The most common is a copper pot sill with a volume of 100 liters, varying in size from 35 to 1000 liters. Only 19 distillers have plants that have been specially built for distillation, while 26 have adapted facilities. Twenty-two respondents placed the pot still in an unconditional facility, and most respondents in the sample, as many as 38, do not have a dedicated facility, effectively distilling rakija in their backyards. Out of 104 respondents, only eight stated that they were engaged in rakija distillation as a professional activity and had a registered distillery but were responsible for as much as 59% of the total quantity of rakija produced. Of these eight, only three distilleries employ additional workers.

Table 1. Descriptive statistics.

	N	Minimum	Maximum	Total	Average
Approximately how many liters of rakija do you distill from all fruits per year?	104	4	25000	106,694.00	
How strong is your rakija in the percentage of alcohol?	102	30	57		44.25
If your rakija is distributed to retail outlets, what are the quantities in liters per year?	5	20	1250	2,470.00	
If your rakija is distributed to restaurants and bars, what are the quantities in liters per year?	11	10	3500	11,710.00	
If you sell rakija, how many liters of rakija do you sell per year from all fruits?	40	20	10000	43,450.00	
If you sell rakija, how many liters of rakija do you sell with an excise stamp, in liters per year?	27	0	4000	12,402.00	
If you sell rakija, what is the average price per liter in dinars?	45	380	3900		950.78
Do you sell plum rakija and how many liters per year?	39	20	20000	37,655.00	
Do you sell plum rakija and at what price per liter in dinars?	38	400	3000		826.32
How old is the largest amount of old plum rakija you put up for sale?	18	2	20		5.06
Do you sell old plum rakija (2–5 y.o.) and how many liters per year?	16	20	20000	26,370.00	
Do you sell old plum rakija (2–5 y.o.) and at what price per liter in dinars?	18	500	5000		1,297.22
Do you sell very old plum rakija (6+ y. o.) and how many liters per year?	15	3	1000	4,286.00	
Do you sell very old plum rakija (6+ y.o.) and at what price per liter in dinars?	14	500	12000		2,650.00
How old is the oldest plum rakija you have for sale?	18		47		9.28
Do you sell quince rakija and how many liters per year?	25	10	2000	8,845.00	
Do you sell quince rakija and at what price per liter in dinars?	26	800	3600		1,507.69
Do you sell grape rakija and how many liters per year?	19	10	3000	5,500.00	
Do you sell grape rakija and at what price per liter in dinars?	20	380	1300		670.50
Do you sell apricot rakija and how many liters per year?	17	10	3000	6,385.00	
Do you sell apricot rakija and at what price per liter in dinars?	18	800	2500		1,455.56
Do you sell pear rakija and how many liters per year?	26	20	2000	8,450.00	
Do you sell pear rakija and at what price per liter in dinars?	28	800	3900		1,375.00
Do you sell apple rakija and how many liters per year?	18	10	2500	7,980.00	
Do you sell apple rakija and at what price per liter in dinars?	17	400	1700		682.35
Do you sell special rakija (with therapeutic herbs) and how many liters per year?	5	20	100	265.00	
Do you sell special rakija (with therapeutic herbs) and at what price per liter in dinars?	5	600	1800		1,000.00
Do you sell rakija of some other fruit and how many liters per year?	4	10	150	310.00	
Do you sell rakija of some other fruit and at what price per liter in dinars?	4	700	1350		962.50
How would you rate the quality of your brandies? Give a rating from 1 (worst) to 10 (best).	104	5	10		7.88
How would you rate your current market position? Give a rating from 1 (weakest) to 7 (strongest).	85	1	7		2.67
How would you rate your future market opportunities? Give a rating from 1 (weakest) to 7 (strongest).	85	1	7		4.19

Eleven producers do not perform double distillation, which is a traditional guarantee of quality, and only one admitted to using artificial flavors. The aging of rakija in barrels is practiced by 30% of producers, the same percentage of producers use barrels, although not for all quantities, while the remaining 40% do not use barrels for aging purposes. Of those who use barrels, 95.3% use oak barrels. Although 98 producers have never teamed up with other producers, 60 would like to do so. Furthermore, 83.7% of producers distill plums, 50% grapes, 46.2% quinces, 45.2% pears, 44.2% apples, and 35.6% apricots. Other fruits, such as peaches, raspberries, cherries, sour cherries, figs, pineapples, bananas, oranges, and mangoes are used in much smaller quantities though only sporadically. Rakija is also produced from prunes and raisins, as well as from honey, wine, and wine lees, but only in small quantities.

The 104 distillers produce 1,069.40 hectoliters of rakija annually with an average strength of 44.25%, a slightly higher percentage of alcohol (Table 1). Of this amount, two-fifths or 434.50 hl are sold at an average price of 950.78 dinars. The average price of the products from the eight professional distilleries is 1,220 dinars, but as this price includes excises and taxes, the net selling price is actually less than a thousand dinars. Only 40 of the 45 rakija producers actually sold their products. Twenty-seven rakija producers sold their product legally, i.e., with an excise stamp. Plum rakija is the most frequently produced, with almost 380 hl per year. Rakija made from other fruits is produced in quantities of less than 100 hl/year, namely, in descending order, quince rakija (88 hl/year), pear rakija (84 hl/year), apple rakija (80 hl/year), apricot rakija (64 hl/year), and grape rakija (55 hl/year). The amount of rakija available for sale from the given fruits was determined to be 753.90 hl. This figure is 73.5% higher than the result of the direct survey on sales quantities. The oldest plum rakija offered on the market is 47 years old and has a price point of 100 euros.

All respondents rated the quality of their rakija, with an average score of a strong 7.88. Despite the fact that the scores ranged from 1 to 10, no producer considered their rakija to be bad, as none gave a score of less than 5 (Figure 1). On a scale of 1 to 7, 85 respondents assessed their current market prospects to be relatively poor, giving them a low score of 2.67 (Figure 2). However, they were considerably more positive in their assessment of future market prospects, awarding a high score of 4.19 (Figure 3).

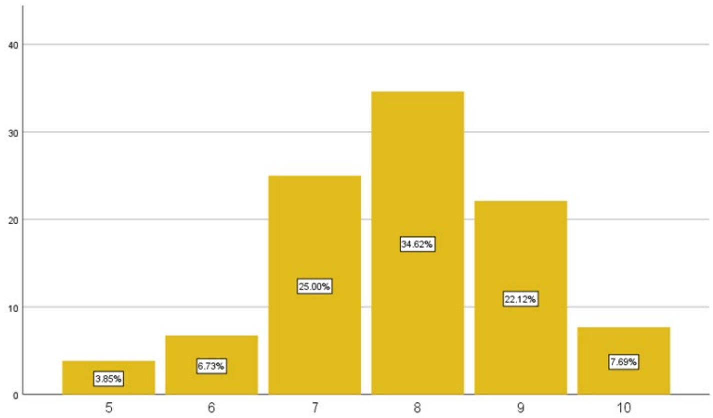

Figure 1. How would you rate the quality of your rakija, on a scale of 1 to 10? (N=104).

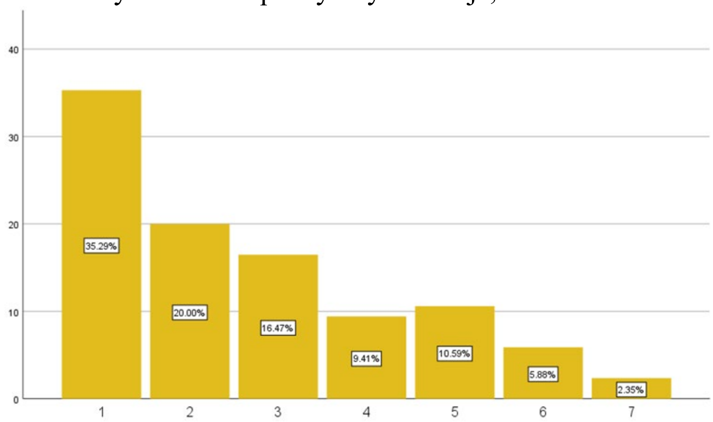

Figure 2. How would you rate your current market position, on a scale of 1 to 7? (N=85).

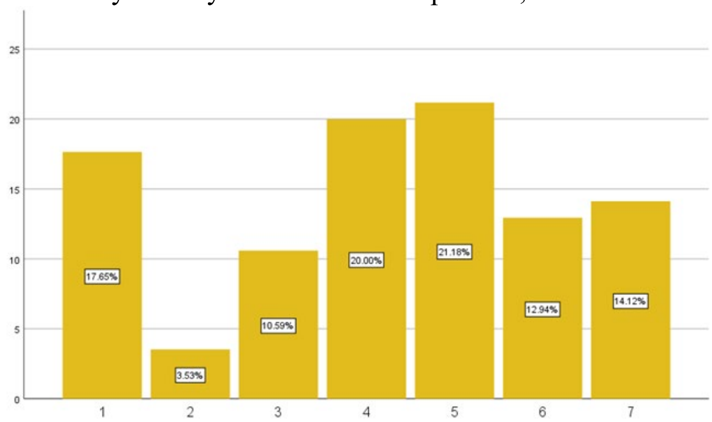

Figure 3. How would you rate your future market opportunities,
on a scale of 1 to 7? (N=85).

