UDC: 63 ISSN 1450-8109

JOURNAL OF AGRICULTURAL SCIENCES BELGRADE

Vol. 70, No. 4, 2025

Published by University of Belgrade
Faculty of Agriculture
Republic of Serbia

UDC: 63 ISSN 1450-8109

JOURNAL OF AGRICULTURAL SCIENCES BELGRADE

Vol. 70, No. 4, 2025

Published by University of Belgrade
Faculty of Agriculture
Republic of Serbia

Journal of Agricultural Sciences (Belgrade) www.joas.agrif.bg.ac.rs
J. Agric. Sci (Bg).

PUBLISHED BY

University of Belgrade-Faculty of Agriculture
11081 Belgrade-Zemun, Nemanjina 6, PO Box 14, Serbia
Tel: + 381 11 4413-555/467; Fax: + 381 11 2193-659; E-mail: redakcija@agrif.bg.ac.rs
URL: http://www.agrif.bg.ac.rs/

DTP Service: Snežana Spirić

Printed by the Faculty of Agriculture, Belgrade-Zemun
Circulation: 100

Publishing is supported by the Ministry of Education, Science and Technological Development
of the Republic of Serbia, Belgrade

According to the opinion of the Ministry of Science of the Republic of Serbia
No. 413-00-1928/2001-01 dated November 6, 2001 this
Journal is exempt from general tax liability

Frequency: Four times per year

Abstracting and Indexing
CAB Abstracts, AGRICOLA, SCIndeks, EBSCO, Scopus, DOAJ

Number of institutions the Journal is exchanged with: 80

JOURNAL OF AGRICULTURAL SCIENCES BELGRADE
Vol. 70, No. 4, 2025

CONTENTS

Original scientific papers:

JOURNAL OF AGRICULTURAL SCIENCES BELGRADE
Vol. 70, No. 4, 2025

S A D R Ž A J

Journal of Agricultural Sciences (Belgrade) https://doi.org/10.2298/JAS2504353P
Vol. 70, No. 4, 2025 UDC: 633.11-181
Pages 353-366 Original scientific paper

EFFECTS OF OPTIMIZED MINERAL FERTILIZATION ON YIELD AND STRUCTURAL ELEMENTS OF WINTER WHEAT ON THE RETISOL OF WESTERN POLISSIA OF UKRAINE

Volodymyr M. Polovyy[1], Liudmyla A. Yashchenko[2*] and Nadiia O. Yuvchyk[3]

[1]Institute of Agriculture of Western Polissia, National Academy of Agrarian Sciences of Ukraine, Shubkiv, Ukraine
[2]Department of Agrochemistry, Soil Science and Agriculture named after S.T. Vozniuk, National University of Water and Environmental Engineering, Rivne, Ukraine
[3]Department of Agroengineering, National University of Water and Environmental Engineering, Rivne, Ukraine

Abstract: The effects of mineral fertilizer rates, based on NPK removal by grain and by grain plus straw, compared with the recommended rate, on winter wheat crop productivity were studied. The treatments were applied against the background of different ameliorants, with plant residues returned to the soil. In Retisol, the highest winter wheat grain yield (4.98 t ha^{-1}) was obtained with the application of the 1.0 Hh (hydrolytic acidity) rate of dolomite lime (DL) with $N_{150}P_{50}K_{125}$ (the rate based on grain and straw NPK removal). This treatment led to the best indicators of yield structure elements. However, the harvest index was lower than with $N_{130}P_{25}K_{35}$ (the rate based on grain NPK removal). This suggests a higher grain-to-straw ratio with the grain-based NPK removal approach. Despite lower structural indicators, the average yield in the treatment with DL (1.0 Hh) + $N_{130}P_{25}K_{35}$ had no statistically significant difference compared to the $N_{120}P_{60}K_{90}$ (the recommended rate) at $P<0.05$. The absence of PK fertilizers in the treatment with N_{130} significantly decreased yield (19%) compared to the other NPK treatments. Applying 1.0 Hh limestone (LS) with the recommended NPK rate did not promote the formation of structural elements, and the yield decreased by 0.21 t ha^{-1} compared to DL (1.0 Hh) under similar conditions. Based on the results, applying mineral fertilizer rates calculated according to main product (grain) NPK removal, combined with 1.0 Hh DL and the return of plant residues to the soil, is recommended for optimal winter wheat productivity on Retisols.

Key words: grain, straw, yield structure, fertilizer rates, dolomite lime, limestone.

[*]Corresponding author: e-mail: rivne_apv@ukr.net

Introduction

Winter wheat plays a vital role in ensuring the long-term food security for the ever-expanding global population. Achieving this requires balanced winter wheat nutrition management for sustainable agriculture. Crop productivity management should address the specific needs of each field and be based on production profitability and the ecological stability of ecosystems. Shah and Wu (2019) and Abdeta (2021) emphasize that it is crucial to consider both soil fertility and crop nutrient requirements. This targeted approach maximizes the impact of fertilization technologies, as fertilizers have a greater effect under such conditions than with blanket recommendation rates. Tailoring winter wheat fertilization to the specific needs of each field can improve nutrient use efficiency, increase yields, and enhance grain quality, ultimately contributing to a more sustainable and productive agricultural system (Sidyakina and Dvoretskyi, 2020).

There are many studies on winter wheat nutrition that offer different views on the optimal fertilization system. Some researchers recommend using high doses of mineral fertilizers to obtain maximum yield, while others believe that more economical and environmentally friendly methods, such as organic fertilizers and green manure, can be equally effective.

Yang et al. (2017) recommend N-application rates of 150–170 kg N ha^{-1} for wheat for obtaining high yields with low environmental risk. According to Panayotova et al. (2017), increasing nitrogen fertilizer application from N_{120} to N_{180} with P_{80} increased the yield of winter wheat by only 2%. Lykhochvor et al. (2022) noted that N_{180} increased the yield of winter wheat grain by 2.94 t ha^{-1}. However, the increase in yield from the additional application in the $P_{60}K_{90}S_{30}Mg_{20}$ plus microfertilizer complex was equivalent to the increase from nitrogen of 2.56 t ha^{-1} (70.3%), highlighting the importance of balanced nutrition in the crop productivity formation.

Under the eco-ecological scenario, the application of 144.7 N and 34.3 kg ha^{-1} P, plus 30 t ha^{-1} manure, provided a grain yield of 4.03 t ha^{-1} (Mohsen and Behzad, 2018). A positive effect on grain yield and components of the winter wheat harvest was obtained for the used NPK fertilizers (120 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}), lime (5 t ha^{-1} $CaCO_3$) and manure (20 t ha^{-1}) (Jelic et al., 2015). Earlier studies by Polovyi and Yashchenko (2021) on light-textured podzolic soil have established that liming is a priority for improving winter wheat nutrition. Liming helps to neutralize soil acidity, while adding organic matter and mineral fertilizers improves nutrient availability.

The optimal fertilizer system for a planned yield of winter wheat should consider the biological features of the variety, and soil and weather conditions, the predecessor of the crop and other factors of agricultural technology (Hospodarenko et al., 2022).

A certain number of chemical fertilizers can ensure a high grain yield. However, when the chemical fertilizers are excessively applied, a decrease in crop response and a faster decline in grain yield than its initial growth can be observed. Inefficient use of fertilizers can also cause several negative effects on the environment (Yang et al., 2017; Jiang et al., 2023).

The possibility of changing approaches to crop fertilization in Ukraine is associated with the increased use of crop residues for fertilization. This practice is particularly widespread in the cultivation of winter wheat, which is the dominant crop in the country. The use of by-products of plants and siderates creates conditions for reducing the rates of mineral fertilizers by 30–50% without reducing the productivity of arable land (Degodiuk et al., 2014).

Consequently, there are theoretical grounds for adjusting recommendations regarding winter wheat fertilization by considering only the nutrient export through the harvested yield (Polovyi and Yashchenko, 2021). This approach would allow farmers to optimize fertilizer use, reducing costs and environmental impacts.

The hypothesis of this research is that winter wheat grown on ameliorated Retisols with straw incorporation will exhibit enhanced structural elements when fertilized at rates optimized based on NPK removal by grain or by both grain and straw, compared to the recommended fertilization rate. This approach could lead to more sustainable and cost-effective winter wheat production on these soils.

The aim was to investigate the possibility of reducing the recommended rate of mineral fertilizers in combination with ameliorants, when plant residuals return to the soil without decreasing the winter wheat crop.

Material and Methods

Study area

The research was conducted from 2021 to 2023 in a stationary field experiment on the lands of the Institute of Agriculture of the Western Polissia of the National Academy of Agrarian Sciences of Ukraine (50º70'81"N; 26º54'55"E). The soil of the experimental plots was sod-podzolic *Albic Retisol* (Arenic, Aric) (WRB, 2022). The experiment was conducted with the Astarta winter wheat variety (developed by the Institute of Plant Physiology and Genetics, NAS of Ukraine). The experimental plots were arranged sequentially with three replications. The sowing area of the plot was 99 m^2 (16.5 × 6 m), and the accounting area was 50 m^2 (12.5 × 4 m).

The recommended rate of mineral fertilizers for winter wheat in the Western Polissia zone was $N_{120}P_{60}K_{90}$. The calculated rates of mineral fertilizers were determined by the normative method, considering the uptake of NPK by one unit of yield and the level of soil nutrient supply: 1) for the formation of 5 t ha^{-1} of grain:

$N_{130}P_{25}K_{35}$; 2) for the formation of 5 t ha^{-1} of grain with a corresponding amount of straw: $N_{150}P_{50}K_{125}$.

The experiment included the following treatment options: V1) without fertilizers (control); V2) DL (1.0 Hh); V3) DL (1.0 Hh) + $N_{120}P_{60}K_{90}$ (recommended rate) + Microfertilizer Nutrivant universal (MF); V4) DL (1.0 Hh) + $N_{130}P_{25}K_{35}$ (normative rate for grain formation) + MF; V5) DL (1.0 Hh) + $N_{150}P_{50}K_{125}$ (normative rate for grain and straw formation) + MF; V6) DL (1.0 Hh) + N_{130} (normative rate for grain formation) + MF; V7) DL (1.5 Hh) + $N_{120}P_{60}K_{90}$ (recommended rate) + MF; V8) LS (1.0 Hh) + $N_{120}P_{60}K_{90}$ (recommended rate).

Mineral fertilizers were applied in the form of ammonium nitrate, ammophos, and potassium chloride in accordance with the treatment option: PK fertilizers were applied during plowing, and N fertilizers were applied three times: N_{40} for cultivation fertilization, N_{60} in early spring at the stage of resumed plant growth, and the remainder at the stage of stem elongation before ear emergence. The Nutrivant universal microfertilizer (MF) was applied foliarly twice at a dose of 2 kg ha^{-1} in the phase of spring tillering (BBCH 25-27) and in the phase of stem elongation (BBCH 33-35) of winter wheat.

Ameliorants in the form of dolomite lime (DL) and limestone (LS) were applied according to the experimental scheme before sowing wheat. The application rates were determined based on the hydrolytic acidity (Hh, mol kg^{-1}) of the soil as follows: $D(1.0Hh) = Hh \times 1.5$. During the experiment, 3.0 t ha^{-1} of DL corresponded to a 1.0 Hh dose of $CaMg(CO_3)_2$, 4.5 t ha^{-1} to a 1.5 Hh dose of $CaMg(CO_3)_2$, and 3.5 t ha^{-1} of LS to a 1.0 Hh dose of $CaCO_3$.

Sampling procedure and measurements

Before initiating the experiment and at the end of winter wheat vegetation, soil samples were collected diagonally from five sampling points within the topsoil layer (0–20 cm) using a soil auger. For each experimental plot, the collected samples were combined and mixed thoroughly to create a representative sample. The samples were then dried, sieved through a 2-mm mesh, and analyzed using the following methods: pH in 1 M KCl by the potentiometric method, hydrolytic acidity by the Kappen’s method, organic carbon by the Tjurin’s method, alkaline hydrolyzable nitrogen by the Cornfield method, and available P_2O_5 and K_2O by the Kirsanov’s method (a soil to 2.0 M HCl extract ratio of 1:5) (Horodnyi et al., 2007). Soil texture was determined in dry soil samples by the pipette method as modified by Kachinsky (Standards Ukraine, 2007).

At physiological maturity (BBCH 89), 20 plants were randomly collected from each treatment plot (three replicates) to determine: ear and straw length, plant density, total number of tillers, number of grains per ear, 1000-grain weight, grain yield, straw yield, and harvest index (Hrytsaienko, 2003).

Statistical analysis

The data was analyzed using one-way analysis of variance (ANOVA) followed by Fisher's LSD test to determine significant differences at $P<0.05$. The treatment results were analyzed using Statistica software, version 10.0 (StatSoft Inc.).

Results and Discussion

Physical and agrochemical properties of soil

Table 1 presents the results of the initial physical and agrochemical properties of the experimental site soil. This loamy sand soil has a high sand content (83.0%) and a very low clay content (1.8%).

Table 1. Initial physical and agrochemical properties of Albic Retisol.

Parameters	Value	Rating
Particle size distribution, %		
sand (>0.05 mm)	83.0	
silt (0.05–0.001 mm)	15.2	
clay (<0.001 mm)	1.80	
Textural class	loamy sand	
Physical and agrochemical properties		
pH_{KCl}	4.05	strongly acid
hydrolytic acidity (Hh) mol kg^{-1}	2.00	needs amelioration
organic carbon (C)%	0.37	low
alkaline hydrolyzable nitrogen (N) mg kg^{-1}	40.6	low
available phosphorus (P_2O_5) mg kg^{-1}	183.0	high
available potassium (K_2O) mg kg^{-1}	68.4	medium

With a soil pH of 4.1, falling within the very acidic range (4.1–4.5), and a high hydrolytic acidity of 2.0 mol kg^{-1} of soil, the experimental site requires significant liming. This is especially crucial as winter wheat is highly sensitive to soil acidity, with an optimal pH level of 6.0–7.0. Baquy et al. (2017) noted that the critical soil pHs at different locations for wheat were 5.29 and 4.66.

The soil analysis result shows low levels of OC and alkaline hydrolysable nitrogen, and a medium level of available potassium. The high rating of available phosphorus (P_2O_5) determined by the Kirsanov method can likely be attributed to previous practices applying phosphorus with fertilizer. Thus, the application of a low rate of P_2O_5 (25–50 kg ha^{-1}) is justifiable to satisfy the wheat crop needs.

At the end of the winter wheat growing season, studies revealed changes in the content of mobile nitrogen, phosphorus, and potassium compounds within the 0–20-cm soil layer. These changes depended on the fertilization options applied (Figure 1).

The most significant changes compared to initial values were observed, on average over three years, in the control plot (no fertilizer) and the DL (1.0 Hh) variant that is due to the absence of additional nutrient input in these treatments. The deficit of hydrolyzable nitrogen and available potassium for subsequent crops will be partially compensated by incorporating the wheat straw into the soil. Interestingly, no decrease in the content of mobile phosphorus was observed compared to initial levels.

It was also found that applying phosphorus (P_{80}) as part of the recommended mineral fertilizer rate, compared to the counted rates (P_{25} and P_{50}), did not significantly increase the content of available phosphorus in the arable soil layer for growing wheat (LSD = ±10.4).

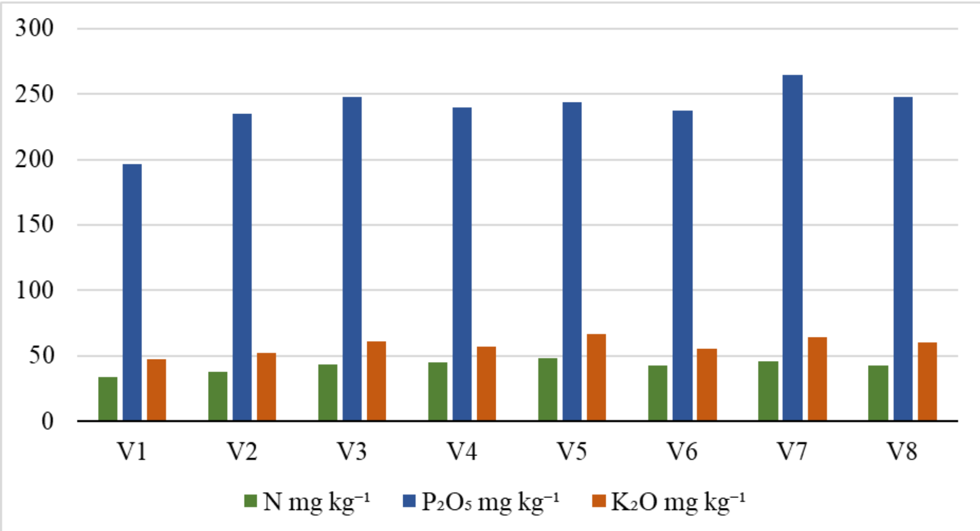
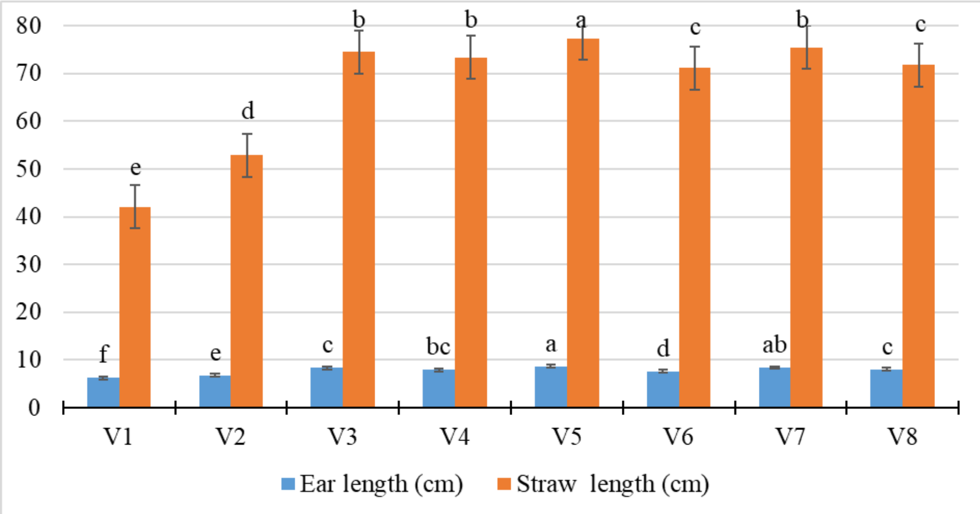


Figure 1. The content of alkaline hydrolyzable nitrogen (N), available phosphorus (P_2O_5) and potassium (K_2O) in the 0–20-cm layer of Retisol at the end of winter wheat vegetation (average for 2021–2023).

Plant height and yield components of winter wheat

Plant height plays a critical role in both wheat development and grain yield. The mean comparison for ear and straw length is presented in Figure 2.



Values with the same letters do not differ statistically at $P = 0.05$.

Figure 2. Indicators of the ear and straw lengths of winter wheat in the experiment, the average for 2021–2023.

The results showed that the application of DL (1.0 Hh) provided a statistically significant increase in plant height compared to the control. In addition, the application of N_{130} against the background of DL (1.0 Hh) statistically increased the length of both ear and straw compared to these treatments at $P<0.05$. However, the greatest increase in plant height was observed with the combination of ameliorants and complete mineral fertilizer. Interestingly, the variant with the recommended rate (DL [1.0 Hh] + $N_{120}P_{60}K_{90}$ [recommended] + MF) resulted in the maximum ear length (8.69 cm) and straw length (77.4 cm). This treatment showed statistically significant differences (LSD = ±0.25) for ear length and (LSD = ±1.61) for straw length compared to other treatments. These results are consistent with the findings of Malghani et al. (2010), who reported a linear response in wheat growth and yield to NPK fertilization. Vishwakarma et al. (2023) suggest that the high solubility of mineral fertilizers allows for the quick release of nutrients into the soil solution, promoting optimal nutrient uptake by plants and consequently enhancing growth and yield.

In the variant with the recommended rate DL (1.0 Hh) + $N_{120}P_{60}K_{90}$ (recommended) + MF, compared to the DL (1.0 Hh) + $N_{130}P_{25}K_{35}$ (normative rate for grain formation) + MF variant, a statistically significant increase in ear length was noted. In contrast, the difference in straw length was not statistically significant at $P<0.05$. Increasing the DL rate from 1.0 to 1.5 Hh in combination with the recommended rate also had no significant effect on plant height.

To create high-yielding crops, it is important to understand how elements of cultivation technology, including chemical soil amelioration and fertilization systems, affect the formation of yield components. For cereal crops, the most important of these are the number of productive tillers, the ear length, the number of grains per ear, and the grain mass per ear (Polishchuk and Konovalov, 2022).

The lowest values of yield structure indicators were obtained in the control plot without fertilizers (Table 2). The three-year average data for these indicators in the control plot were statistically comparable to the results from other experimental variants. The dolomite lime treatment DL (1.0 Hh) represents a dividing line between the unfertilized control and the treatment where the ameliorant was applied in combination with NPK fertilizer. The application of DL (1.0 Hh) led to a statistically significant result (*P*<0.05) for all yield structure indicators compared to the other variants.

Table 2. Elements of the structure of the winter wheat crop depending on fertilization and ameliorants (the average for 2021–2023).

Treatment	Plant density pcs. m^2	Total number of tillers pcs. m^2	Number of grains per ear pcs.	1000-grain weight, g
V1	248^{e}	289^{e}	25.8^{f}	27.4^{d}
V2	287^{d}	339^{d}	27.0^{e}	29.3^{c}
V3	322^{ab}	390^{b}	33.9^{bc}	34.1^{a}
V4	320^{ab}	387^{b}	33.6^{bc}	33.7^{a}
V5	329^{a}	405^{a}	35.0^{a}	35.1^{a}
V6	307^{c}	362^{c}	31.4^{d}	32.2^{b}
V7	324^{ab}	396^{ab}	34.1^{ab}	34.4^{a}
V8	319^{b}	386^{b}	32.9^{c}	33.9^{a}
LSD_{05}	9.29	13.5	1.02	1.43

Means within each column with the same letters do not differ statistically at *P*<0.05.

Wheat yield potential is heavily influenced by the number of tillers a plant produces. Estimating tiller numbers serves as a valuable tool for monitoring wheat growth and ultimately forecasting final yield (Wu et al., 2022). Improving mineral nutrition through fertilization on a limed background promoted the growth of plant density and total number of productive stems. However, neither the types of ameliorants (DL or LS) nor the rates (1.0 or 1.5 DL), in combination with $N_{120}P_{60}K_{90}$ (recommended) + MF, had a statistically significant effect on tillering. Iljkić et al. (2011) found that the liming with dolomite meal significantly increased the number of spikes at all liming treatments compared with the control, but no significant difference was observed between rates of 5–15 t ha^{-1} of dolomite.

On the positive side, in the variant DL (1.0 Hh) + $N_{130}P_{25}K_{35}$ (normative rate for grain formation) + MF, the decrease in phosphorus and potassium compared to the recommended rate did not cause a significant decrease in the total number of shoots per m^2, but the difference was significant compared to the variant DL (1.0 Hh) + $N_{150}P_{50}K_{125}$ (normative rate for grain and straw formation) + MF. According to Brennan and Bolland (2008), the effectiveness of potassium fertilizer application depends heavily on the level of nitrogen available to the plant. In general, applying increasing rates of K increased the rate of N required to achieve 90% of the maximum grain yield. The absence of phosphorus and potassium in the winter wheat nutrition scheme in the DL (1.0 Hh) + N_{130} (normative rate for grain formation) + MF variant caused a decrease in plant density by 13–22 pcs. m^2 and in the total number of tillers by 24–43 pcs. m^2 compared to other NPK rates in the treatments.

The highest total number of tillers (405 pcs. m^2) was obtained in the DL (1.0 Hh) + $N_{150}P_{50}K_{125}$ (normative rate for grain and straw formation) + MF variant. The lowest among the fertilized variants was 362 pcs. m^2 in DL (1.0 Hh) + N_{130} (normative rate for grain formation) + MF.

The number of grains per ear (ranging from 25.8 to 35.0 pcs.) and thousand-grain weight (from 27.4 to 35.1 g), both important yield parameters affecting wheat grain yield, varied across the three-year treatments. The highest average values for both parameters were recorded with the application of DL (1.0 Hh) + $N_{150}P_{50}K_{125}$ (normative rate for grain and straw formation) + MF, while the unfertilized treatment resulted in the lowest values. According to Usman et al. (2020), a balanced nutrient supply promotes ear elongation, leading to more spikelets per spike and ultimately, heavier, and fuller grains.

The application of the fertilizer rate calculated based on the nutrient removal by the main product (DL [1.0 Hh] + $N_{130}P_{25}K_{35}$ [normative rate for grain formation] + MF) did not cause a significant decrease in the number of grains per ear compared to the application of the recommended NPK rate on different backgrounds of dolomite lime and limestone.

The weight of 1000 grains did not change significantly with the application of different NPK rates together with ameliorants and microfertilizers (LSD = ±1.43).

Yield and harvest index

This soil is characterized by low natural fertility, especially in terms of organic matter and nitrogen content. This resulted in an average winter wheat yield of 2.04 t ha^{-1} in the unfertilized control variant from 2021 to 2023 (Table 3).

The application of ameliorants created the preconditions for increasing the efficiency of mineral fertilizers. Applying DL (1.0 Hh) under winter wheat increased grain yield by 0.64 t ha^{-1} and straw yield by 0.65 t ha^{-1} compared to the control. The combination of DL (1.0 Hh) and the recommended rate of $N_{120}P_{60}K_{90}$ (recommended) + MF resulted in the average grain yield increase for 2021–2023 of 122.1 and 69.0% compared to the control and DL (1.0 Hh), respectively. However, increasing the DL rate to 1.5 Hh did not significantly affect the grain or straw yield compared to the previous variant at $P<0.05$.

Table 3. The influence of fertilization systems and chemical melioration on the productivity of winter wheat.