The following table of price statistics (Table 2), which presents an analysis of the prices of rakija produced from various fruits, shows the median as well as the mean. When the number of responses is disproportionately higher on one side of the curve, the median deviates significantly from the mean. In this case, it is thus more appropriate to use the median. The median, in this case, can be called the medium price, because it is the price that separates the first half of the set from the second. The median, or medium price of all rakija in our sample, is 750 dinars. This means that half of the respondents in the sample sell rakija for less than 750 dinars, while the other half sells for more. The medium price of the national spirit šljivovica is lower than the medium price for all brandies, both for the young (less than 2 years old) šljivovica (600 dinars per liter) and the old (2+ years old) šljivovica (675–700 dinars per liter). The median prices of apple brandies (500 dinars), grape brandies (600 dinars), and special brandies with therapeutic herbs (700 dinars) are all below average. Pear rakija (1,200 dinars) and apricot rakija (1,200 dinars) are well above the average price level (1,400 dinars). Quince rakija has the best price, with a median of 1,500 dinars per liter, which is double the average price of all brandies (approximately 12 euros). Table 2 also shows the price range of the various brandies, from the lowest to the highest price.

Table 2. Price statistics for various kinds of brandies.

		Mean	Median	Std. dev.	Minimum	Maximum	
						Valid	Missing
If you sell rakija, what is its average price (din/l)?	951	750	674	380	3900	45	59
What is the average price of plum rakija (din/l)?	826	600	525	400	3000	38	66
What is the average price of old plum rakija (din/l)?	1297	700	1169	500	5000	18	86
What is the average price of very old plum rakija (din/l)?	2650	675	3754	500	12000	14	90
What is the average price of quince rakija (din/l)?	1508	1500	556	800	3600	26	78
What is the average price of grape rakija (din/l)?	671	600	249	380	1300	20	84
What is the average price of apricot rakija (din/l)?	1456	1400	509	800	2500	18	86
What is the average price of pear rakija (din/l)?	1375	1200	671	800	3900	28	76
What is the average price of apple rakija (din/l)?	682	500	368	400	1700	17	87
What is the average price of special rakija with herbs (din/l)?	1000	700	505	600	1800	5	99
What is the average price of rakija from other fruits (din/l)?	963	900	287	700	1350	4	100

Finally, the influence of rakija prices on market segmentation was investigated using a one-way between-groups analysis of variance. According to their price range, the segments were classified into three groups (1 – Low segment: 500 dinars or less; 2 – Middle segment: 501 to 1000 dinars; 3 – High segment: 1001 dinars and above). The results of these analyses are shown in Table 3, including the descriptive statistics and the one-way ANOVA F test. For the three segments, there was a statistically significant difference at the $p < .1$ level: $F (2, 42) = 37.160$, $p < .001$. The actual difference between the groups' mean score was quite large. The effect size, calculated using eta squared, was .64. Because the p value is less than .001, we reject the null hypothesis that there are no differences in means among the segments.

Table 3. Results of ANOVA tests.

Descriptives If you sell rakija, what is its average price per liter in dinars?					
	N	Mean	Std. deviation	Minimum	Maximum
1 Low	9	484.44	39.721	380	500
2 Middle	27	758.33	143.614	600	1000
3 High	9	1994.44	912.567	1200	3900
Total	45	950.78	673.718	380	3900

ANOVA If you sell rakija, what is its average price per liter in dinars?					
	Sum of squares	df	Mean square	F	Sig.
Between groups	12760303.333	2	6380151.667	37.160	.000
Within groups	7211094.444	42	171692.725		
Total	19971397.778	44			

We have two distinct statistics in the research results when it comes to the amount of rakija sold. When asked directly how much rakija the members of the sample sold, the answer was 43,450 liters, and when asked how much rakija from a particular fruit they sold, the answer was 75,390 liters, which is 31,940 liters more. We presume that the lower figure accurately reflects the reality, and that the higher figure represents all the rakija that was offered on the market but never sold. Serbia produces 50–60 million liters of rakija every year, according to the Ministry of Agriculture (Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia, 2020). To test this assumption and the results obtained, we compared the production and sales data from this study with the data given by official statistics on the consumption of strong alcoholic beverages. For the purposes of this analysis, we will use the data obtained from the direct question about sales, i.e., the lower amount. According to the findings, rakija production in the sample was 106,694 liters, while sales were 43,450 liters, implying that 2.46 times more rakija is produced than sold. According to official statistics (Statistical Office of the Republic of Serbia, 2019), Serbs consume 2.9 liters of strong alcoholic drinks per capita, or a total of 20 million liters (there are around 6.9 million Serbs), with beer consumption accounting for 40.3 liters and wine consumption accounting for 6.8 liters. When we look at the sold-to-produced ratio in the sample and multiply it by the previous total consumption (20 multiplied by

2.46), we get about 50 million liters of rakija produced annually in Serbia (more exactly, 49.2 million), i.e., 7.13 liters per capita. The difference between the smaller and larger quantities reported in the results is interpreted as follows: the actual sale is 43,450 liters, and the 70% higher volume indicates market surpluses, i.e., rakija that is not sold or cannot be sold. The reasons may be different – bad quality, high price, etc. – but the facts clearly demonstrate a market imbalance and an issue with the sale of rakija.

A typical small Serbian distillery intended for the production of rakija is that of a man in his forties without a university degree. They have a small distillery with a capacity of 100 liters which, when used, is placed in the meadow or under the eaves because there is no special facility. They use their own fruit and most often distill plums. They work alone and distilling rakija is their hobby. Their main objective is to produce enough rakija for themselves and all visitors, but they also want to sell it. They make strong rakija with an alcohol content of almost 45%. Such rakija burns the throat and is not pleasant to drink, but with this strength, the distiller can mask the shortcomings of the rakija, which can occur for several reasons, mainly because of the poor quality of the fruit. Even if they sell rakija, they do not settle their obligations to the state and compete unfairly with registered distilleries. Although the primary goal of the state should be the collection of taxes, it seems that the control of tens of thousands of small distilleries in Serbian villages is a difficult and expensive task; hence, the rakija market in Serbia is essentially unregulated. The disorder of the market is a serious shortcoming and a limiting factor for growth and development. In our sample of 45 respondents selling rakija, 27, or about half, do not fulfill their obligations to the state.

Rakija distillers give their rakija a good rating of roughly 8 out of 10, while they give their market condition a low rating of 2.7 out of 7. This feature alone causes them concern, as a good product should have a strong market position. Without getting into the debate over their possibly unreasonably high quality rating, it is self-evident that doing business in the highly competitive alcoholic beverage industry is impossible without marketing. There is little reason for distilleries to be enthusiastic about future market success because rakija producers have not accepted the need for marketing (4.2 out of 7 points). In order for a product to gain a good position in the market, it must be of good quality. The common methods used by distillers to distill rakija do not guarantee that the desired quality will be obtained. A quality product requires branding. There is fierce competition in the alcoholic beverage market. There are a large number of brands of spirits and substitutes, and thus without marketing and communication with the market, even the highest quality product can be rendered effectively invisible. The existing production and business methods are in no way responsible for the market's vision of the future and the high expectations that distilleries place on it. With current business approaches and outdated means of production, their future can only be worse than the present.

Segmentation of the Serbian rakija market in terms of price

Research has shown that the alcoholic beverage market has two to three segments in terms of price (Carew et al., 2017). The hypothesis that the rakija market in Serbia has three segments was investigated and confirmed, since the average price of rakija in the sample was 951 dinars, and the average price of rakija among Serbian retailers is 587 dinars. The first segment is the most price-sensitive, and these buyers generally demand rakija worth up to 500 dinars. In the sample considered here, one-fifth of distillers address this segment, offering cheap and low-quality rakija. They hold 35% of sales in the rakija market, which is the largest share. The next segment expects rakija of higher quality. That middle segment is ready to pay 501 to a maximum of 1,000 dinars for rakija. It is also the most common segment in our sample, addressed by three-fifths of distillers. However, most producers sell slightly less rakija than the no-frills segment, accounting for 34% of the total market volume. Above this is the luxury segment, which is not price sensitive. One-fifth of the distillers in the sample sell their rakija to this market. They have the smallest share of the rakija market (31%), which is expected. Nevertheless, there are no significant differences in the quantities of rakija sold among the segments.

The very fact that the Serbian rakija market is dominated by either no-frills products or luxury products indicates a serious market imbalance. The majority of distillers selling the mid-price rakija face problems selling their goods. Other alcoholic beverage markets are the polar opposite; standard grade goods have by far the highest market share. It is apparent that the small distillers failed to bring to the market the rakija of standard quality, which would become the flagship of the rakija industry. Such a product is clearly missing on the market.

We must make two additional remarks here. First, the group that we examined consists of distillers that combine traditional and modern technical-technological procedures to produce high-quality rakija, and it is expected that four out of five distillers from the sample will produce quality rakija that can achieve higher prices. It is debatable whether identical results would be obtained outside the observed Facebook group, which excludes the majority of distillers in Serbia. Second, while price and quality are undoubtedly linked, customer choice is impacted by a variety of factors that should be taken into account in future segmentation studies in the Serbian rakija industry. The most important factor is marketing. Obviously, a large number of distillers from the middle segment are not successful in the market, which we can attribute to their ignorance of marketing. Large producers, who are better at marketing, achieve higher prices. The obvious advice to distillers is to either be more successful and adept at marketing and branding to secure a position in the luxury segment, or to move to the low-price segment and sell their rakija at the lowest possible price.

The average price of rakija on the Serbian market is 951 dinars. The median or medium price is 750 dinars, which is about one-fifth lower than the average price. The medium price applies to half of the sample; half of the respondents sell rakija above, and the other half below 750 dinars. The price of rakija on the domestic market varies between 380 and 3,900 dinars. The largest price range is for very old plum rakija, which sells in the range of 500 to 12,000 dinars. The cheapest is apple rakija, and the most expensive is quince rakija. Plum rakija, as the most commonly produced national drink, only achieves a price lower than the medium on the market although plum rakija has the potential to be aged in oak barrels, only one-third of distillers choose this method. Although some compare plum rakija aged in oak, distilled by modern oenological methods, and produced from the highest quality fruits with French cognac and Scottish single malt (Nikićević and Tešević, 2005), old plum rakija in this sample did not reach the average price of rakija on the Serbian market. Therefore, there is no confirmation that old plum rakija has great export potential, which is completely in line with Matković's (2015) claim that plums and plum products are highly underrepresented in exports.