Treatment	Grain, t ha^{-1}		Straw, t ha^{-1}		Harvest index, %
	yield	increase compared to control	yield	increase compared to control	
V1	2.04^{g}	-	2.39^{f}	-	46^{d}
V2	2.68^{f}	0.64	3.04^{e}	0.65	47^{cd}
V3	4.52^{bc}	2.48	4.78^{b}	2.39	49^{b}
V4	4.38^{dc}	2.34	4.15^{d}	1.76	51^{a}
V5	4.97^{a}	2.93	5.21^{a}	2.91	46^{bc}
V6	3.66^{e}	1.62	4.40^{c}	2.01	45^{d}
V7	4.64^{b}	2.60	4.89^{b}	2.50	49^{b}
V8	4.31^{d}	2.27	4.77^{b}	2.38	47^{cd}
LSD_{05}	0.17		0.23		1.85

Means within each column with the same letters are not statistically different at $P = 0.05$.

Replacing DL (1.0 Hh) with LS (1.0 Hh) in combination with $N_{120}P_{60}K_{90}$ (recommended) + MF resulted in a significant decrease in the average grain yield by 0.21 t ha^{-1} but did not affect the straw yield. The advantage of DL is probably due to the improvement of not only the physical and chemical properties of the soil but also the plant nutrition with magnesium, which is very important due to its light granulometric composition.

The application of DL (1.0 Hh) + $N_{130}P_{25}K_{35}$ (normative rate for grain formation) + MF provided an average grain yield of 4.38 t ha^{-1} over the years of research. The difference in grain yield for this variant, compared to the recommended rate of $N_{120}P_{60}K_{90}$ (recommended) + MF with 1.0 Hh of ameliorant, regardless of its type, did not exceed the LSD = ±0.17 of the experiment. However, the difference in straw yield was significant (LSD = ±0.21). This means that the application of the recommended rates of $P_{60}K_{90}$ in the NPK nutrition increases the total plant biomass. Mojid et al. (2012) note that the treatment with 40 kg P ha^{-1} produced the longest plant height and the maximum biomass yield, but not the highest grain yield or harvest index.

The complete exclusion of PK from the winter wheat fertilization system in the variant DL (1.0 Hh) + N_{130} (normative rate for grain formation) + MF, which is sometimes practiced in production conditions, led to a statistically significant decrease in grain yield to 3.66 t ha^{-1} and straw yield to 4.40 t ha^{-1} compared to other fertilized variants at P<0.05. At the same time, a harvest index of 45 indicates an increase in straw with the unilateral application of nitrogen fertilizers.

The highest average yields of winter wheat grain (4.97 t ha^{-1}) and straw (5.21 t ha^{-1}) over the research years were determined in the DL (1.0 Hh) + $N_{150}P_{50}K_{125}$ (normative rate for grain and straw formation) + MF variant. However, the yield index of 48 units was lower than that of the DL (1.0 Hh) + $N_{130}P_{25}K_{35}$ (normative rate for grain formation) + MF variant (51 units), indicating a more significant increase in straw within the crop biomass. To assess the relationship between grain yield and its structural elements, the Pearson's correlation coefficient was calculated (Table 4).

Table 4. The Pearson's correlation between winter wheat grain yield and structural elements of the harvest.

Parameter	Grain yield, t ha^{-1}	Ear length, cm	Straw Length, cm	Plant density, pcs. m^2	Total number of tillers, pcs. m^2	Number of grains per ear, pcs.	1000 grain weight, g
Grain yield, t ha^{-1}	1						
Ear length, cm	0.994	1.000					
Straw length, cm	0.972	0.968	1.000				
Plant density, pcs. m^2	0.967	0.959*	0.979	1.000			
Total number of tillers, pcs. m^2	0.982	0.975	0.972	0.995	1.000		
Number of grains per ear, pcs.	0.994	0.987	0.978	0.953*	0.965	1.000	
1000-grain weight, g	0.997	0.990	0.981	0.975	0.985	0.993	1

The correlation is significant at the probability levels of $P<0.001$, $*P<0.01$.

The results of the study revealed strong positive correlations between grain yield and several structural elements, with significance levels of $P<0.001$ and in some cases $P<0.01$. The correlation coefficients between grain yield and ear length, number of grains per ear, and 1000-grain weight were particularly high, exceeding 0.95 in all cases. These findings indicate that increasing these structural elements through breeding or agronomic practices could lead to significant gains in crop productivity.

Conclusion

The study reveals that the return of winter wheat plant residues into the Retisoil with high available phosphorus and average potassium enables a reduction in phosphorus and potassium fertilizer rates for winter wheat, matching the amounts removed by the main products, without significantly affecting the yield. This practice also improves the harvest index ratio. In the DL (1.0 Hh) + $N_{130}P_{25}K_{35}$ (normative rate for grain formation) + MF variant, yield structure indicators were comparable to those achieved with the recommended dose of

$N_{120}P_{90}K_{90}$ mineral fertilizer, and grain yield differences were not statistically significant. Although the highest yield structure and crop indicators were observed in the DL (1.0 Hh) + $N_{150}P_{50}K_{125}$ (normative rate for grain and straw formation) + MF variant, the optimal harvest index (51.0) was attained with fertilizer doses tailored to winter wheat grain removal. Furthermore, the absence of phosphorus-potassium nutrition in the study led to a significant decrease in both grain yield and the yield index.

Given that the use of crop by-products as fertilizer is promising for reducing mineral fertilizer rates, further research in this area is needed to ensure the sustainable and productive functioning of agriculture.

Acknowledgments

This research was part of the Scientific Research Program 2 “Farming Systems for Land Use Optimization in Agro-landscapes” of the National Academy of Agrarian Sciences of Ukraine, state registration number: 0121U108408.

References

Abdeta, A. (2021). Soil Test Based Fertilizer Recommendation for Wheat Production in Ethiopia: Review. *Research & Development*, *2* (3), 50-53. https://doi.org/10.11648/j.rd.20210203.13

Baquy, M. A.-A., Li, J.-Y., Xu, C.-Y., Mehmood, K., & Xu, R.-K. (2017). Determination of critical pH and Al concentration of acidic Ultisols for wheat and canola crops. *Solid Earth, 8*, 149-159. https://doi.org/10.5194/se-8-149-2017

Brennan, R.F., & Bolland, M.D.A. (2008). Comparing the Nitrogen and Potassium Requirements of Canola and Wheat for Yield and Grain Quality. *Journal of Plant Nutrition*, *32* (12), 2008-2026. https://doi.org/10.1080/01904160903308127

Degodiuk, E.H., Vitvitska, O.I., & Degodiuk, T.S. (2014). Modern approaches to optimization of mineral nutrition of plants in organic farming. *Collection of scientific works of the National Scientific Center "Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine"*, 1-2, 33-39.

Horodnyi, M., Lisoval, A., & Bykin, A. (2007). *Agrochemical analysis*. Kyiv: Aristei.

Hospodarenko, H., Mostoviak, I., Karpenko, V., Liubych, V., & Novikov, V. (2022) Yield and quality of winter durum wheat grain depending on the fertiliser system. *Scientific Horizons*, *25* (3), 16-25. https://doi.org/10.48077/scihor.25(3).2022.16-25

Hrytsaienko, Z.M. (2003). *Methods of biological and agrochemical research of plants and soils*. K.: CJSC "NICHLAVA".

Jelic, M., Milivojevic, J., Nikolic, O., Djekic, V., & Stamenkovic, S. (2015). Effect of long-term fertilization and soil amendments on yield, grain quality and nutrition optimization in winter wheat on an acidic pseudogley. *Romanian Agricultural Research*, *32*, 165-174.

Jiang, X., Li, J., An, Z., Liang, J., Tian, X., Chen, Y., Sun, Y., & Li, Y. (2023). Optimal Fertilization Strategies for Winter Wheat Based on Yield Increase and Nitrogen Reduction on the North China Plain. *Sustainability*, *15* (5), 4199. https://doi.org/10.3390/su15054199

Iljkić, D., Rastija, M., Drezner, G., Karalić, K., & Sudar, R. (2011). Impacts of liming with dolomite on the wheat yield. *Proceedings of International Conference „Soil, Plant and Food Interactions”,* (pp. 141-146). Faculty of Agronomy, Mendel University in Brno, Czech Republic.

Lykhochvor, V., Gnativ, P., Andrushko, O., Ivanyuk, V., & Olifir, Y. (2022). The role of nutrients in the formation of yield and grain quality of winter wheat. *Bulgarian Journal of Agricultural Science*, *28* (1), 103-109. DOI: https://www.agrojournal.org/28/01-14.pdf

Malghani, A.L., Malik, A.U., Sattar, A., Hussain, F., Abbas, G., & Hussain, J. (2010). Response of growth and yield of wheat to NPK fertilizer. *Science International (Lahore), 24* (2), 185-189.

Mohsen, J., & Behzad, M.A. (2018). Optimizing application rate of nitrogen, phosphorus and cattle manure in wheat production: An approach to determine optimum scenario using response-surface methodology. *Journal of Soil Science and Plant Nutrition*, *18* (1), 13-26. https://dx.doi.org/10.4067/S0718-95162018005000102

Mojid, M.A., Wyseure, G.C.L., & Biswas, S.K. (2012). Requirement of nitrogen, phosphorus and potassium fertilizers for wheat cultivation under irrigation by municipal wastewater. *Journal of Soil Science and Plant Nutrition*, *12* (4), 655-665. http://dx.doi.org/10.4067/S0718-95162012005000023

Panayotova, G., Almaliev, M., & Kostadinova, S. (2017). Nitrogen uptake and expense in durum wheat depending on genotype and nitrogen fertilization. *Agricultural Science and Technology*, *8*, 26-34. https://doi.org/10.15547/ast.2017.01.005

Polishchuk, V., & Konovalov, D. (2022). Elements of crop structure and biological productivity depending on the technology of growing winter wheat seeds. *Agrobiology, 2*, 193-199. https://doi.org/10.33245/2310-9270-2022-174-2-193–199

Polovyi, V.M., & Yashchenko, L.A. (2021). Optimization of growing conditions for winter wheat on sod-podzolis soil by the fertilization and melioration in Western Polissia of Ukraine. *Achievements of Ukraine and the EU in ecology, biology, chemistry, geography and agricultural sciences*: Collective monograph. Vol.3. Riga, Latvia: "Baltija Publishing", pp. 90-108. https://doi.org/10.30525/978-9934-26-086-5-37

Shah, F., & Wu, W. (2019). Soil and Crop Management Strategies to Ensure Higher Crop Productivity within Sustainable Environments. *Sustainability, 11*, 1485. https://doi.org/10.3390/su11051485

Sidyakina, O.V., & Dvoretskyi, V.F. (2020). Productivity of winter wheat depending on nutrition backgrounds in the conditions of western Polissya. *Scientific Horizons, 7*, 45-52. https://doi.org/10.33249/2663-2144-2020-92-7-45-52

Standards Ukraine (2007). Soil quality. Determination of microaggregate composition by the pipette method in modifigation of N. A. Kachinsky (DSTU 4728:2007). Kyiv.

Usman, K., Tamado, T., & Wogeyehu, W. (2020). Effects of blended (NPSB) fertilizer rates on yield components, yield and grain quality of bread wheat (Triticum Aestivum L.) varieties at Kulumsa, South-Eastern Ethiopia. *International Journal of Research Studies in Biosciences, 8* (9), 14-27. https://doi.org/10.20431/2349-0365.0809003

Vishwakarma, M., Kulhare, P.S., Tagore, G.S., & Gontia, A.S. (2023). Growth Response of Wheat as Affected by Different Nutrient Sources and NPK Levels under Vertisols. *International Journal of Plant & Soil Science, 35* (21), 835-845. https://doi.org/10.20546/ijcmas.2020.910.316

WRB (2022). World Reference Base for Soil Resources. International soil classification system for naming soils and creating legends for soil maps. International Union of Soil Sciences (IUSS).

Wu, F., Wang, J., Zhou, Y., Song, X., Ju, C., Sun, C., & Liu, T. (2022). Estimation of Winter Wheat Tiller Number Based on Optimization of Gradient Vegetation Characteristics. *Remote Sensing*, *14* (6), 1338. https://doi.org/10.3390/rs14061338

Yang, X., Lu, Y., Ding, Y., Yin, X., Raza, S., & Tong, Y.A. (2017). Optimising nitrogen fertilisation: A key to improving nitrogen-use efficiency and minimising nitrate leaching losses in an intensive wheat/maize rotation (2008-2014). *Field Crops Research,* 206, 1-10. https://doi.org/10.1016/j.fcr.2017.02.016

Received: December 18, 2024
Accepted: October 4, 2025

UTICAJ OPTIMIZOVANIH MINERALNIH ĐUBRIVA NA PRINOS I NJEGOVE KOMPONENTE OZIME PŠENICE NA RETISOLU ZAPADNOG POLESJA U UKRAJINI

Volodymyr M. Polovyy[1], Liudmyla A. Yashchenko[2*] i Nadiia O. Yuvchyk[3]

[1]Institute of Agriculture of Western Polissia, National Academy of Agrarian Sciences of Ukraine, Shubkiv, Ukraine
[2]Department of Agrochemistry, Soil Science and Agriculture named after S.T. Vozniuk, National University of Water and Environmental Engineering, Rivne, Ukraine
[3]Department of Agroengineering, National University of Water and Environmental Engineering, Rivne, Ukraine

R e z i m e

Ispitivani su uticaji primene različitih doza mineralnih đubriva, zasnovanih na akumulaciji NPK u zrnu i zrnu i slami, u poređenju sa preporučenom dozom, na produktivnost useva ozime pšenice. Tretmani su primenjeni u odnosu na različite poboljšivače zemljišta, uz vraćanje biljnih ostataka u zemljište. Na retisolu je najviši prinos zrna ozime pšenice (4,98 t ha^{-1}) ostvaren primenom doze od 1,0 Hh (hidrolitička kiselost) dolomitnog kreča (DK) uz $N_{150}P_{50}K_{125}$ (doza zasnovana na akumulaciji NPK u zrnu i slami). Ovaj tretman je doveo do najboljih pokazatelja komponenti prinosa. Međutim, žetveni indeks bio je niži u poređenju sa $N_{130}P_{25}K_{35}$ (doza zasnovana na akumulaciji NPK u zrnu). Ovo ukazuje na veći odnos zrna i slame kod pristupa zasnovanog na akumulaciji NPK u zrnu. Uprkos slabijim pokazateljima komponenti prinosa, prosečan prinos u tretmanu sa DK (1,0 Hh) + $N_{130}P_{25}K_{35}$ nije pokazao statistički značajnu razliku u poređenju sa $N_{120}P_{60}K_{90}$ (preporučenom dozom) na nivou $P<0,05$. Izostanak đubriva PK u tretmanu sa N_{130} značajno je smanjio prinos (za 19%) u poređenju sa ostalim tretmanima u kojima je korišćeno đubrivo NPK. Primena krečnjaka u dozi od 1,0 Hh uz preporučenu dozu NPK nije poboljšala komponente prinosa, a prinos je bio manji za 0,21 t ha^{-1} u poređenju sa DK (1,0 Hh) u sličnim uslovima. Na osnovu rezultata, za optimalnu produktivnost ozime pšenice na retisolima preporučuje se primena doza mineralnih đubriva izračunatih prema iznošenju NPK glavnog proizvoda (zrna), u kombinaciji sa 1,0 Hh DK i vraćanjem biljnih ostataka u zemljište.

Ključne reči: zrno, slama, struktura prinosa, doze đubriva, dolomitni kreč, krečnjak.

Primljeno: 18. decembra 2024.
Odobreno: 4. oktobra 2025.

[*]Autor za kontakt: e-mail: rivne_apv@ukr.net

Journal of Agricultural Sciences (Belgrade) https://doi.org/10.2298/JAS2504367V
Vol. 70, No. 4, 2025 UDC: 635.15-181.1(477)
Pages 367-384 Original scientific paper

THE ROLE OF MICRONUTRIENT FERTILIZERS IN IMPROVING THE SEED QUALITY OF *RAPHANUS SATIVUS* L. VAR. *OLEIFERA* METZG. IN THE CARPATHIAN REGION OF UKRAINE

Oleksandra P. Voloshchuk, Ihor S. Voloshchuk, Valentyna V. Hlyva*, Halyna Y. Bilovus and Khrystyna V. Bilonizhka

Institute of Agriculture of Carpathian Region of National Academy of Agrarian Sciences of Ukraine, Volskogo Street, 5, Obroshino village, Lviv district, Lviv region, 81115, Ukraine

Abstract: The aim of the study was to determine the effect of foliar micronutrient fertilization on the productivity and seed quality of oil radish (*Raphanus sativus var. oleiformis* Pers.). The study included the Zhuravka and Fakel varieties, characterized by high yield potential and good adaptability to the conditions of the Carpathian region. The methodological basis included a field experiment, biometric measurements, and statistical analyses. The experimental plot area was 50 m^2 with three replications. The research was conducted during 2022–2024 at the Department of Seed Production and Seed Science of the Institute of Agriculture of the Carpathian Region, NAAS of Ukraine. The experiment included four foliar micronutrient application variants: control (without micronutrients), Oracul multicomplex, Yara Vita Rexolin, and Intermag-oil, all applied against a background of mineral fertilization ($N_{30}P_{60}K_{70}$ + N_{50} at the BBCH 14–16 stage and N_{20} at the BBCH 52–53 stage). It was found that the applied micronutrients increased seed yield to 3.24–3.70 t·ha^{-1}, exceeding the control by 0.34–0.46 t·ha^{-1}. The difference between varieties was insignificant (0.09–0.10 t·ha^{-1}). The 1000-seed weight increased by 0.20–0.57 g (ranging from 8.86 to 10.22 g, depending on the year). The sowing qualities of seeds remained high: germination energy – 90.6–91.8%, and laboratory germination – 94.5–95.6%. The results have scientific and practical importance: combining mineral fertilization with foliar micronutrient applications enhances the realization of the genetic potential of oil radish, improving both yield and seed quality.

Key words: oil radish, variety, hydrothermal coefficient (HTC), seed yield, 1000-seed weight, germination energy, laboratory germination.

*Corresponding author: e-mail: valentinahlyva@gmail.com

Introduction

The intensive development of modern agro-industrial production depends by 30% on the use of high-quality seed material, which ensures uniform and timely germination of crops, reduces the impact of harmful organisms on plants, and contributes to increasing the yield potential of crops and the quality of the produced products without additional energy costs (Gavrilyuk, 2007; Bahan et al., 2020; Bahan et al., 2023).

A number of researchers have devoted their work to the theoretical substantiation of methods for cultivating seed material of agricultural crops, as well as to the preservation and improvement of its quality after harvest (Shelest et al., 2023; Grabovskyi et al., 2023; Panchyshyn et al., 2023; Hereshko et al., 2021).

Researchers describe the differences in morphological traits, biochemical composition, and physiological state during seed formation under the influence of various endogenous and exogenous factors at different stages of the maternal plant's life (Palamarchuk et al., 2017; Tsitsyura, 2019; Hasanuzzaman et al., 2013; Xu et al., 2006).

As a result of the influence of various factors during the life stages of maternal plants, seeds undergo changes and exhibit differences (Tsitsyura and Tsitsyura, 2015; Dorofeev et al., 2013). Oilseed radish is characterized by variability in seed formation both within the pods in the spatial structure and on the lateral productive branches of the stem. This crop has a number of specific features, including: indehiscent pods with relatively strong walls; high variability in pod linear dimensions within an inflorescence; pronounced maternal variability within the inflorescence, particularly between the extreme apical and lower basal pods; intensive lateral branching with significant differences in flowering and maturation stages; and rapid drying of the generative part of the stem compared to its vegetative portion. All these factors determine high variability in the morphological and weight parameters of seeds within the plant, which affects the thousand-seed weight. The heterogeneity of seeds in terms of physical, sowing, and physiological-biochemical properties within the reaction norms of the genotype to environmental conditions is regulated by DSTU 2949-94 (1996).

One of the important technological elements and a key reserve for improving the sowing qualities of oilseed crops is the enhancement of soil and foliar nutrient supply conditions for plants (Jia et al., 2021a; Butenko and Jia, 2022; Jia et al., 2021b; Radchenko, 2008; Butenko et al., 2022; Makrushin et al., 2006).

Tsitsyura and Kovalchuk (2019) state that the thousand-seed weight, as a biological parameter, is a varietal-specific trait that remains relatively stable for the crop, maintained by plant architecture and a reduction in the number of seeds per pod. However, the use of foliar applications of the complex water-soluble micronutrient fertilizer Folikea, along with the frequency of foliar feedings, can increase this parameter and enhance the fractional composition based on the external surface area, which serves as a reliable indicator of the seed linear dimension expressions.

The aim of the study was to investigate the effect of foliar application of micronutrient fertilizers on the formation of varietal productivity components and the sowing qualities of oilseed radish seeds under the conditions of the Carpathian region of Ukraine.

Material and Methods

The research was conducted during 2022–2024 at the Department of Seed Production and Seed Science of the Institute of Agriculture of the Carpathian Region, National Academy of Agrarian Sciences (NAAS) of Ukraine (49°47′07″ N, 23°52'07"E; 314 m a.m.s.l.).

The yield and sowing qualities of oilseed radish varieties were determined depending on foliar application of micronutrient fertilizers.

The soil of the experimental plots was gray forest soil, surface-gleyed, light loam, characterized by the following weighted average agrochemical indicators: humus content (according to Tyurin) – 2.3%, sum of exchangeable bases – 13.7 mg-eq per 100 g of soil, alkali-hydrolyzable nitrogen (according to Kornfeld) – 89.6 mg/kg of soil, available phosphorus and exchangeable potassium (according to Kirsanov) – 69.5 and 68.0 mg/kg of soil, respectively. According to the classification, this soil has very low nitrogen and potassium content and medium phosphorus content. The soil solution reaction (pH_{sol}) was slightly acidic at 5.4.

The forest-steppe zone extends from the Carpathians to the eastern borders of Ukraine, covering an area of over 14 million hectares, with more than a third (33.6%) classified as agricultural land. This zone is characterized by heterogeneous soil and climatic conditions, which determine the crop composition in crop rotations recommended for cultivation. When planning crop rotations, soil moisture conditions are taken into account, as they influence the choice of predecessor for each subsequent crop and affect soil moisture regimes. The Lviv Oblast is located in the subzone of sufficient moisture, where the annual precipitation ranges from 570 to 600 mm, and during the growing season – from 380 to 450 mm. The sum of temperatures above 10°C reaches 2300–2500°C, while the hydrothermal coefficient (HTC) varies from 1.5 to 1.8.

During the growing season of oilseed radish in the study years, the hydrothermal coefficient (HTC) was 0.87 in 2022 (moderately insufficient), 1.66 in 2023 (excessive), and 1.16 in 2024 (optimal), compared to the standard range of 1.1–1.6 accepted for the Western forest-steppe (Figure 1).

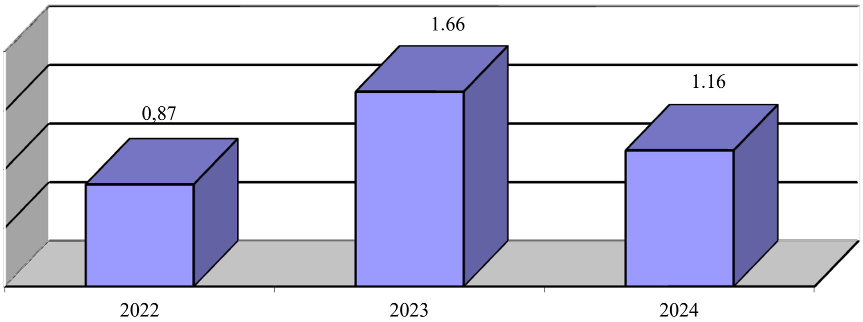


Figure 1. Humidity level (2021–2023).

Note. HTC – level of moisture: 0.5–0.7 – weak; 0.8–1.0 – average insufficient; 1.1–1.5 – optimal; > 1.6 – excessive.

During the spring sowing period of spring oilseed crops in 2022, the temperatures exceeded 5 °C in the third decade of March (Figure 2). April was cold, with air temperatures below the long-term average in all decades; the monthly mean was 6.5 °C compared to the norm of 7.4 °C. In the first and third decades, significant precipitation was recorded (31.0 mm and 44.9 mm, respectively, compared to norms of 16 mm and 19 mm). The total monthly precipitation exceeded the norm by 31 mm.

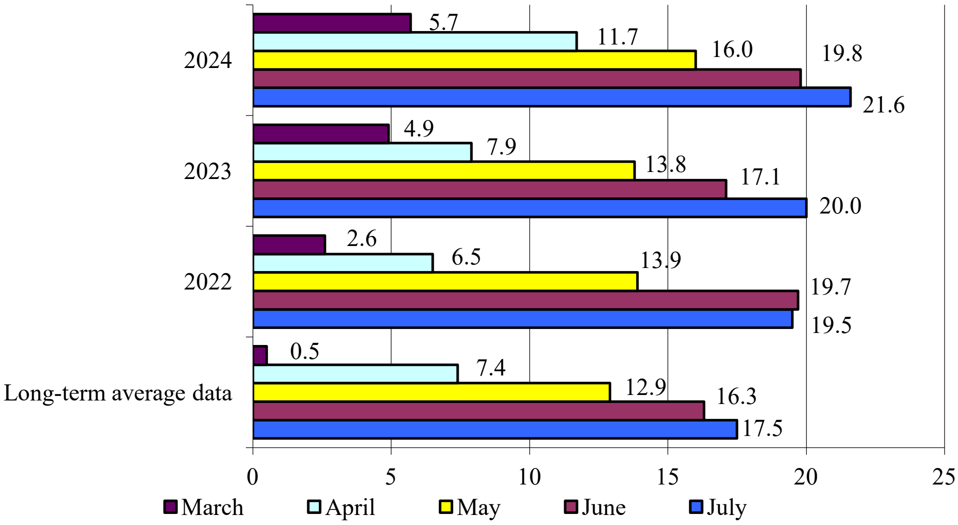


Figure 2. Average daily air temperature during the growing season (2022–2024), °C.