Challenges to the rakija industry

We have created a SWOT matrix to help us visualize the foreseeable future of the rakija industry (Figure 4). The SWOT analysis (Whittington et al., 2020) brings together the key elements of the business environment and strategic capabilities of the organization that are most likely to influence strategic development. The goal is to identify the key strengths and weaknesses relevant to the organization, as well as the organization's ability to exploit and overcome opportunities and threats from the environment.

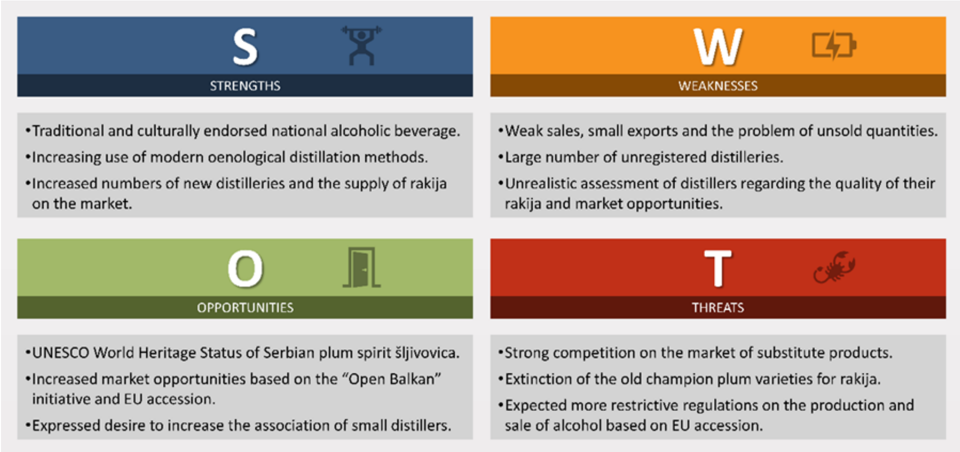

Figure 4. The SWOT analysis of the Serbian rakija industry.

Rakija is a traditional and culturally endorsed alcoholic beverage that Serbs are proud of. It is the biggest internal strength of this industry. The strengths of the industry are the increasing acceptance of modern oenological distillation methods and the increased number of new distilleries and new products on the market. New technologies could develop new rakijas, with a richer and more pleasant flavor. Newly opened distilleries and new rakija brands may help to enhance the existing undeveloped rakija market by increasing competition.

On the other hand, the biggest internal weakness is the unfavorable situation in the rakija market, expressed through weak sales, small exports, and substantial unsold inventories. In Serbia, there are hundreds of registered distilleries, but there are ten times as many unregistered distilleries on the market. These "wild" distilleries are exempted not only from taxes, but also from the official product quality monitoring system. Even if rakija and small pot distillation are a tradition in our villages, this should not be an excuse for the government authorities and inspections to remain inactive. Finally, the weakness of the industry lies in the critical ignorance of business practices and the marketing myopia of small distillers, which can also be observed in this research through their unrealistic assessment of rakija quality and market opportunities.

The UNESCO World Heritage Status of Serbian plum spirit šljivovica represents a huge external opportunity for the further popularization of the Serbian national beverage, particularly in the Balkan countries through the current initiative "Open Balkan", and further in the entire European market through Serbia's EU accession process. Although many small distillers have not yet joined together in associations or other cooperative business models, they have a strong desire to do so. This cooperation process should result in the companies becoming more professional, financially stronger, and marketing savvy.

Strong competition from substitute products poses a huge external threat to the weak rakija industry. On the local market, beer and on the international markets, vodka, are the two main competitors. Furthermore, if science fails to provide new plum varieties that can be used to distill rakija that is at least as good as previously, there is a risk that the old plum varieties that were responsible for popularizing rakija in the past will die out. Finally, the production and sale of alcohol in Serbia will be subject to stricter regulations as a result of EU accession, which might pose a significant threat to distilleries if they are not prepared.

After identifying strengths, weaknesses, opportunities, and threats, the next step of the SWOT analysis should be to find ways how to capitalize on the positive factors and limit the negative factors to identify alternative strategies for the rakija industry. Crossing the elements of the SWOT analysis results in four types of alternative strategies: SO or max-max, WO or min-max, ST or max-min, and WT or min-min. The association of the increased number of small, but oenologically advanced distilleries, to take advantage of the opportunities of a wider market thanks to the UNESCO status of Serbian šljivovica, is imposed as a max-max strategy. Utilizing the UNESCO status and initiating a nationwide process of registering small distilleries while facilitating the cooperation process of distilleries in order to grow and become more business-oriented enterprises is seen as a min-max strategy. A max-min strategy appears to be intensifying the development of new plum varieties more suitable for distillation with new oenological agents, supplying the market with these new and improved rakija spirits in order to enhance the competitive position of rakija in relation to substitutes. The worst case scenario, or a min-min strategy, would be to face restrictive regulation at the EU level with a weak rakija industry comprised of small, unregistered distillers who are unaware of market developments. Obviously, this strategy should be avoided. By synthesizing alternative strategies, the following feasible strategy was developed. The intensification of the development of new plum varieties and initiation of the national process of registering small, but oenologically advanced distilleries so that larger and business-oriented distilleries can take advantage of the opportunities of a wider market due to the UNESCO World Heritage Status of Serbian plum spirit šljivovica, and be ready to meet the restrictive EU regulations.

The best-selling alcoholic beverage in the world is Chinese Maotai Baiju (Statista, 2022), a strong Chinese spirit with 53% alcohol. It is made from sorghum. Its annual sales are $45 billion. After Maotai, the next four brands on the list are also Chinese. They earn $44 billion. Serbian distillers like to point out that rakija is made from fruit. Foreign consumers do not have to be interested in that, only the end product itself. The reason for drinking alcohol is the physical effect it has after drinking, not the origin of the raw material for the production of beverages or the method of distillation. Almost nowhere else are fruits used for alcohol production, except in the region of Southeastern Europe. It is not used because excise and taxes on alcohol are high everywhere, and in order to make money, one must use the cheapest raw materials for the production of alcohol, which is not the fruit. Even in Serbia, such large quantities of rakija would not be distilled in rural households if farmers had a greater opportunity to sell their fruits. There is a higher profit from alcoholic beverages almost everywhere, except in Serbia because the producers are small, fragmented, and inefficient.

Surveys have significant shortcomings, and this research is a good example. The way the question was asked, the way it was understood, and the way it was answered, do not necessarily have to match. One such example is the disparity in quantities sold. Although we had a way to check which answer really indicates the right quantities sold, we do not know which part of the unrealized sales was unsold due to the impossibility of placing the products on the market, and which were not yet ready for sale because the rakija had not matured, had not been bottled, etc. We do not know because we did not ask; furthermore, the reality cannot be guessed from the answer, nor do we want to guess. Directly, more precise data would certainly be obtained through interviews, but it would take a lot of time to conduct 100 interviews with distillers throughout Serbia, and a smaller number of interviews would not yield such representative results.

Conclusion

Summarizing the results, we can answer our research question "What can we conclude from the perception of Serbian rakija producers about the quality of their spirits and the market position and perspective?" The perception of rakija quality and of market power moves in two directions. Distillers think they have quality products, but they are unable to sell them. The high expectations of their future market opportunities are quite unrealistic. It is certain that their future may be even more unclear with existing business practices and outdated production methods. According to our findings, there are three price segments in the rakija market: low-priced (up to 500 dinars), mid-priced (between 501 and 1000 dinars), and high-priced (1001 dinars and above). The analysis of these segments reveals that most distillers, marketing standard quality rakija in the middle price range sell, on average, the fewest items on the market. It is evident that there is a scarcity of average quality rakija on the market. After synthesizing the SWOT analysis findings, intensifying the development of new plum varieties and initiating the national process of registering small but oenologically advanced distilleries are seen as a way forward for the Serbian rakija industry, so that larger and more commercially savvy distilleries can take advantage of the opportunities of a wider market due to the Serbian šljivovica UNESCO status, and be prepared to meet the restrictive EU regulations.

Finally, we are convinced that the results obtained explain the problems with rakija sales in Serbia and that they form a good basis for future, more detailed research on certain topics. An extensive questionnaire, which could certainly take up to an hour to complete, and which was completed by literally everyone who participated in the survey, indicates that producers are interested in information about the production of and market for rakija. We believe that these data will be important for agricultural policymakers, not only because of the possibility of wider taxation but primarily because of the obvious need to impose stricter quality standards that would ultimately increase the quality of rakija in general, in order to fully exploit the position of šljivovica on the UNESCO Intangible Cultural Heritage Lists.

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NAČIN NA KOJI SRPSKI PROIZVOĐAČI RAKIJA OCENJUJU KVALITET I TRŽIŠNU POZICIJU SVOJIH PIĆA

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R e z i m e

Cilj ovog istraživanja je da pruži odgovore na pitanja kako srpski destileri ocenjuju kvalitet svojih proizvoda i kakve su šanse srpskih destilera na tržištu. Autor takođe namerava da odredi broj tržišnih segmenata za rakiju, srpsko nacionalno alkoholno piće. Kao prvo poznato istraživanje o destilerima i ekonomiji proizvodnje rakije u Srbiji, istraživanje je eksploratornog tipa. Kvantitativno istraživanje profesionalnih i hobi destilera rakije (N = 104) sprovedeno je onlajn u oktobru 2021. godine, što znači da je na nivou verovatnoće od 95% greška uzorkovanja niža od 10%. Destileri rakije ocenjuju kvalitet svoje rakije kao relativno visok – 7,88 od 10, dok, obrnuto, situaciju na tržištu ocenjuju kao relativno nisku – 2,67 od 7. Oni su puni entuzijazma u vezi sa svojim budućim tržišnim izgledima – 4,19 od 7, ali sa trenutnim pristupima poslovanju i zastarelim pristupima proizvodnji, njihova budućnost nije izvesna. Otkriveno je da tržište rakije u Srbiji ima tri segmenta u odnosu na cenu: niska cena (do 500 dinara), srednja cena (između 501 i 1000 dinara) i visoka cena (1001 dinar i više). Medijana, odnosno srednja cena svih rakija u našem uzorku, iznosila je 750 dinara. Konačno, SWOT/TOWS analizom sintetizovana je izvodljiva strategija nastupa na tržištu rakije. Nalazi istraživanja biće od koristi kako destilerima, tako i kreatorima poljoprivredne politike zbog očigledne potrebe uspostavljanja strožih standarda u cilju obezbeđivanja višeg kvaliteta rakija.

Ključne reči: rakija, jaka alkoholna pića, kvalitet proizvoda, tržišna pozicija, segmentacija, destileri.

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GENDER DIFFERENCES AND PROFITABILITY ANALYSIS OF PEPPER (*CAPSICUM SPECIES*) PRODUCTION, KADUNA STATE, NIGERIA

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Abstract: This study analysed gender differences and profitability of pepper (*Capsicum species*) production in Kaduna State, Nigeria. A multi-stage sampling technique was adopted. One hundred pepper farmers were selected. Primary data sources were employed with the help of a well-designed and well-structured questionnaire. The results show that 66% of pepper farmers were between 21 and 50 years old. Pepper production was profitable in the study area. Gender differences in average costs and returns in pepper production revealed that the gross margin was higher for male farmers at 137,556.51 Naira than for female pepper farmers at 109, 711.77 Naira per hectare. The gender differences in factors influencing pepper production show that age (X_1), and fertiliser input (X_4), were significant factors influencing pepper production among male farmers at the 1% probability level, while age (X_1), labour input (X_3), and fertiliser input (X_4), were significant factors influencing pepper production among female farmers at the 1% probability level. The return to scale (RTS) of pepper production was estimated at 2.798 for male farmers, which signifies an increase in the return to scale. The return to scale (RTS) was calculated for female pepper farmers at 0.033, which implies a decrease in the return to scale. The major constraints faced by pepper farmers were: lack of fertilisers, pest and disease infestations, and inadequate capital. The study recommends that female pepper farmers should have more access to farm inputs and low interest loans to increase productivity.

Key words: gender differences, profitability analysis, pepper production, Kaduna State, Nigeria.

Introduction

Pepper (*Capsicum species*) is a highly valued, varied and widely grown spice crop for food and cash by farmers all over the world (Aliyu et al., 2012). Pepper ranks second (2nd) after tomatoes in the world as the most important fruit vegetable

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(Alabi et al., 2022). Pepper constitutes about 40% of human vegetable consumption and it is the world's most commonly used spice (Adeoye et al., 2014). Pepper is the most widely produced type of colouring food and spices and is an excellent source of natural colourants and anti-oxidants (Alabi et al., 2022). Nigeria has good soil and weather conditions that can support the growth and productivity of pepper. Nigeria is one of the largest pepper producers in the world, accounting for 50% of Africa's production (Mohammed et al., 2013). Nigeria produced 762,174 tonnes of green chillies and peppers in 2020, which is 0.27% more than in 2019, when its production amounted to 760,114 tonnes (FAO, 2020). The average yield of green chillies and peppers in 2020 was 2 to 2.5 tonnes per hectare (FAO, 2020) The area under green chillies and peppers was 101,350 hectares in 2020, the yield of green chillies and peppers was 75,202 hg/ha (FAO, 2020). The production of dry chillies and peppers in 2020, was 62,556 tonnes which implies a 0.32% increase in the production compared to 2019 when it amounted to 62,356 tonnes (FAO, 2020). The area and yield of dry chillies and peppers in 2020, were 36,605 ha and 17,089 hg/ha respectively (FAO, 2020). Pepper is a medicinal and nutritional plant which has potentials to generate foreign exchange, reduce unemployment, and its use in pharmaceuticals, culinary and confectionary purposes has increased. According to Dipeolu and Akinbode (2008), peppers contain vitamins A, B, C, B_1, B_2 and B_3. All varieties of peppers are good and excellent sources of vitamins A, and C, potassium, folic acid and fibre (Alabi et al., 2022). Most Nigerian pepper is produced by small-scale, resource-poor, smallholder farmers who sell their produce to middlemen or traders who re-sell the products to processors (Adeoye et al., 2014). Pepper is widely cultivated throughout Nigeria, especially in northern Nigeria. However, the yields obtained by resource-poor farmers are still low (Ogunbo, 2015). Production constraints include: lack of farm inputs, lack of credit facilities, pests and diseases, weeds, low soil fertility, and poor management practices (Dennis and Kentus, 2018; Ogunbo, 2015). High potential pepper producing areas of Nigeria include: Kano, Kaduna, Jigawa, Plateau, Sokoto, and Bauchi States. Pepper grown in Nigeria is in high demand because of it pungency and good flavour (Dennis and Kentus, 2018).

Gender refers to the social opportunities and attributes associated with being a woman or a man and to the relationships between men and women (UNDP, 2009). Gender plays a significant role in the agricultural sector where both women and men participate and complement each other in the agricultural value chain activities (Adam et al., 2018). Women make up 60 to 80 % of the agricultural labour force in Nigeria (World Bank, 2003). In sub-Saharan Africa including Nigeria, women are known to be more involved in agricultural activities than men. About 73% of African women were involved in cash crops, arable and vegetable gardening, 16% in post-harvest activities, and 15% of African women were involved in agro-forestry activities (Ajibade et al., 2021). Women have practically taken over the processing and production of arable crops in Nigeria and are responsible for as much as 80% of staple foods (Afolabi, 2008; Ogunlela and Mukhtar, 2009). Despite the high percentage of women in agriculture in Nigeria, the productivity of female farmers is lower compared to productivity of their male counterparts (Olakojo, 2017). Women tend to have less access to agricultural productive resources than men due to gender specific constraints (FAO, 2011). Productive resources include: access to extension services, access to credit facilities, ownership of land, crop and livestock, access to farm inputs; access to education, skills and knowledge related to agriculture, and agricultural resource management (Moore et al., 2015). Women also had a problem with access to agricultural information. When adequate information is available to female farmers, they can share experiences, receive financial supports, learn about best practices, and access new markets. In order to improve agricultural production and achieve agricultural sustainable development, information on agriculture is crucial for any nation (Lawal et al., 2017). The productive capacity of women in the agricultural sector remains lower than that of their male counterparts, which negatively affects overall productivity (Olakojo, 2017). Male and female farmers have equal productive efficiency especially when inputs, credit and market access as well as physical and human capital are adequately controlled (Olakojo, 2017)

Objectives of the study

This study analysed gender differences and performed profitability analysis in the production of pepper (*Capsicum species*) in Kaduna State, Nigeria. Specifically, the objectives were to:

(i) determine the socio-economic characteristics of pepper farmers;
(ii) analyse the gender differences in the costs and returns of pepper production;
(iii) evaluate the gender differences in the factors influencing output of pepper production;
(iv) evaluate the gender differences in elasticities of production, and return to scale of pepper production and
(v) determine the constraints faced by pepper farmers in the study area.

Material and Methods

This research study was conducted in Kaduna State, Nigeria. Kaduna State lies between Longitudes 06^0 $15^|$ and 08^0 $50^|$ East of the prime meridian and Latitudes 09^0 $02^|$ and 09^0 $02^|$North of the equator. The State has total land area of 4.5 million hectares. The vegetation of Kaduna State is divided into the Northern Guinea Savanna and the Southern Guinea Savanna. There are two (2) seasons in Kaduna State: the dry season and the wet season. The dry season lasts from October to March, and the wet season lasts from April to October with the short harmattan period from November to February in between. The average rainfall is about 1,482mm. The temperature of Kaduna State ranges from 35^0C to 36^0C during the humid period and from 10^0C to 23^0C during the harmattan period. The population of Kaduna in 2021 was 8.9 million. They are involved in agricultural activities. The crops grown include: pepper, maize, ginger, sorghum, rice, yam, cassava, millet, and tomatoes. Animals reared include: cattle, goats, sheep, rabbit, and poultry. A multi-stage sampling technique was used. One hundred (100) pepper farmers were selected. The data collected from the pepper farmers were from primary sources using a well-designed and well-structured questionnaire. The questionnaire was administered to the pepper farmers by well-trained enumerators. The data were analysed using the following analytical tools:

Descriptive statistics: This involves the use of mean, range, percentages and frequency distributions to summarise the socio-economic characteristics of pepper farmers as stated in specific objective one (i).

Farm budgetary technique: The farm budgetary technique used was gross margin analysis (GM) and it is defined as the difference between gross farm income (GFI) and total variable cost (TVC). This tool of analysis was used to determine the gender differences in the costs and returns of pepper production as specified in specific objective two (ii). The gross margin model is described as follows:

$$GM = TR - TVC \tag{1}$$

$$GM = \sum_{i=1}^{n} P_i Q_i - \sum_{j=1}^{m} P_j X_j \tag{2}$$

$$NFI = TR - TC \tag{3}$$

$$NFI = \sum_{i=1}^{n} P_i Q_i - \left[\sum_{j=1}^{m} P_j X_j + \sum_{k=1}^{k} GK\right] \tag{4}$$

where,

P_i = Price of pepper ($\frac{₦}{Kg}$),

Q_i = Quantity of pepper (kg),

P_j = Price of variable inputs ($\frac{₦}{unit}$),

X_j = Quantity of variable inputs (units),

TR = Total revenue obtained from the sales of pepper (₦),

TVC = Total variable cost (₦),

GK = Cost of all fixed inputs (Naira),

NFI = Net farm income (Naira).