All three decades of May were warm and dry. Air temperatures exceeded the long-term averages by 1.6°C, 1.2°C, and 0.4°C, while precipitation was lower by 21.8 mm, 27.2 mm and 11.7 mm, resulting in only 28.6% of the monthly norm. The average monthly temperature in June was 3.4°C higher, and precipitation was lower, amounting to 66% of the long-term average. A similar trend was observed in July, with air temperatures in all decades 0.9–3.8°C above the long-term average and precipitation 16.5 mm below the norm.

In 2023, the temperature increased to 9.8 °C during the second decade of April and to 10°C in the third decade, and sufficient precipitation (22.9 and 20.0 mm) facilitated the sowing of white mustard in the third decade of April (Figure 3).

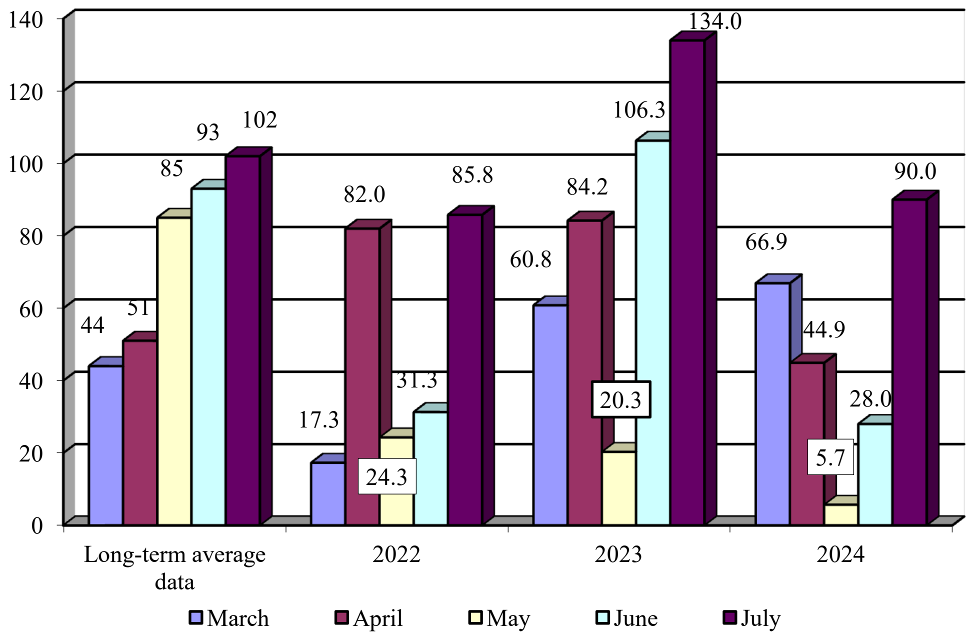


Figure 3. Precipitation during the growing season (2022–2024), mm.

The reserves of productive moisture in the soil layer (0–10 cm) amounted to 16.5 mm, which was sufficient for achieving uniform germination. In the first decade of May, a slight decrease in air temperature by 0.6°C and low precipitation of 4.3 mm (compared to the long-term decade average of 24 mm) were observed. In the second decade, the temperature slightly increased by 0.5°C, but precipitation remained insufficient (12.8 mm compared to the norm of 30 mm). In the third decade, air temperature was 2.8°C higher, while precipitation reached only 41.9%

of the norm. The second and third decades of June were characterized by abundant rainfall, exceeding the long-term decade averages by 17.0 and 17.6 mm, respectively. In the first decade of July, the air temperature rose to 20.5°C (compared to 16.7°C), while precipitation decreased to 26.5 mm against the decade average of 32.0 mm. The temperature regime in the second and third decades of July was also higher by 2.5 and 1.4°C, while precipitation corresponded to the long-term decade norms.

In 2024, the average monthly temperature in March exceeded the long-term average by 5.2°C, and precipitation was higher by 22.9 mm. All decades of April were abnormally warm, with the average monthly temperature 4.3°C above the long-term norm and slightly lower precipitation by 6.1 mm. During the first decades of May, temperatures remained high with very low precipitation (1.8–1.7 mm); the monthly mean temperature exceeded the long-term average by 3.1°C, while precipitation was 72.2 mm lower than the norm (85 mm). In the first decade of June, precipitation was also lower by 26.9 mm, while air temperature was 3.4°C higher. The second and third decades of June were wet (+16.8 and +17.6 mm) and warm (+2.3 and +4.9°C) compared to the long-term averages. In the first decade of July, high temperatures also prevailed at 20.9°C (based on long-term average data 16.7°C), with precipitation slightly higher by 4.8 mm than the long-term average. In the second and third decades of July, temperatures exceeded the norm by 6.0 and 2.3°C, while precipitation was lower by 8.5 and 30.2 mm, respectively.

The cultivation technology, commonly used for this crop in the region, included: soil preparation – stubble cultivation to a depth of 10–12 cm, and plowing to 20–22 cm. The predecessor crop was common maize. Sowing took place in the third decade of April. The seed rate was 2.0 million viable seeds per hectare. Fertilization included $N_{30}P_{60}K_{70}$ + N_{50} at BBCH 14–16 (leaf development) + N_{20} at BBCH 52–53 (flowering). Seeding depth was 2–4 cm. The sowing method was conventional row planting (15-cm spacing). Seed protection comprised: seed dressing – Modesto 480 FS, 48 % flowable concentrate (insecticidal-fungicidal action, 12.5 l t^{-1}); plant protection – herbicides: Roundup NEW 48% aqueous solution (applied 2–3 weeks before plowing), Butisan® 400 suspension concentrate (1.75–2.50 l ha^{-1}); insecticide (against hidden weevil and pollen beetle) – Calypso 48% suspension concentrate (0.15 l ha^{-1}). Total plot area was 60 m², accounting area – 50 m², and replication was done three times.

The objects of the study were oilseed radish varieties: Zhuravka developed by the Prykarpattia State Breeding and Experimental Station (DSDS) of the Institute of Agriculture of the Carpathian Region NAAS of Ukraine, and Fakel – from the Institute of Oilseed Crops NAAS of Ukraine (Figure 4).

a) b)

Figure 4. Sowing of oilseed radish in the Institute's experimental plots:
a) Zhuravka, b) Fakel at the main growth stage 7 (fruit formation),
b) BBCH phase 78 (80% of pods have reached their final size).

The research was carried out using the generally accepted methods outlined below.

Based on data from the Hydromelioration Observation Station of the Institute of Agriculture of the Carpathian Region NAAS of Ukraine, the sum of the temperature regime (°C) and the amount of precipitation (mm) during the growing season of oilseed radish plants were determined.

For each variety, the seeding rate (SR) of seeds was calculated, and adjusted for sowing quality, using the following formula.

For each variety, the seeding rate (R) of seeds adjusted for sowing suitability was determined using the formula:

$$\mathbf{R} = \frac{\boldsymbol{N * M}}{\mathbf{SS * 10000}}, \quad (1)$$

where N – the number of plants per hectare (pcs);

M – the thousand-seed weight (g);

SS – the seed germination percentage (%);

10000 – a constant value.

H – the purity was determined (from 3 samples of 1 kg of seeds each) based on the ratio of the mass of seeds of the main crop to the total sample taken for analysis (%).

Seed quality for sowing (SS) was calculated using the following formula:

$$\mathbf{SS} = \frac{\mathbf{LG * P}}{\mathbf{100}}, \quad (2)$$

where LG – the laboratory germination of seeds (the proportion of germinating seeds determined under laboratory conditions by germination at an optimal temperature of 23°C in a dry-air thermostat TS-80 (Figure 5) for 6 days, according to DSTU 4138-2002 (2003), expressed as a percentage;

P – the purity, calculated (from 3 samples of 1 kg of seeds each) as the ratio of the mass of seeds of the main crop to the total mass of the sample taken for analysis (%).

Figure 5. Dry-air thermostat TS-80.

Thousand-seed weight (M) was determined by weighing two samples of 1,000 seeds each, and the average mass was calculated with an accuracy of 0.1 g. If the mass of the two samples differed from the average by more than 0.5 %, a third sample was weighed, and the final value was calculated using the following formula:

$$M = \frac{M1x(100-h)}{100-Sh} \quad (3)$$

M_1 – mass of 1000 seeds, g,

h – seed moisture content, %,

Sh – standard moisture content of oilseed radish seeds – 8 %.

The methodology for evaluating oilseed radish (*Raphanus sativus L. var. oleifera Metrg.*) varieties for distinctness, uniformity, and stability was applied (Ministry of Agrarian Policy and Food of Ukraine, 2023). Yield was determined by harvesting each plot with a Sampo-130 combine and weighing the harvested seeds. Sowing qualities of the seeds were assessed in the laboratory. Statistical analysis of the results was performed using analysis of variance (ANOVA), and the processing and generalization of experimental results were conducted using a single-factor design on a computer with Microsoft Excel (Ushkarenko et al., 2014).

Results and Discussion

The fullest realization of the genetic potential of oilseed radish varieties is ensured by the application of both macro- and micronutrients during the critical stages of plant development (Hereshko et al., 2021).

To achieve maximum productivity of oilseed radish varieties, the cultivation technology included foliar feeding with micronutrients in addition to mineral fertilization at a rate of $N_{30}P_{60}K_{70}$, with additional top-dressings of N_{50} at the 4–6-leaf stage and N_{20} at the main shoot flowering stage (Figure 6). In 2023, seed yield in the control group (without micronutrients) was 2.88 t ha^{-1} for the Zhuravka variety, and 3.06 t ha^{-1} for the Fakel variety, with an average of 2.97 t ha^{-1}. The foliar application of the micronutrient fertilizer Orakul multicomplex (2.0 l ha^{-1}) increased the yield of Zhuravka by 0.46 t ha^{-1} compared to the control, Intermag–oil by 0.53 t ha^{-1}, and Yara Vita Rexolin by 0.62 t ha^{-1}. For Fakel, the control yield was 3.06 t ha^{-1}, while foliar feeding with Orakul multicomplex increased it by 0.43 t ha^{-1}. Higher gains of 0.54 and 0.60 t ha^{-1} were recorded with the application of Intermag–oil and Yara Vita Rexolin, respectively. In 2024, the average seed yield of oilseed radish in the control group (without micronutrients) was 2.63 t ha^{-1}, while foliar application of micronutrients increased yield by 0.24–0.32 t ha^{-1}. The highest statistically significant and practically comparable yields were obtained with the use of Intermag–oil (2.0 l ha) – 2.90 t ha^{-1}, and Yara Vita Rexolin (2.0 l ha^{-1}) – 2.95 t ha^{-1}.

Over the years of the study, the yield of the Zhuravka variety ranged from 3.19 t ha^{-1} in the control group (without foliar feeding) to 3.65 t ha^{-1} with the application of the micronutrient Yara Vita Rexolin at 2.0 l ha^{-1}. The yield increase compared to the control was 0.34 t ha^{-1} with Orakul multicomplex (2.0 l ha^{-1}), 0.40 t ha^{-1} with Intermag–oil (2.0 l ha^{-1}), and 0.46 t ha^{-1} with Yara Vita Rexolin (2.0 l ha^{-1}).

The average seed yield of the Fakel variety over the years of the study ranged from 3.29 t ha^{-1} in the control group (without foliar feeding) to 3.74 t ha^{-1} with the application of the micronutrient Yara Vita Rexolin at 2.0 l ha^{-1} (Figure 7). The yield increase compared to the control was 0.34 t ha^{-1} with Orakul multicomplex (2.0 l ha^{-1}), 0.40 t ha^{-1} with Intermag–oil (2.0 l ha^{-1}), and 0.45 t ha^{-1} with Yara Vita Rexolin (2.0 l ha^{-1}).

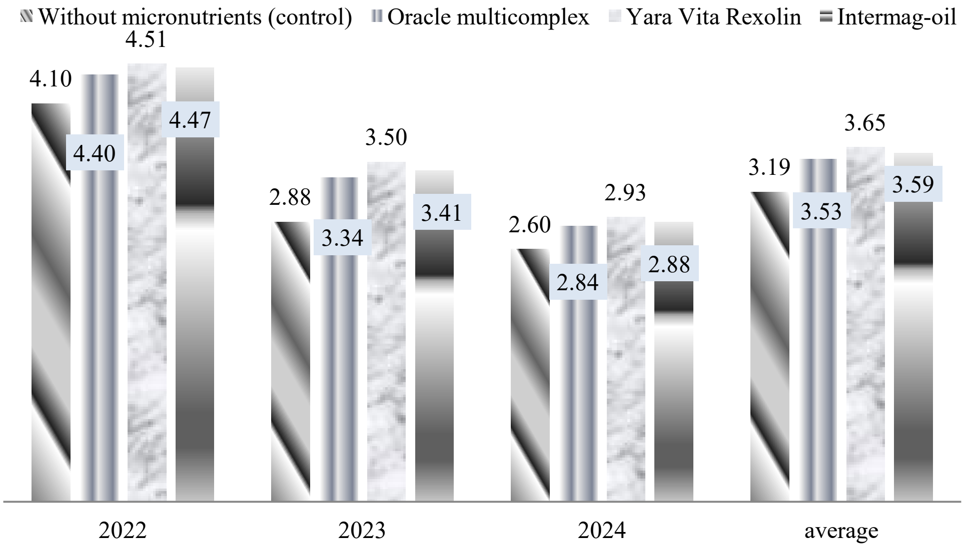


Figure 6. Seed yield of the Zhuravka oilseed radish variety depending on foliar application of micronutrients (2022–2024), t ha^{-1}.