Financial analysis: This is an analytical tool used to determine the gender differences in profitability of pepper production. The financial analysis was used to achieve part of specific objective two (ii). Gross margin ratio is defined according to Alabi et al. (2020) and Ben-Chendo et al. (2015) as follows:

$$Gross\ margin\ ratio = \frac{Gross\ margin}{Total\ revenue} \tag{5}$$

The operating ratio (OR) is defined according to Olukosi and Erhabor (2015) as follows:

$$Operating\ Ratio = \frac{TVC}{GI} \quad (6)$$

where,
TVC = Total variable cost (Naira),
GI = Gross income (Naira).

According to Alabi et al. (2020) and Olukosi and Erhabor (2015), an operating ratio of less than one (1) implies that the gross income from the pepper enterprise was able to pay for the cost of the variable inputs used in the enterprise.

The rate of return per Naira invested (RORI) in pepper production is defined according to Alabi et al. (2020) as follows:

$$RORI = \frac{NI}{TC} \quad (7)$$

where,
$RORI$ = Rate of return per Naira invested (unit),
NI = Net income (Naira),
TC = Total cost (Naira).

The Cobb-Douglas production function model: The model is defined as follows:

$$Log\ Y = \beta_0 + \beta_1 Log\ X_1 + \beta_2 Log\ X_2 + \beta_3 Log\ X_3 + \beta_4 Log\ X_4 + \beta_5 Log\ X_5 + \beta_6 Log\ X_6 + U_i \quad (8)$$

Y = Output of pepper (kg),
X_1 = Age of farmers (years),
X_2 = Farm size (hectares),
X_3 = Labour input (mandays),
X_4 = Fertiliser input (kg),
X_5 = Seed input (kg),
X_6 = Chemical input (litres),
U_i = Error term,
$\beta_1 - \beta_6$ = Regression coefficients,
β_0 = Constant term.

This was used to evaluate gender differences in factors influencing pepper production as stated in specific objective three (iii).

Elasticity of production and return to scale: According to Alabi et al. (2020), the elasticity of production and return to scale of pepper production can be defined as follows:

$$RTS = \sum_i^n EP \quad (9)$$

$$RTS = \sum_1^6 \beta_i \quad (10)$$

$\text{RTS} = 1,$ Constant return to scale,
$\text{RTS} > 1,$ Increasing return to scale,
$\text{RTS} < 1,$ Decreasing return to scale,
where,
$RTS =$ Return to scale (units) and
$EP =$ Elasticity of production inputs (units).

This was used to evaluate the gender differences in the elasticity of production and return to scale of pepper production as stated in specific objective four (iv).

Principal component analysis: The gender differences in the constraints faced by pepper farmers were subjected to a principal component analysis. This was used to achieve specific objective five (v).

Results and Discussion

Socio-economic characteristics of the pepper farmers in the study area

The socio-economic characteristics of the sampled pepper farmers were age, gender, marital status, educational status, household size, access to credit facilities, contact with extension agents, years of farm experience, and farm size (Table 1). The results show that 66% of the sampled pepper farmers were between 21and 50 years old. The mean age was 43 years. This implies that the pepper farmers in the study area were active, energetic, and resourceful in their youthful age. This is in line with the findings of Alabi et al. (2022), who reported that the average age of the pepper farmers was 38 years implying that they are relatively young, energetic, within the active age in pepper production, thus high productivity is expected. Mohammed et al. (2016) reported that younger pepper farmers were more flexible to risks and new ideas, and therefore, more likely to adopt innovations than older farmers. Gender analysis in this research study classified pepper farmers into males and females. About 78% of the pepper farmers were male, while 22% were female. This means that pepper farming was dominated by males. This finding is in line with that of Alabi et al. (2022) who reported a 4:1 ratio of males to females in pepper farming in their study. About 43% of pepper farmers had formal education, while 57% had non-formal education. Dennis and Kentus (2018) reported that illiteracy among pepper farmers could affect negatively their ability to participate in extension training as well as adopt high levels of innovations and improved practises in pepper production. Alabi et al. (2010) reported that education acquired by pepper farmers was an important socio-economic factor influencing management decisions and adoption of new technologies. Furthermore, 74% of the pepper farmers had between 1 and 10 persons as household members. Averagely, there were 8 persons per household. Mohammed et al. (2015) reported an average household size of 11 persons for pepper farming households implying that a considerable number of family members are available to carry out the various farming activities. Similarly, Sani et al. (2010) have reported that larger households among pepper farmers provide enough persons for family labour which signifies that little or less money will be needed to pay for hired labour. In addition, 83% of pepper farmers had access to credit facilities, while 35% did not have access to credit facilities.

Table 1. Socio-economic characteristics of pepper farmers in the study area.

Variables	Frequency	Percentage	Mean
Age (years)			
21 – 30	28	28.00	
31 – 40	19	19.00	
41 – 50	19	19.00	43.61
> 51	34	34.000	
Gender			
Male	78	78.00	
Female	22	22.00	
Marital status			
Single	07	07.00	
Married	84	84.00	
Divorced	09	09.00	
Educational status			
Primary	21	21.00	
Secondary	15	15.00	
Tertiary	07	07.00	
Non-Formal	57	57.00	
Household size (units)			
1 – 5	36	36.00	
6 – 10	38	38.00	8.0
11 – 15	21	21.00	
16 – 20	05	05.00	
Access to credit facilities			
Yes	65	65.00	
No	35	35.00	
Contact with extension agents			
Yes	83	83.00	
No	17	17.00	
Years of farm experience			
1 – 5	75	75.00	
6 – 10	23	23.00	4.35
11 – 15	02	02.00	
Farm size (hectares)			
0 – 0.99	40	40.00	
1 – 1.99	50	50.00	1.01
2 – 2.99	10	10.00	
Total	100.00	100.00	

Source: Field survey (2021).

The low access to credit could be due to the fact that the government rarely provides financial credit to farmers (Ekong, 2003). Access to credit is a very important factor in the development of any business. The availability of credit could determine the extent of production capacity (Mohammed et al., 2016). Access to micro-credit could improve the productivity of pepper farmers and contribute to uplifting the livelihood of peasant resource-poor rural farming communities (Nasiru, 2010). Farm experience of pepper farmers is another important socio-economic factor that can bring about an increase in pepper productivity. About 98% of pepper farmers had between 1 and 10 years of experience in pepper farming. Experienced pepper farmers can correct past errors and can forecast future market situations of their products at higher prices to make better profits (Alabi et al., 2022). Averagely, pepper farmers had 1.01 hectares of planted pepper area. They are small-scale, smallholder, resource-poor pepper farmers. According to Alabi et al. (2022) Nigerian farms are classified into small-scale (less than 5 hectares), medium scale (5 – 10 hectares), and large scale (more than 10 hectares). According to Ogunbo (2015), farm size may influence the adoption of technologies, scale of production, output level, and revenue accruable to pepper farmers.

Gender differences in profitability analysis of pepper production in the study area

The gender differences in the costs and returns of pepper production are presented in Table 2. All costs incurred and revenues obtained were based on the market price as at the time of the field survey. The variable costs incurred in pepper production for male and female farmers include: fertiliser input, seed input, herbicides, insecticides, bags, and labour input. The depreciated fixed costs involved in pepper production for both male and female farmers include: sprayer, land rent, hoe, water pump, and cutlass. There was a significant difference in the total variable costs involved in pepper production between male and female farmers. The average total variable costs of pepper production were 155,409.01 Naira and 122,800.73 Naira for males and females which accounted for 81.87% and 81.81% of the total cost of production per hectare, respectively. There was also a significant difference in the average total costs incurred in pepper production between male and female farmers. The male farmers incurred an average total cost of 189,824.06 Naira, while the female farmers incurred 82,418.15 Naira. Pooling the data for both male and female farmers together, the average total cost incurred for both male and female farmers in pepper production was 134,430.66 Naira. The gross margin analysis per hectare revealed that pepper production was profitable for both male and female farmers. The enterprise was worthwhile for both male and female pepper farmers. The gross margin per hectare was higher for male pepper farmers at 137,556.51 Naira than for female pepper farmers at 109,711.77

Naira. The net farm income analysis also revealed that both male and female pepper farmers were profitable. There was a significant difference in the net farm income for both male and female pepper farmers. The net farm income of male pepper farmers was higher at 103, 141.46 Naira than that of female pepper farmers at 82,418.15 Naira per hectare. Pooling the data together for both male and female pepper farmers, the net farm income was estimated at 98,582.33 Naira. This implies that pepper production in the study area was profitable. The financial analysis revealed that the gross margin ratios of pepper production for male and female farmers and for the pooled data were 0.47 each.

Table 2. Gender differences in average costs and returns of pepper production per hectare.

Items	Male		Female		Pooled	
	Amount (Naira)	Percentage	Amount (Naira)	Percentage	Amount (Naira)	Percentage
Total revenue	292,965.52		232,512.50		279,665.85	
Variable cost						
Seed input	1,480.10	0.779	1,280.01	0.852	1,436.08	0.793
Fertiliser input	44,919.14	23.66	39,231.20	26.13	43,667.79	24.11
Herbicides	6,063.84	3.194	4,547.88	3.030	5,730.33	5.164
Insecticides	1,450.46	0.764	1,160.37	0.775	1,386.64	0.965
Bags	1,989.06	1.047	1,591.24	1.060	1,901.54	1.050
Labour input						
(a) Land clearing	12,044.33	6.344	9,033.25	6.018	11,381.89	6.285
(b) Soil tillage	13,385.22	7.051	10,038.91	6.688	12,649.03	6.905
(c) Planting	11,240.39	5.921	8,430.29	5.616	10,622.16	5.865
(d) Manure application	8,275.86	4.339	6,620.68	4.411	7,911.72	4.369
(e) Chemical application	8,122.17	4.248	6,497.74	4.329	7,764.79	4.289
(f) Weeding	18,622.66	9.810	14,898.13	9.923	17,803.26	9.831
(g) Fertiliser application	8,029.56	4.230	5,620.69	3.744	7,499.61	4.141
(h) Harvesting	15,822.66	8.335	11,075.86	7.379	14,778.364	8.161
(i) Bagging	3,963.55	2.088	2,774.48	1.848	3,701.96	2.044
Fixed cost (depreciation)						
(a) Land rent	26, 256.16	13.83	21,004.92	15.999	25,100.89	13.86
(b) Sprayer	2,384.03	1.255	1,668.82	1.111	1,859.68	1.026
(c) Hoe	2,123.30	1.185	1,698.64	1.131	2,029.87	1.120
(d) Cutlass	238.73	0.125	190.98	0.127	228,23	0.126
(e) Water pump	3,412.83	1.797	2,730.26	1.819	3,254.86	1.797
Total variable cost	155,409.01	81.87	122,800.73	81.81	148,235.19	81.86
Total fixed cost	34,415.05	18.13	27,293.62	18.19	32,848.33	18.14
Total cost	189,824.06	100.00	150,094.35	100.00	181,083.58	100.00
Gross margin	137, 556.51		109,711. 77		134,430.66	
Net farm income	103,141.46		82,418.15		82,418.15	98,582.33
Quantity (50 Kg)	14.64	11.62			13.98	
Price	20,000		20,000		20,000	
Operating ratio	0.53		0.52		0.53	
Rate of return on investment	0.55		0.54		0.544	
Gross margin ratio	0.47		0.47		0.47	

Source: Field survey (2021).

This implies that for one Naira invested in pepper production, 46 kobos covered profits, taxes, expenses, and depreciation. The rate of return on investment was higher for male pepper farmers at 0.55 than for female pepper farmers at 0.54, implying that for one Naira invested by male pepper farmers, additional 55 kobos were earned. This is in line with the findings of Alabi et al. (2022), who obtained a gross margin of 167,642.49 Naira and gross margin ratio of 0.481 for pepper production per hectare in Abuja, Nigeria. Ajibade et al. (2021) reported similar results for the same group of vegetable producers: the gross margin of tomato production was at 67,083.64 Naira per hectare for male farmers, higher than the gross margin of tomato production at 34,325.38 Naira per hectare for female farmers in Abuja, Nigeria.

Gender differences in factors influencing the output of pepper (*Capsicum species*) production in the study area

Gender differences in factors influencing the output of pepper production are presented in Table 3. The explanatory variables considered in the Cobb-Douglas production model were age (X_1), farm size (X_2), labour input (X_3), fertiliser input (X_4), seed input (X_5), and chemical input (X_6). All the regression coefficients for male and female pepper farmers and pool data were positive. Age (X_1) , and fertiliser input (X_4) were statistically significant at $(P < 0.01)$ for male pepper farmers, while age (X_1), labour input (X_3), and fertiliser input (X_4) were statistically significant at $(P < 0.01)$ for female pepper farmers. The pooled data revealed that age (X_1), and labour input (X_3) were statistically significant at $(P < 0.01)$. The coefficient of multiple determinations (R^2) was 0.81 for male pepper farmers and 0.56 for female pepper farmers. The coefficient of multiple determinations (R^2) for pooled data was 0.755. The coefficient of determinations (R^2) of 0.81 implies that 81% of variations in production of pepper by male pepper farmers were explained by the explanatory variables included in the model. The coefficient of determinations (R^2) of 0.56 implies that 56% of variations in the production of pepper by female pepper farmers were explained by the explanatory variables included in the model. The F-values were statistically significant at $(P < 0.01)$ for male (225.71), female (196.21) pepper farmers and pooled data (219.22) respectively. This confirmed the explanatory variables included in the model as jointly responsible for variations in production of pepper by male, and female pepper farmers and pooled data, respectively. The regression coefficients of farm size and fertiliser input were 0.521 and 0.491 for male pepper farmers, while the regression coefficients for female pepper farmers were 0.020 and 0.001 respectively. This implies that a 1% increase in farm size will lead to a 52.1% increase and a 2.0% increase in pepper production for male and female farmers, respectively. This finding is in line with Alabi et al. (2022), who have reported that a 1% increase in farm size will lead to a 69.85% increase in pepper production among smallholder farmers in Abuja, Nigeria. Similarly, Adeoye et al. (2014) have reported that a 1% increase in farm size will lead to a 05.15% increase in pepper production among farmers under tropical conditions.

Table 3. The result of multiple regression analysis of the Cobb-Douglas production function model.

Variable	Male			Female		
	Regression coefficient	Standard error	t-statistics	Regression coefficient	Standard error	t-statistics
Age (X_1)	0.412	0.1141	3.61***	0.035	0.011	3.21***
Farm size (X_2)	0.521	0.2059	2.53**	0.020	0.008	2.57**
Labour input (X_3)	0.361	0.1332	2.71**	0.006	0.002	3.64***
Fertiliser input (X_4)	0.491	0.1323	3.71***	0.039	0.001	3.45***
Seed input (X_5)	0.530	0.2070	2.56**	0.014	0.006	2.41**
Chemical input (X_6)	0.483	0.2185	2.21**	0.012	0.005	2.56**
Constant	4.012	1.6786	2.39**	2.844	1.252	2.27**
RTS	2.798			0.033		
R^2	0.81			0.56		
Adjusted R^2	0.78			0.51		
F-Value	225.71***			196.21***		

Source: Data analysis (2021). *Significant at the 10% probability level; **Significant at the 5% probability level, ***Significant at the 1% probability level.

Table 3. Continued. The result of multiple regression analysis of the Cobb-Douglas production function model.

Variable	Pooled data		
	Regression coefficient	Standard error	t-statistics
Age (X_1)	0.3291	0.0093	3.52***
Farm size (X_2)	0.4108	0.1624	2.53**
Labour input (X_3)	0.2829	0.0972	2.91***
Fertiliser input (X_4)	0.3916	0.1072	3.65***
Seed input (X_5)	0.4165	0.1646	2.53**
Chemical input (X_6)	0.3793	0.1663	2.28**
Constant	3.7550	1.3372	2.808**
RTS	2.2064		
R^2	0.755		
Adjusted R^2	0.720		
F-value	219.22***		

Source: Data analysis (2021). *Significant at the 10% probability level; **Significant at the 5% probability level, ***Significant at the 1% probability level.

Gender differences in elasticity of production and return to scale of pepper production in the study area

The gender differences in elasticity of production and return to scale of pepper production are presented in Table 3. The regression coefficients of the male and female pepper farmers and the pooled data were the elasticities of production. The sum of the elasticities of production gave the return to scale for male and female pepper farmers and for the pooled data respectively. The elasticities of production of fertiliser input were 0.491 for male, and 0.039 for female pepper farmers. The elasticity of production of fertiliser input for pooled data was 0. 3916. All the elasticities of production for variable inputs included in the Cobb-Douglas production model were positive for male and, female pepper farmers and for pooled data respectively. The return to scale (RTS) of pepper production for male farmers was 2.798, which signifies increasing return to scale. This implies that a unit increase in any production input in pepper production will lead to more than a proportionate increase in the output of pepper produced. The return to scale (RTS) of pepper production for female farmers was 0.033, which signifies a decrease in return to scale. This implies that a unit increase in any production inputs will lead to disproportionately small decrease in the output of pepper produced. The return to scale for the pooled data was 2.206, which signifies an increase in the return to scale of pepper production. This result is similar to the findings of Dossah and Mohammed (2016), who obtained the return to scale (RTS) of 1.314 for male vegetable farmers (increasing return to scale), and 0.97 for female vegetable farmers (decreasing return to scale) in Plateau State, Nigeria.

Constraints faced by pepper farmers in the study area

Table 4 shows the constraints faced by pepper farmers in the study area using the principal component model. Principal component analysis (PCA) is an analytical technique that can transform many interrelated constraints of pepper farmers into few uncorrelated constraints.

Constraints with Eigen-values greater than one (1) were retained by the principal component model. Constraints with Eigen-values less than one (1) were discarded by the model. Lack of fertilisers with an Eigen-value of 3.2091 ranked 1st among the constraints based on the perception of pepper farmers, explaining 21.71% of all the constraints retained by the principal component model. Pest and disease infestations ranked 2nd based on the perceptions of pepper farmers, and this explained 21.60% of all the constraints retained by the model. The other constraints faced by pepper farmers include: inadequate capital (3rd), high perishability of commodities (4th), poor soil fertility (5th), lack of improved seeds (6th), and lack of storage facilities (7th). The retained constraints faced by pepper farmers explained 83.76% of all the constraints faced by pepper farmers in the study area. This is in line with the findings of Alabi et al. (2022), who reported that, using the principal component model and based on the perceptions of smallholder pepper farmers, lack of fertilisers and lack of improved seeds ranked 2nd and 3rd among the constraints faced by smallholder pepper farmers in Abuja, Nigeria.

Table 4. Principal component analysis of constraints faced by pepper farmers.