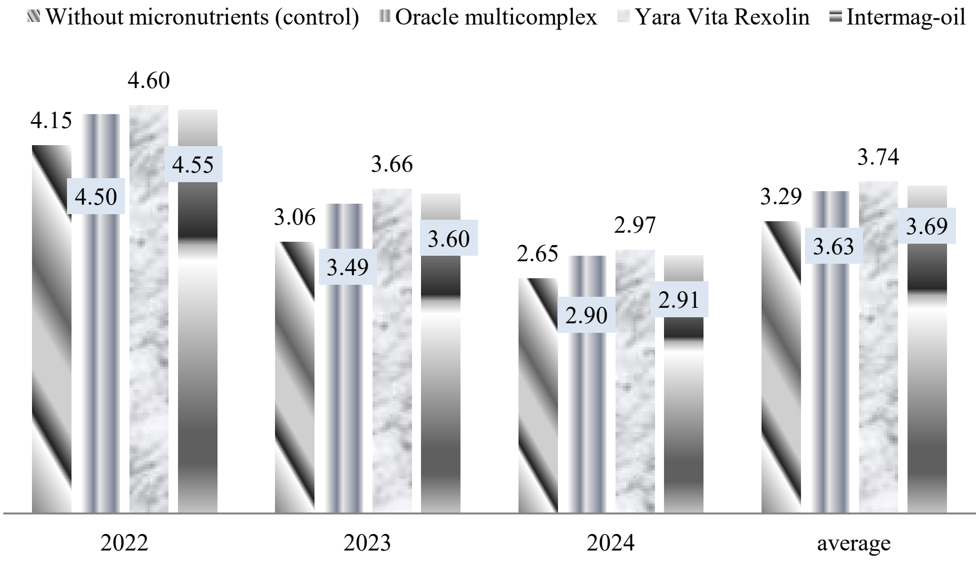


Figure 7. Seed yield of the Fakel oilseed radish variety depending on foliar application of micronutrients (2022–2024), t ha^{-1}.

As crop production intensifies, obtaining varietal seeds with high sowing and yield qualities becomes increasingly important. Thousand-seed weight indicates seed size. Sowing seeds with a high thousand-seed weight ensures uniform emergence, even plant development, synchronized maturation, and higher yields compared to small and lightweight seeds (Dorofeev et al., 2013).

The expansion of oilseed radish cultivation requires the production of a sufficient quantity of high-quality seeds. The formation of seed sowing qualities in various crops has been studied by many researchers; however, such studies on oilseed radish are limited, requiring further scientific generalization. The foliar application of micronutrients was observed to increase the thousand-seed weight (Figure 8). For the Zhuravka variety, this parameter ranged from 9.13 g in the control group (without micronutrients) to 9.65 g with the foliar application of Yara Vita Rexolin. A slight decrease in weight was noted with the use of Intermag–oil (by 0.11 g) and Orakul multicomplex (by 0.32 g). The highest thousand-seed weights (9.48–10.05 g) were recorded in 2022, while the lowest (8.74–9.15 g) were recorded in 2024.

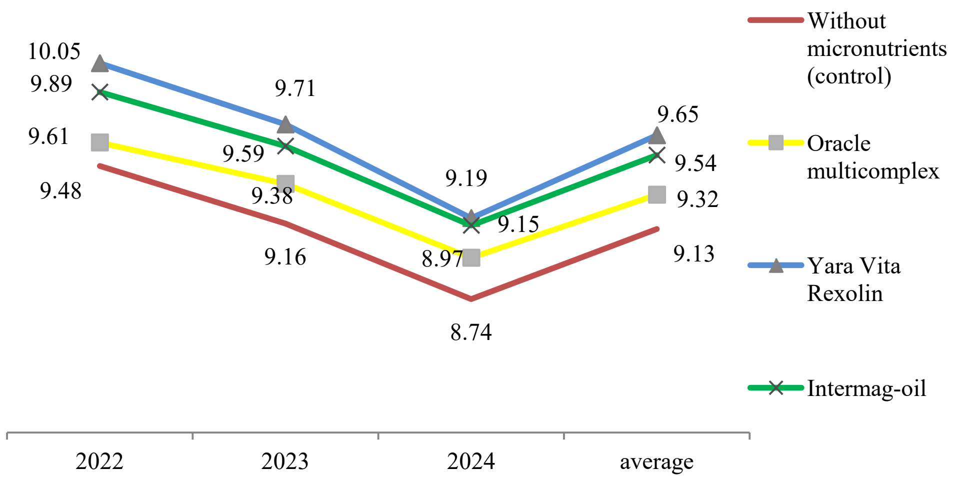


Figure 8. Thousand-seed weight of the Zhuravka oilseed radish variety depending on foliar application of micronutrients (2022–2024), g.

A similar trend was observed in the Fakel variety (Figure 9). The average thousand-seed weight in the control group (without micronutrients) was 9.24 g and increased to 9.86 g with foliar application of the micronutrient Yara Vita Rexolin. The increase in this parameter was 0.19 g with Orakul multicomplex (2.0 l ha^{-1}), 0.40 g with Intermag–oil (2.0 l ha^{-1}), and 0.62 g with Yara Vita Rexolin (2.0 l ha^{-1}).

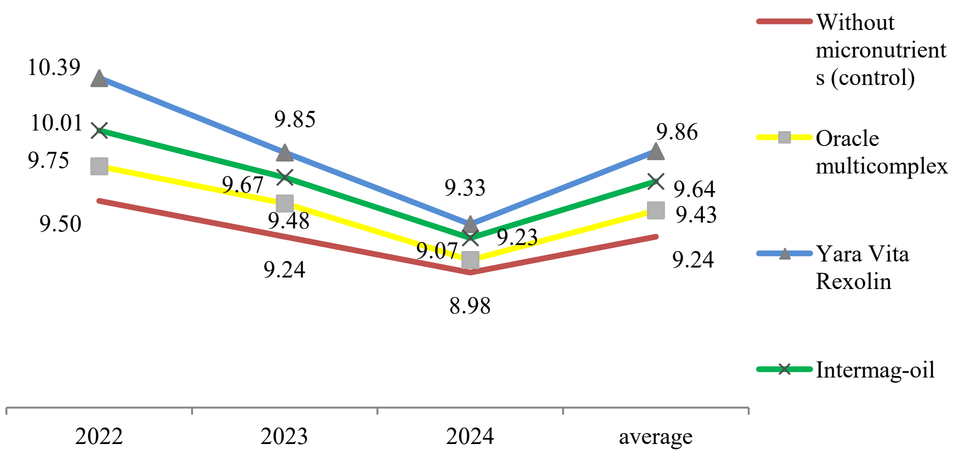


Figure 9. Thousand-seed weight of the Fakel oilseed radish variety depending on foliar application of micronutrients (2022–2024), g.

The greatest influence on the formation of thousand-seed weight was exerted by foliar-applied micronutrients (factor A) – 50%. The contribution of the variety (factor B) was 8%, their interaction (A×B) – 17%, and weather conditions (residual factor) – 25%.

One of the most important indicators for assessing seed quality is germination energy, which affects the uniformity of seedlings and the efficient use of growth factors. Seeds with high germination energy experience less suppression from weeds and show greater resistance to adverse environmental conditions. Germination energy depends on direct factors, such as thousand-seed weight, and indirect factors, such as the temperature regime during seed formation (Table 1).

Table 1. Germination energy of oilseed radish seeds depending on foliar micronutrient applications (average for varieties, 2022–2024), %.

Microfertilizer	Application rate of microfertilizers, l ha^{-1}, kg ha^{-1}	Year			Average		
		2021	2022	2023	%	± before control	
Without micronutrients (control)	-	91.9	90.4	89.5	90.6	-	-
Oracle multicomplex (control)	2.0	92.2	91.9	90.3	91.5	0.9	-
Yara Vita Rexolin	2.0	92.7	92.0	90.6	91.8	1.1	0.3
Intermag-oil	2.0	92.5	92.3	90.5	91.8	1.1	0.3
$SSD_{0.05}$		0.03	0.02	0.04			

In 2024, germination energy was the lowest, ranging from 89.5% to 90.6%, while in 2022 it was the highest at 91.9–92.7%. In the control group (without micronutrients), the average value over the years of the study was 90.6%, and it increased by 0.9–1.1% with the application of foliar micronutrients.

A high percentage of germination energy contributed to the formation of laboratory germination of oil radish seeds at the following levels: in 2022 – 95.2–96.1%, in 2023 – 94.5–96.0%, and in 2024 – 93.8–94.8% (Figure 10).

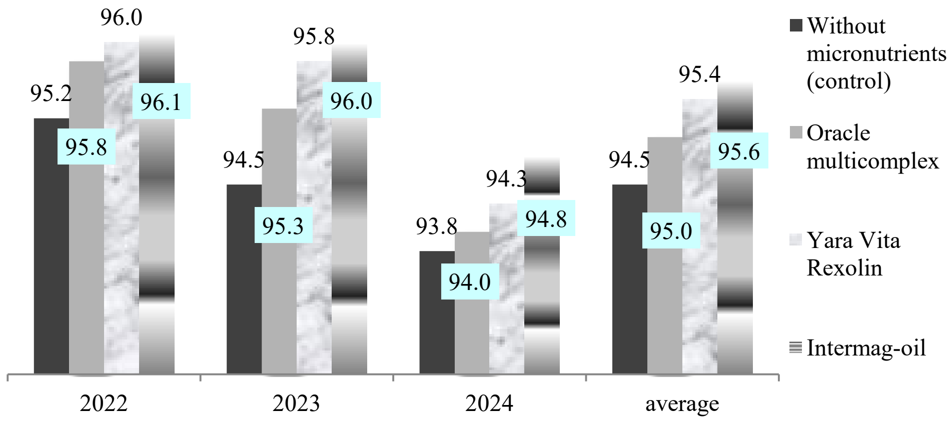


Figure 10. Laboratory germination of oil radish seed varieties depending on foliar micronutrient fertilization (average for varieties, 2022–2024), %.

Modern production technologies used in recent years in Ukraine and worldwide help reduce the negative anthropogenic impact on soils and promote energy and natural resource savings. To increase the production of high-quality oil radish seed varieties, a key element of the cultivation technology is a balanced plant nutrition system, which accounts for 40–50% of the yield formation. Foliar application of micronutrients is particularly effective, as it maintains optimal nutrient levels until the end of the growing season and positively influences plant growth, photosynthesis, and productivity (Yevtushenko and Skok, 2023).

Ukrainian researchers have substantiated (Palamarchuk et al., 2022) that seeds represent biological and genetic markers, objects of intellectual property, and commodities for production. They serve as the foundation of any crop cultivation technology, determining both the quantity and quality of future yields, and possess a number of valuable properties: genetic memory, the ability to transmit all parental traits to offspring, the capacity to maintain viability under adverse conditions during dormancy, as well as adaptive and protective functions.

Tsytsyura and Kovalchuk (2019) note that for the group of cruciferous crops, the use of micronutrient fertilizers containing boron, manganese, and zinc is recommended, including *Nutrivant Plus Oilseed*, *Granubor Natur*, *Ecolist Micro RB*, *Ecolist Monobor*, *Rostok Oilseed*, and others. These fertilizers provide a reliable source of micronutrients, ensure a balanced growth process, and promote the qualitative differentiation of individual plant organs in a harmonious combination.

Voloshchuk (2024) emphasizes that supplying white mustard plants with nutrients throughout the entire growing season is crucial; therefore, the fertilization system should be based on the biological characteristics of the variety and the soil and climatic conditions of the cultivation region. The highest increase in seed yield compared to the control (without fertilizers) – 2.46 t ha^{-1} – was obtained with the application of mineral fertilizers at the rate of $N_{30}P_{90}K_{100}$ + N_{50} (BBCH stage 14–16) + N_{30} (BBCH stage 52–53), which resulted in an increase in the thousand-seed weight by 1.85 g.

Butenko and Jia (2022) found that, under the conditions of the northeastern forest-steppe of Ukraine, the combined use of the growth regulators Bioforge and Fast Start is recommended for producing high-quality seeds of the white mustard variety Bila Pryntsesa. This treatment ensured a seed yield of over 2.2 t ha^{-1} and an oil yield of 0.6 t ha^{-1}. For the gray mustard variety Felicia, the most effective growth regulators were Anti-Stress, Agrinos, and Regoplan, which contributed to achieving the highest seed yield (1.86–1.89 t ha^{-1}) and oil yield (0.73–0.74 t ha^{-1}).