Constraints	Eigen-value	Difference	Proportion	Cumulative
Lack of fertilisers	3.2091	0.4120	0.2171	0.2171
Pest and disease infestation	3.1020	0.3971	0.2160	0.4331
Inadequate capital	2.9801	0.3651	0.1131	0.5462
High perishability of commodity	2.9107	0.3402	0.1001	0.6463
Poor soil fertility	2.8709	0.3101	0.0971	0.7434
Lack of improved seeds	1.8701	0.2907	0.0621	0.8055
Lack of storage facilities	1.6701	0.2770	0.0321	0.8376
Bartlett test of sphericity				
KMO	0.6701			
Chi square	490.67			
Rho	1.000000			

Source: Data analysis (2021). ***Significant at the 1% probability level.

Conclusion

This research study has shown that pepper production was a profitable enterprise for both male and female farmers in the study area. The pepper farmers were active, energetic, resourceful, and in their youthful age. Pepper production was mainly dominated by male farmers and households were large with an average of 8 persons per household. They were small-scale, smallholder, peasant and resource-poor pepper farmers with an average farm size of 1.01 hectares of farm land. Gender differences in average costs and returns of pepper production show that the gross margin of male pepper farmers was higher at 137,141.46 Naira per hectare than that of female pepper farmers with a gross margin of 109,711.77 Naira per hectare. The net farm income of male pepper farmers was higher at 103,141.46 Naira per hectare than that of female pepper farmers with a net farm income of 82,418.15 Naira per hectare. The financial analysis revealed that the gross margin ratios were for male and female pepper farmers 0.47 each. This signifies that for every Naira invested in pepper production, 47 kobos covered taxes, profits, expenses, interest, and depreciation. The rate of return on investment was higher for male pepper farmers at 0.55 than for female pepper farmers who had a rate of return on investment of 0.54. The gender differences in factors influencing pepper production show that age and fertiliser input were the statistically significant factors influencing the production of pepper by male farmers at the 1% probability level, while age, labour input, and fertiliser input were the statistically significant factors influencing production of pepper by female farmers at the 1% probability level. The coefficient of multiple determinations (R^2) was 0.81 for male pepper farmers and 0.56 for female pepper farmers. The return to scale was estimated at 2.798 for male pepper farmers which signifies increasing return to scale, while that of female pepper farmers was calculated at 0.033 which implies decreasing return to scale. The constraints faced by pepper farmers include: lack of fertilisers, pest and disease infestations, inadequate capital, high perishability of commodities, poor soil fertility, lack of improved seeds, and lack of storage facilities. This research study recommends the following:

To increase productivity, male and female pepper farmers should be provided with farm inputs such as improved seeds, fertiliser, and chemicals.

Female pepper farmers should be given more access to low interest loan rate to increase productivity.

The government should hire female extension agents to disseminate research findings and new technologies to pepper farmers.

The government should promote mechanised farming by providing equipment such as tractors, motorised sprayers, irrigation facilities etc. to increase productivity.

Storage facilities should be provided to the pepper farmers to solve the problem of high perishability of commodities.

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RODNE RAZLIKE I ANALIZA PROFITABILNOSTI PROIZVODNJE PAPRIKE (RODA *CAPSICUM*), DRŽAVA KADUNA, NIGERIJA

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R e z i m e

U okviru ove studije analizirane su rodne razlike i profitabilnost proizvodnje paprike (roda *Capsicum*) u državi Kaduna, Nigerija. Usvojena je tehnika višestepenog uzorkovanja. Izabrano je sto proizvođača paprike. Primarni izvori podataka korišćeni su uz pomoć dobro osmišljenog i dobro strukturiranog upitnika. Rezultati pokazuju da je 66% proizvođača paprike imalo između 21 i 50 godina. Proizvodnja paprike je bila profitabilna u ispitivanom području. Rodne razlike su uticale na visinu troškova i prihoda u proizvodnji paprike, pa su proizvođači muškog pola ostvarili veću bruto maržu – 137.556,51 naira od proizvođača paprike ženskog pola – 109.711,77 naira po hektaru. Rodne razlike među faktorima koji utiču na proizvodnju paprike pokazuju da su starost (X_1) i đubrivo (X_4) značajni faktori koji utiču na proizvodnju paprike među proizvođačima na nivou verovatnoće od 1%, dok su starost (X_1), radna snaga (X_3), i đubrivo (X_4) značajni faktori koji utiču na proizvodnju paprika među proizvođačima ženskog pola na nivou verovatnoće od 1%. Prihod u proizvodnji paprike u odnosu na rast inputa (RTS) procenjen je na 2,798 za proizvođače muškog pola, što označava povećanje prihoda u odnosu na obim inputa. Prihod u proizvodnji paprike u odnosu na rast inputa (RTS) je izračunat za proizvođače paprike ženskog pola na 0,033, što implicira smanjenje prihoda u odnosu na obim inputa. Glavna ograničenja sa kojima se suočavaju proizvođači paprike su: nedostatak đubriva, napadi štetočina i bolesti i neadekvatan kapital. U okviru studije se preporučuje da proizvođači paprike ženskog pola treba da imaju veći pristup poljoprivrednim inputima i kreditima sa niskim kamatama kako bi se povećala produktivnost.

Ključne reči: rodne razlike, analiza profitabilnosti, proizvodnja paprike, država Kaduna, Nigerija.

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UPUTSTVO ZA PRIPREMU RUKOPISA

Autori su dužni da se pridržavaju uputstva za pripremu radova. Rukopisi u kojima ova uputstva nisu poštovana biće odbijeni bez recenzije.

Za obradu teksta treba koristiti program MS-Word. Rukopise treba slati u jednom od sledećih formata .doc, .docx, koristiti font Times New Roman, veličina 12, jednostruki prored, margine 2,5 cm. Strane ne treba numerisati.
Originalan naučni rad – Rad koji sadrži prethodno neobjavljivane rezultate sopstvenih istraživanja. Obim ovog rada treba da iznosi od 6 do 12 strana.
Pregledni rad – Rad koji sadrži originalan, detaljan i kritički prikaz istraživačkog problema ili područja u kome je autor ostvario određeni doprinos, vidljiv na osnovu autocitata (najmanje 10). Obim ovog rada treba da iznosi od 15 do 20 strana.

Prethodno saopštenje – Originalan naučni rad punog formata, ali manjeg obima ili preliminarnog karaktera (od 2 do 6 strana).
Obavezna poglavlja svakog originalnog naučnog rada i prethodnog saopštenja su sledeća: naslov rada, imena autora, naziv ustanove autora, sažetak, ključne reči, uvod, materijal i metode, rezultati i diskusija, zaključak, zahvalnica, literatura i rezime na srpskom jeziku (ako je rad na engleskom i obrnuto). Pregledni rad mora da sadrži: naslov rada, imena autora, naziv ustanove autora, sažetak, ključne reči, uvod, analizu-diskusiju određene teme, zaključak, literaturu i rezime na srpskom jeziku (ako je rad na engleskom i obrnuto). Ako su radovi na engleskom jeziku, prednost se daje britanskoj varijanti ovog jezika.

Naslov rada
Naslov rada treba što vernije da opiše sadržaj rada i da ima što manje reči. U interesu je autora da se u naslovu koriste reči prikladne za indeksiranje i pretraživanje. Naslov se piše velikim slovima i centrirano. Ako je rad prethodno bio izložen na nekom skupu u vidu usmenog saopštenja, pod istim ili sličnim naslovom, podatak o tome treba navesti pri dnu prve stranice, posle podataka autora za kontakt.

Imena autora
Navodi se puno ime, srednje slovo i prezime svih autora, u originalnom obliku. Imena se pišu ispod naslova, malim slovima, centrirano i boldovano. Ukoliko su autori iz različitih institucija brojčanom oznakom u superskriptu, iza prezimena, označiti ustanovu u kojoj radi svaki autor. Autor za kontakt označava se zvezdicom u superskriptu, iza prezimena, komandom „insert footnote“, a njegova e-mail adresa navodi se ispod crte pri dnu prve stranice članka.

Naziv ustanove autora
Navodi se pun naziv i adresa ustanove u kojoj je autor zaposlen. Ispisuje se neposredno nakon imena autora, centrirano. Ukoliko su autori iz različitih institucija brojčanom oznakom u superskriptu ispred institucije označava se ustanova u kojoj je zaposlen svaki od navedenih autora.

Sažetak
Sažetak je kratak informativni prikaz sadržaja članka koji čitaocu omogućava da brzo i tačno odredi njegovu relevantnost. U interesu je autora da sažetak sadrži termine koji se koriste za indeksiranje i pretraživanje. Sažetak ne sme da sadrži reference. Sastavni delovi sažetka su cilj istraživanja, metode, rezultati i zaključak. Sažetak treba da ima od 200 do 250 reči. Reč „Sažetak“ piše se boldovano i uvlači jednim tabulatorom, nakon čega slede dve tačke, a zatim tekst sažetka.

Ključne reči
Ključne reči su termini ili fraze koje najbolje opisuju sadržaj članka za potrebe indeksiranja i pretraživanja. Broj ključnih reči može biti od 3 do 10. Navode se ispod sažetka. Naslov „Ključne reči“ piše se boldovano i uvlači jednim

tabulatorom. Nakon toga slede dve tačke, a zatim nabrajanje ključnih reči malim slovima, sa tačkom na kraju. Treba izbegavati korišćenje ključnih reči koje se nalaze u naslovu rada. Ključne reči se dostavljaju na srpskom i engleskom jeziku posle sažetaka na oba jezika.

Uvod

Uvod treba da sadrži informacije o dosadašnjim istraživanjima po navedenom pitanju i šta se datim istraživanjem želi postići. Prilikom osvrta na literaturu, navesti autora i godinu, a autora citirati u spisku literature. Naslov „Uvod“ piše se sa prvim velikim slovom, centrirano i boldovano, nakon čega sa jednim razmakom ispod naslova sledi tekst uvoda poravnat po levoj i desnoj margini. Svaki novi pasus uvlači se jednim tabulatorom. Ova pravila važe i za sva ostala poglavlja.

Materijal i metode

Materijal i metode treba izložiti jasno uz objašnjenje svih primenjenih postupaka u radu. Opšte poznate metode izložiti kratko, a detaljnije ih objasniti ukoliko se odstupa od ranije objavljenih postupaka. Za radove eksperimentalnog karaktera obavezno navesti način statističke obrade podataka. U ovom poglavlju, kao i u poglavlju „Rezultati i diskusija“, po potrebi se mogu dati i određena podpoglavlja.

Rezultati i diskusija

U poglavlju „Rezultati i diskusija“ interpretiraju se podaci dobijeni na osnovu zapažanja i izvršenih eksperimenata. U komentaru rezultata treba se pozivati na literaturu koja se navodi na kraju rada, čime se obezbeđuje poređenje dobijenih rezultata sa dosadašnjim saznanjima u toj oblasti.

Zaključak

U zaključku treba ukratko navesti najznačajnije rezultate dobijene u radu. Izbegavati nabrajanje svih rezultata istraživanja sa ponavljanjem brojčanih vrednosti koje su prethodno već navedene u poglavlju „Rezultati i diskusija“. Zaključak ne sme da sadrži reference.

Zahvalnica

Zahvalnica treba da sadrži naziv i broj projekta, odnosno naziv programa u okviru koga je rad nastao, kao i naziv institucije koja je finansirala projekat ili program.

Literatura

Poglavlje „Literatura“ treba da sadrži samo radove citirane u glavnom tekstu. Rad citiran u tekstu treba da sadrži prezime autora i godinu. Ako citat obuhvata jednog autora on se navodi kao Jalikop (2010) ili (Jalikop, 2010). Kada citat obuhvata dva autora on se navodi kao Sadras i Soar (2009) ili (Sadras i Soar, 2009). Ako se u tekstu citiraju više od dva autora posle prezimena prvog autora navodi se skraćenica „et al.“, a zatim godina. Ovakav citat navodi se kao Lehrer et al. (2008) ili (Lehrer et al., 2008). Ako se za određeni problem istovremeno citira više radova onda se oni hronološki nabrajaju. Odvajanje većeg broja citiranih radova van

zagrade vrši se zarezom (,) a u zagradi tačkom i zarezom (;). Ako se citiraju dva ili više rada istog autora oni moraju biti poređani prema hronološkom redu (1997, 2002, 2006, itd.). Ukoliko se određeni autor pojavljuje nekoliko puta u istoj godini, dodaju se slova (2005a, b, c, itd.). Citate ličnih komunikacija i neobjavljenih podataka treba izbegavati, osim ako je to apsolutno neophodno. Takvi citati bi trebali da se pojave samo u tekstu (npr. Brown, lična komunikacija), ali ne i u spisku referenci.
Literatura koja je citirana u tekstu navodi se u spisku referenci u originalnom obliku, po abecednom redu, bez numeracije. Ako se citira veći broj radova istog autora najpre se navode radovi kada je autor sam, a zatim kada su prisutna dva i više autora. Ako se u nekoj od ovih kategorija javlja veći broj radova, treba ih hronološki srediti po godinama (1997, 2002, 2006, itd.), a ako se u istoj godini javlja veći broj radova dodaju se slova (2005a, 2005b, 2005c, itd.). Literaturni podatak treba da sadrži: prezime autora, početno slovo imena, godinu izdanja u zagradi, naslov rada, naziv časopisa, volumen i broj stranica (prva-poslednja). Prilikom citiranja knjiga navodi se izdavač i mesto izdavanja. Redovi svake reference posle prvog reda moraju biti uvučeni. U časopisu se koristi APA - Publication Manual of the American Psychological Association citatni stil.

Primeri navođenja referenci su sledeći:

Periodičan časopis
Gvozdenović, S., Saftić Panković, D., Jocić, S., & Radić, V. (2009). Correlation between heterosis and genetic distance based on SSR markers in sunflower (Helianthus annuus L.). *Journal of Agricultural Sciences*, *54*, 1-10.

Knjiga
Steel, R.G.D., & Torrie, J.H. (1980). *Principles and procedures of statistics*. New York: McGraw-Hill Book Company.

Poglavlje u knjizi
Bell, R.L., Quamme, H.A., Layne, R.E.C., & Skirvin, R.M. (1996). Pears. In J. Janick & J.N. Moore (Eds.), *Fruit breeding, Volume I: Tree and tropical fruits.* (pp. 441-514). New York: John Wiley and Sons, Inc.

Zbornik
Behera, T.K., Staub, J.E., Behera, S., Rao, A.R., & Mason, S. (2008). One cycle of phenotypic selection combined with marker assisted selection for improving yield and quality in cucumber. In M. Pitrat (Ed.), *Proceedings of the IXth EUCARPIA meeting on genetics and breeding of Cucurbitaceae* (pp. 115-121). Avignon.

Teza
Singh, N.K. (1985). *The structure and genetic control of endosperm proteins in wheat and rye*. University of Adelaide.

Izveštaj
Ballard, J. (1998). *Some significant apple breeding stations around the world*. Selah, Washington.

Veb sajt
Platnick, N.I. (2010). The world spider catalog, version 10.5. *American Museum of Natural History*. Retrieved February 12, 2016, from http://research.amnh.org/entomology/spiders/catalog/index.html

Rezime
Rezime na srpskom jeziku (za radove napisane na engleskom jeziku) ili na engleskom jeziku (za radove napisane na srpskom jeziku) navodi se na kraju rada i treba da ima od 200 do 250 reči. Ispred osnovnog teksta rezimea, navodi se naslov rada, puno ime, srednje slovo i prezime svih autora i naziv i adresa ustanove autora. Naslov „Rezime" piše se razmaknuto i centrirano. Nakon naslova sledi jedan razmak, a zatim tekst rezimea, uvučen jednim tabulatorom. Neposredno nakon teksta rezimea, navode se ključne reči, sa tačkom na kraju. E-mail adresa autora za kontakt navodi se ispod crte, pri dnu stranice.

Tabele
Tabele obeležene arapskim brojevima (1, 2, itd.) praćene naslovom treba da se nalaze na odgovarajućem mestu u tekstu, u fontu 9. Maksimalna širina tabela treba da bude 13 cm. One treba da budu jasne, što jednostavnije i pregledne. Treba izbegavati vertikalne crte, a broj kolona ograničiti tako da tabela ne bi bila preširoka. Takođe, treba izbegavati nepotrebnu upotrebu horizontalnih crta. Naslov tabele, poravnat po levoj i desnoj margini, sa tačkom na kraju, navodi se sa jednim razmakom iznad tabele. Ispod tabele treba dati detaljno objašnjenje skraćenica, simbola i znakova korišćenih u samoj tabeli. Svaka tabela mora biti pomenuta u tekstu.

Ilustracije
Svi grafikoni, dijagrami i fotografije treba da se nazovu „Slika" (1, 2, itd.). Prilažu se na odgovarajućem mestu u tekstu. Grafikone i dijagrame treba uraditi fontom 9, u crno-beloj tehnici i sa maksimalnom širinom od 13 cm. Voditi računa da oni budu čitki i jasni i nakon redukcije veličine. Za svaki grafikon i dijagram treba obezbediti detaljnu legendu bez skraćenica. Fotografije moraju biti visokog kvaliteta da bi se tehnički mogle dobro reprodukovati. Prilažu se u „TIF" ili „JPG" formatu, u crno-beloj tehnici. Naslov ilustracije, poravnat po levoj i desnoj margini, sa tačkom na kraju, navodi se sa jednim razmakom ispod ilustracije. Svaka ilustracija mora biti pomenuta u tekstu.

Skraćenice i jedinice
U radu treba koristiti samo standardne skraćenice. Merne jedinice treba izražavati u internacionalnom sistemu jedinica (SI). Kod navođenja jedinica posle broja treba da stoji razmak (osim za % i °C). Skraćenice se mogu koristiti i za druge izraze pod

uslovom da se ti izrazi navedu u punom obliku prilikom prvog pominjanja, sa skraćenim oblikom u zagradi. Vrednosti od 1 do 9 mogu se izražavati slovima, a ostali brojevi isključivo numerički.

Nomenklatura

Celokupna nomenklatura (hemijska i biohemijska, taksonomska, genetička itd.) mora biti usklađena sa međunarodnim kodeksima i komisijama, kao što su *International Union of Pure and Applied Chemistry, IUPAC-IUB Combined Commission on Biochemical Nomenclature, Enzyme Nomenclature, International Code of Botanical Nomenclature, International Code of Nomenclature of Bacteria* itd.

Formule

Sve formule i jednačine u radu moraju biti urađene pomoću programa „Word Equation". Pri pisanju formula, radi preglednosti, ostaviti dovoljno praznog prostora oko same formule. Subskripti i superskripti treba da budu jasni. Prilikom pisanja jednačina treba dati smisao svih simbola odmah posle jednačine u kojoj se simbol prvi put koristi. Jednačine treba da budu numerisane arapskim brojevima, serijski u zagradama, na desnoj strani linije. Svaka jednačina mora biti pomenuta u tekstu kao Eq. (1), Eq. (2), itd.

Nakon objavljivanja rada, autoru za kontakt će biti poslat jedan primerak časopisa. Mole se svi budući saradnici da rad pripreme prema datom uputstvu, kako bi olakšali rad redakcije časopisa. Ukoliko se rad ne pripremi po navedenom uputstvu neće biti prihvaćen za objavljivanje.

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