Studies by Egyptian scientists (Aly et al., 2023) showed that the seeds of red radish obtained from plants exposed to various doses of gamma radiation (10, 20, 40, and 80 Gy) differed in structural parameters such as the number of pods per plant (NPP), total pod weight per plant (TWPP, g), and seed yield per plant (SYP, g). All seed yield traits were statistically significant across all irradiation levels, except for the weight of 100 seeds (100-SW, g), which was not affected by the radiation treatment.

Conclusion

The cultivation conditions of agricultural crops on grey forest surface-gleyed soils in the Carpathian region of Ukraine are characterized by a low level of natural fertility, which necessitates the optimization of plant nutrition systems. Research has shown that the highest efficiency is achieved through an integrated fertilization system that combines the basic application of mineral fertilizers with additional foliar feeding using micronutrient fertilizers.

Against the background of mineral nutrition with macro- and micronutrients – Orakul multicomplex, Yara Vita Rexolin, and Intermag-oil, applied during the flowering phase (growth stage 6, BBCH 69) – oil radish plants were adequately supplied with essential nutrients during the critical phases of growth and development, which had a positive effect on the synthesis of organic matter.

The increased uptake of nutrients through both the root system and the leaf surface created favorable conditions for the formation of generative organs, ensuring a consistently high level of productivity. With the mineral fertilization at $N_{30}P_{60}K_{70}$ + N_{50} (at the 4–6 leaf stage) + N_{20} (at the main shoot flowering stage), oil radish varieties produced a seed yield of 3.24–3.70 t ha^{-1}, with an additional yield increase of 0.34–0.46 t ha^{-1} resulting from the application of micronutrient fertilizers.

The difference in seed yield between the Zhuravka and Fakel varieties was statistically insignificant and amounted to only 0.09–0.10 t ha^{-1}. According to the results of variance analysis, the share of the effect of foliar application of micronutrient fertilizers on yield formation was 32%, the influence of varietal genetic characteristics accounted for 24%, the interaction of these factors – 12%, and the influence of weather conditions – 32%.

The use of micronutrient fertilizers also improved the qualitative characteristics of the seeds. An increase in the 1000-seed weight by 0.20–0.57 g compared to the control was recorded. The highest values for this indicator were observed in 2022 (9.49–10.22 g), while the lowest were recorded in 2024 (8.86–9.26 g), primarily due to variations in weather conditions during the study years.

The seed germination parameters of oil radish remained high across all experimental treatments: germination energy – 90.6–91.8%, and laboratory germination – 94.5–95.6%. The application of micronutrient fertilizers increased these values by 0.9–1.1% and 0.5–1.1%, respectively, indicating an improvement in the physiological condition of the seeds.

The effectiveness of modern micronutrient fertilizers available on the agrochemical market varies significantly depending on their composition, application rates, and agroecological conditions. Therefore, agricultural producers need scientifically grounded information on their practical efficiency and application technology. In the experiments, Orakul multicomplex and Intermag-oil (at a rate of 2.0 l ha^{-1}) and Yara Vita Rexolin (at a rate of 2.0 kg ha^{-1}) showed the highest efficiency, making these products recommended for inclusion in the nutrition systems of oil radish grown on grey forest soils of the Carpathian region.

Acknowledgments

This study was carried out at the Institute of Agriculture of the Carpathian Region of the NAAS of Ukraine by order of the National Academy of Agrarian Sciences of Ukraine in accordance with the PND “Sustainable development of the Carpathian region in the context of the implementation of European integration priorities” (State Registration Number 0120U105630).

References

Aly, A.A., Maraei, R.W. Sharafeldin, R.G., & Safwat, G. (2023). Yield Traits of Red Radish Seeds Obtained from Plants Produced from γ-Irradiated Seeds and Their Oil Characteristics. *Hybrid Gold Open Access, 75*, 5, 2089-2099. DOI: https://doi.org/10.1007/s10343-023-00859-8

Bahan, A.V., Yurchenko, S.O., & Shakaliy, S.M. (2020). Formation of seed sowing qualities of legumes depending on growth stimulator Foliar Concentrate. *Tavria Scientific Bulletin*, *113*, 3-9. DOI: https://doi.org/10.32851/2226-0099.2020.113.1

Bahan, A.V., Shakalii, S.M., Yurchenko, S.O., & Chetveryk, O.O. (2023). Formation of sowing qualities of legume and grain crops seeds. *Agricultural innovations*. Land reclamation, agriculture, crop production, 19, 7-11. DOI: https://doi.org/10.32848/agrar.innov.2023.19.1

Butenko, S.O., & Jia, P.P. (2022). The influence of plant growth regulators on the quality of mustard seeds in the conditions of the north-eastern Forest steppe of Ukraine. *Tavria Scientific Bulletin, 124,* 10-18. DOI: https://doi.Org/10.32851/2226-0099.2022.124.2

Butenko, S., Melnyk, A, Melnyk, T., Jia, P., & Kolosok, V. (2022). Influence of Growth Regulators with Anti–Stress Activity on Productivity Parameters of *Sinapis alba* L. *Journal of Ecological Engineering*, 23 (9), 128-135. DOI: https://doi.org/10.12911/22998993/151780

Dorofeev, N.V., Bojarkin, E.V., & Peshkova, A.A. (2013). Factors Defining Field Germination of Oilseed Radish Seeds. *Journal of Stress Physiology & Biochemistry, 9*, 3, 159-168.

DSTU 2949-94 (1994). Seeds of agricultural plants. Terms and definitions. [Effective 1996-01-01]. Developer: Selection and Genetics Institute UAAS, Odessa.

DSTU 4138-2002 (2003). Crop seeds. Methods for determining quality National standard of Ukraine. Official publication. Kyiv: Gospotrebstandart of Ukraine.

Gavrilyuk M.M.Ed. (2007). Seed production and seed science of field crops. Kyiv:Agricultural Science.https://nubip.edu.ua/sites/default/files/u167/gavrilyuk_m.m._nasinnictvo_y_nasinniezn avstvo_polovih_kultur.pdf

Grabovskyi, M., Mostypan, O., Fedoruk, Y., Kozak, L., & Ostrenko, M. (2023). Formation of grain yield and quality indicators of soybeans under the influence of fungicidal protection. *Scientific Horizons*, *26 (2)*, 66-76. DOI: https://doi.org/10.48077/scihor.26(2).2023.66-76

Hasanuzzaman, M., Nahar, K., Md. Alam, M., Roychowdhury, R., & Fujita, M. (2013). Physiological, Biochemical, and Molecular Mechanisms of Heat Stress Tolerance in Plants. *International Journal of Molecular Science*, *14,* 9643-9684. DOI: https://doi.org/10.3390/ijms14059643

Hereshko, H.S., Voloshchuk, I.S., Voloshchuk, O.P., Hlyva, V.V., & Bilonizhka, Kh.V. (2021). Oilseed radish – valuable crop of a wide range use. *Foothill and mountain agriculture and livestock breeding, 70* (2), 8-17. DOI: https://doi.org/10.32636/01308521.2021-(70)-2-1

Jia, P., Melnyk, A., Zhang, Zh., Li, L., Kong, X., Dai, H., & Butenko, S. (2021a). Effects of drought and rehydration on the growth and physiological characteristics of mustard seedlings. *Journal of Central European Agriculture*, *22* (4), 836-847. DOI: https://doi.org/10.5513/JCEA01/22.4.3246

Jia, P., Melnyk, A., Zhang, Zh., Butenko, S., & Kolosok, V. (2021b). Effect of seed pre-treatment with plant growth compound regulators on seedling growth under drought stress. *Agraarteadus: Journal of Agricultural Science*, *32* (2), 251-256. DOI: https://doi.org/10.15159/jas.21.35

Makrushin, M.M., Makrushina, E.M., Peterson, N.V., & Melnikov, M.M. (2006). *Plant Physiology*. Vinnitsa: New Book.

Ministry of Agrarian Policy and Food of Ukraine, Ukrainian Institute for the Examination of Plant Varieties (2023). Methodology for the examination of oilseed plant varieties for difference, uniformity and stability

Palamarchuk, V.D., Polishchuk, I.S., Mazur, V.A., & Palamarchuk, O.D. (2017). *The latest agricultural technologies in crop production.* Vinnitsa: Vinnytsia Agrarian National University.

Palamarchuk, V.D., Doronin, V.A., Kolisnyk, O.M., & Alekseev, O.O. (2022). *Fundamentals of seed science* (theory, methodology, practice). Vinnitsa: Print.

Panchyshyn, V., Moisiienko, V., Kotelnytska, A., Tymoshchuk, T., & Stotska, S. (2023). Formation of narrow-leaved lupine productivity depending on seed inoculation and fertilization. *Scientific Horizons*, *26* (1), 31-42. DOI: https://doi.org/10.48077/scihor.26(1).2023.31-42

Radchenko, M.V. (2008). Seed productivity of oilseed radish depending on mineral nutrition conditions. *Seed production and seed science*, *95*, 210-214. DOI: https://doi.org/10.30835/2413-7510.2008.84777

Shelest, M., Kalnaguz, A., Datsko, O., Zakharchenko, E., & Zubko, V. (2023). System of pre-sowing seed inoculation. *Scientific Horizons*, *26* (7), 140-148. DOI: https://doi.org/10.48077/scihor7.2023.140

Tsitsyura, Ya, G., & Tsitsyura, T.V. (2015). Oilseed radish. Use and cultivation strategy. Vinnitsa: Nilan LTD LLC. http://socrates.vsau.org/b04213/html/cards/getfile.php/8309.pdf

Tsitsyura, Ya, G. (2019). Viability of oilseed radish seeds and its components using laboratory assessment methods. *Agriculture and forestry. Selection, seed production, seed science and variety science, 12,* 53-68.

Tsitsyura, Ya, G., & Kovalchuk, Yu, A. (2019). The influence of foliar fertilizing on the formation of quality indicators of oilseed radish seeds in the forest-steppe of the Right Bank of Ukraine. *Agriculture and forestry. Plant growing, current state and development prospects, 15*, 30-44. DOI: https://doi.org/10.37128/2707-5826-2019-4-3

Ushkarenko, V.O., Vozhegova, R.A., Goloborodko, S.P., & Kokovikhin, S.V. (2014). *Methodology of field experience (Irrigated agriculture)*. Kherson: Grin, D.S.

Voloshchuk, M., Yu. (2024). The formation of the yield of white mustard seeds depending on the level of mineral nutrition of plants. *Foothill and mountain agriculture and animal husbandry*, *75* (1), 18-29. DOI: https://doi.org/10.32636/01308521.2024-(75)-1-2

Xu, S., Li, J., Zhang, X., Wei, H., & Cui, L. (2006). Effects of heat acclimation pretreatment on changes of membrane lipid peroxidation, antioxidant metabolites, and ultrastructure of chloroplasts in two cool-season turfgrass species under heat stress. *Environmental and Experimental Botany*, *56,* 3, 274-285. DOI: https://doi.org/10.1016/j.envexpbot.2005.03.002

Yevtushenko, O.T., & Skok, S.V. (2023). The impact of growth regulators on growth and development of agricultural crops (overview). *Bulletin of Sumy National Agrarian University*. The Series: Agronomy and Biology, *51* (1), 53-63. DOI: https://doi.org/10.32782/agrobio.2023.1.7

Received: March 23, 2024
Accepted: November 12, 2025

ULOGA MIKROĐUBRIVA U POBOLJŠANJU KVALITETA SEMENA *RAPHANUS SATIVUS* L. VAR. *OLEIFERA* METZG. U KARPATSKOM REGIONU UKRAJINE

Oleksandra P. Voloshchuk, Ihor S. Voloshchuk, Valentyna V. Hlyva[†], **Halyna Y. Bilovus i Khrystyna V. Bilonizhka**

Institute of Agriculture of Carpathian Region of National Academy of Agrarian Sciences of Ukraine, Volskogo Street, 5, Obroshino village, Lviv district, Lviv region, 81115, Ukraine

R e z i m e

Cilj istraživanja bio je da se utvrdi uticaj folijarne primene mikroelemenata na produktivnost i kvalitet semena uljane rotkve (*Raphanus sativus var. oleiformis* Pers.). U istraživanje su bile uključene sorte žuravka i fakel, koje se odlikuju visokim potencijalom prinosa i dobrom prilagodljivošću uslovima Karpatskog regiona. Metodološku osnovu činili su poljski ogled, biometrijska merenja i statističke analize. Površina ogledne parcele iznosila je 50 m² sa tri ponavljanja. Istraživanje je sprovedeno tokom 2022–2024. godine na Katedri za semenarstvo Instituta za poljoprivredu Karpatskog regiona Nacionalne akademije poljoprivrednih nauka Ukrajine. Ogled je obuhvatio četiri varijante folijarne primene mikroelemenata – kontrolu (bez mikroelemenata), *Oracul multicomplex*, *Yara Vita Rexolin* i *Intermag-oil* – uz primenu mineralnog đubrenja $N_{30}P_{60}K_{70}$ + N_{50} u fazi BBCH 14–16 i N_{20} u fazi BBCH 52–53. Utvrđeno je da primena mikroelemenata povećava prinos semena na 3,24–3,70 $t \cdot ha^{-1}$, što je za 0,34–0,46 $t \cdot ha^{-1}$ više od kontrole. Razlike između sorti bile su neznatne (0,09–0,10 $t \cdot ha^{-1}$). Masa 1000 semena porasla je za 0,20–0,57 g (u rasponu od 8,86 do 10,22 g, zavisno od godine). Vrednosti kvaliteta semena ostale su visoke: energija klijavosti iznosila je 90,6–91,8%, a laboratorijska klijavost 94,5–95,6%. Dobijeni rezultati imaju naučni i praktični značaj jer kombinovanje mineralnog đubrenja sa folijarnom primenom mikroelemenata doprinosi boljoj realizaciji genetskog potencijala uljane rotkve, uz istovremeno povećanje prinosa i poboljšanje kvaliteta semena.

Ključne reči: uljana rotkva, sorta, hidrotermički koeficijent (HTK), prinos semena, masa 1000 semena, energija klijavosti, laboratorijska klijavost.

Primljeno: 23. marta 2024.
Odobreno: 12. novembra 2025.

[*]Autor za kontakt: e-mail: valentinahlyva@gmail.com

Journal of Agricultural Sciences (Belgrade) https://doi.org/10.2298/JAS2504385O
Vol. 70, No. 4, 2025 UDC: 635.64-181(669)
Pages 385-395 Original scientific paper

EFFECTS OF FERTILIZER MICRODOSING ON SOIL PHOSPHORUS AND SULPHUR AVAILABILITY TO *SOLANUM MACROCARPON* IN SOUTHWEST NIGERIA

Ifeoluwa A. Oluwaponle[1], Francis T. Olatoberu[1*], Mary K. Idowu[1], Durodoluwa J. Oyedele[1], Omotayo R. Akinremi[1], Ojo K. Adekunle[2] and Odunayo C. Adebooye[2]

[1]Department of Soil Science and Land Resources Management, Obafemi Awolowo University, Ile-Ife, Nigeria
[2]Department of Crop Production and Protection, Obafemi Awolowo University, Ile-Ife, Nigeria

Abstract: This present study aimed at evaluating the effect of fertilizer rate and time of application on yield, and determined the availability of soil P and S to *S. macrocarpon*. The experiment was conducted in the derived savanna (Ogbomoso) and the rainforest (Ilesha) in southwest Nigeria. The treatments were arranged in a factorial combination and laid out in a split-plot design with four replicates. The main plots were the fertilizer rates of 0, 20, 40, 60, and 80 kg N ha $^{-1}$ (without organic fertilizer), with the time of urea application (at planting and two weeks after planting) as a sub-plot. *S. macrocarpon* was the test crop. Plant fresh weight, P, and S uptake were determined at the first harvest. The results showed that a fertilizer rate of 20 kg N ha $^{-1}$ produced significantly higher yields and uptake of P and S in the derived savanna (4.2 ha $^{-1}$) and in the rainforest (1.2 t ha $^{-1}$). Application at two weeks after planting (2 WAP) produced higher yields (3.3 t ha $^{-1}$) in the derived savanna, while the application at planting (AAP) produced the highest yield (1.2 t ha $^{-1}$) in the rainforest. Although the time of fertilizer application did not affect fresh yields and nutrient availability, this study concluded that 60 kg N ha $^{-1}$ plus 5 tons ha $^{-1}$ was the optimum fertilizer combination for *S. macrocarpon* production in southwest Nigeria.

Key words: *Solanum macrocarpon*, phosphorus, sulfur, fresh weight, fertilizer, microdosing.

*Corresponding author: e-mail: tolatoberu@oauife.edu.ng

Introduction

Solanum macrocarpon contains essential macro and micronutrients, vitamins, and considerable amounts of protein, making it economically, nutritionally, and medicinally important. The roots, leaves, and fruit of *S. macrocarpon* possess medicinal qualities. In Nigeria, the fruit is used as a laxative and to treat cardiac diseases, while the flowers are chewed on to clean the teeth. In Sierra Leone, the leaves are used to ease throat pain. In Kenya, the roots are boiled, and the juice is then consumed to eliminate hookworms in the stomach (Plant Resources of Tropical Africa – PROTA, 2004). The root is also used for bronchitis, body aches, asthma, and to accelerate wound healing. It contains high levels of Ca, Mg, and Zn (Idowu et al., 2014; NICANVEG, 2014).

Nitrogen (N), phosphorus (P), and sulphur (S) are essential nutrients needed for high yields and quality of vegetables. For example, N is vital for the photosynthetic activity, and both vegetative and reproductive metabolisms; P is involved in energy storage needed for physiological processes and photosynthetic reactions, while S is an important component of chlorophyll, certain vitamins, and proteins in plants (Adepetu et al., 2014). These nutrients have specific functions and synergistic relationships; therefore, it is expedient that they are supplied to the plant in sufficient quantities at the right time (Omotoso and Akinrinde, 2013). The effective placement and timing of fertilizers maximize both yield and nutrient use efficiency (Jones and Jacobsen, 2009), increase net returns for vegetable farmers, and reduce environmental pollution from fertilizers. Although vegetables respond positively to organic and/or inorganic fertilizer application in Nigeria (Idowu, 2010; Ajibola et al., 2015; Ehigiator et al*.,* 2015), the cost of these fertilizers is unaffordable by resource poor farmers in Southwest Nigeria (Adebisi-Adelani et al., 2011; FEPSAN, 2014), and they lack adequate knowledge of fertilizer application or recommended rates. Consequently, the nutritional, medicinal, and economic benefits of these vegetables are forfeited.

Fertilizer microdosing involves the application of relatively small quantities of fertilizer at sowing or shortly after sowing, substantially reducing the recommended fertilizer rates that subsistence farmers need to apply while giving plants enough nutrients for optimal growth (ICRISAT, 2009). The implementation of this technology has resulted in greater nutrient use efficiency and positive responses of increased production of crops such as maize and pearl millet in some African countries (Twomlow et al., 2010; Bagayoko et al., 2011). It also permits a more precise and better-timed fertilizer placement, resulting in improved fertilizer management (Sanginga and Woomer, 2009). However, there is limited information on the effects of urea and organic fertilizer application under microdosing on the yield and uptake of P and S in the selected vegetable crops, which is the focus of this study.

The specific objectives of this research were to examine the effects of fertilizer rate and application timing on yield and soil P and S availability to *S. macrocarpon*, with the aim of establishing the optimum fertilizer application for vegetable production in southwest Nigeria.

Material and Methods

The study was conducted in two locations: the rainforest zone (Ilesha, Osun State) and the derived savannah (Ogbomoso, Oyo State). These zones were part of the Nigeria-Canada-Vegetable/Micro-Veg project sites and had been under vegetable cultivation for 3 years. The experiment was conducted in 2015 at the experimental fields. Ogbomoso is located at latitude 8^0 6’ 35” N and longitude 4^0 18’ 41” E in Oyo State with a bimodal rainfall pattern that ranges between 1296 mm and 1306 mm. Ilesha is located at latitude 7^0 38’ 36” N and longitude 4^0 45’ 40” E in Osun State, with a bimodal rainfall pattern varying between 1600 and 2000 mm.

Bulk surface soil samples were randomly collected at a 0–15-cm depth from the unfertilized plots for routine analysis. Soil samples were air-dried, crushed in an agate mortar, and passed through a 2-mm sieve to remove roots, stones, and other debris. The fraction that passed through the sieve was kept in an air-tight container and analyzed for the following properties. Particle size distribution was determined by the modified hydrometer method (Bouyoucous, 1962) using 0.2 M NaOH solution as the dispersing agent. Soil pH was determined using a glass electrode pH meter in 0.01 M $CaCl_2$ solution, using a 1:2 soil: $CaCl_2$ solution (Thomas, 1996). Soil organic carbon was determined by the chromic acid digestion method (Walkey and Black, 1934). The total N concentration was determined by the macro-Kjeldahl method (Bremner, 1996), available S was extracted using KH_2SO_4 and was determined using the turbidimetric method (Tabatabai, 1974). The available P was extracted by the Bray-1 method (Kuo, 1996) and determined using a spectrometer (Model 721 Visible Spectrophotometer, Axiom Mediral LMD U.K.). Exchangeable Ca, Mg, K, and Na were extracted with a neutral (pH 7) solution of 1N NH_4OAc. Potassium, Ca, and Na were determined using a flame photometer (Model 2655-00 Digital Flame Analyzer, Cole-Parmer Instrument Company, Chicago, Illinois 60061), and Mg was determined by the atomic absorption spectrophotometry (PG-900 Atomic Absorption Spectrophotometer Model, PG-instrument Ltd., United Kingdom).

The experimental plots measured 3 m × 2 m, with 1-m spacing within a total area of 29 m × 15 m. The treatment consisted of a factorial combination of five nitrogen levels (0, 20, 40, 60, and 80 kg N ha^{-1}, without organic fertilizer), two urea application times (at planting and two weeks after planting). Organic fertilizer (3.5% N, 1% P, and 1.2% K) was applied at 5 tons ha^{-1} as a basal fertilizer one week before urea application, with the exception of 80 kg N ha^{-1}. All the treatments were replicated four times.

Solanum macrocarpon shoots were harvested at seven weeks after planting (WAP). The shoots were harvested by cutting the stem at about 8 cm above the soil surface. Subsequent harvests were conducted every two weeks; the fresh weight of the harvested edible shoots was measured per plot and immediately transported to the Soil Science Laboratory at Obafemi Awolowo University, Ile-Ife, Nigeria. The vegetable leaf samples were randomly collected from each harvested shoot. The vegetable samples were dried in a draft oven set at 70˚C in the laboratory, and 0.5 g of the dried vegetable tissue was digested using the wet ashing method (Piper, 1944). The ash was extracted with 2 ml of 6 N H_2SO_4, and the extract was quantitatively transferred to a 50 ml volumetric flask and made up to the mark. Appropriate dilutions were prepared, and the elements were analyzed against their standards. All the samples were analyzed along with a blank solution. Phosphorus content was determined using the vanadomolybdate method (Kuo, 1996), and absorbance was measured using a visible spectrophotometer at 440 nm wavelengths, while S content was determined using the turbidimetric method (Tabatabai, 1974), with absorbance measured at 420 nm wavelength using the visible spectrophotometer. Standard solutions of P and S at different concentrations were also measured. A standard curve was plotted with the concentrations of the standards against the absorbance readings, and this was used to determine the concentrations of P and S in the samples.

Data collected was subjected to analysis of variance (ANOVA) to assess treatment effects and time of application on fresh yield and the uptake of phosphorus and sulphur by the vegetable. Means were separated using Duncan's multiple range test at the 5% level of probability (SAS 9.1).

Results and Discussion

The soils (Table 1) were strongly acidic (pH 5.4) in the rainforest (Ilesha) and moderately acidic (pH 5.70) in the derived savanna (Ogbomoso) when measured in 0.01 M $CaCl_2$. The textural classification of the soil for both locations was loamy sand. The organic carbon and total N contents of the soils in the rainforest zone (8.4 and 2.3 g kg^{-1}) and the derived savanna (16.6 and 1.8 g kg^{-1}) were within the medium fertility class (Sobulo and Adepetu, 1987; Adepetu, 1990). The available P was high in the rainforest and medium in the derived savanna. The available S in both agro-ecologies was low (Adetunji and Adepetu, 1987). Exchangeable Ca, Mg, K, and Na were above the critical levels (0.03 cmol kg^{-1}) established for maize in the region (Adepetu et al., 2014).

Table 1. The physical and chemical properties of the soil (0–15 cm) used for the experiment.

Soil properties	RAINFOREST	DERIVED
Sand ($mgkg^{-1}$)	760	820
Silt "	90	50
Clay "	150	130
Textural class	Loamy sand	Loamy sand
pH (0.01M $CaCl_2$)	5.4	5.7
Total N (gkg^{-1})	2.3	1.8
Organic C (gkg^{-1})	16.6	8.45
Available P ($mgkg^{-1}$)	24	19
Available S ($mgkg^{-1}$)	3.59	3.31
Exchangeable Ca ($cmolkg^{-1}$)	1.78	1.30
" Mg "	0.49	0.43
" K "	0.48	0.40
" Na "	0.11	0.10

Table 2 shows that the fertilizer treatment using microdosing technology had a significant effect on the fresh yield of *S. macrocarpon.* The application of organic and inorganic fertilizer at rates of 20, 40 and 60 kg N ha^{-1} significantly increased yields, although these were not significantly different from the yields obtained with 80 kg N ha^{-1}, compared to the control. This result is in line with Akintoye et al. (2006), who found that the use of inorganic fertilizer alone supports the production of *S. macrocarpon*. Furthermore, this result substantiates the findings of Ncube et al. (2007), who reported that larger average gains could be obtained by combining nitrogen fertilizer with a basal application of manure. Twomlow et al. (2010) also reported significant increases in cereal grain yield with 17 kg N ha^{-1} (approximately 25% of recommended levels) compared to recommended rates of 55 kg ha^{-1} under microdosing.

In this study, significant increases in the yield of the vegetables with 20 kg N ha^{-1} were observed compared to the recommended rates of Nafiu et al. (2011), who have established that 30 kg N is optimum for *S. macrocarpon* production. Although the time of application did not have a significant effect on the yields of *S. macrocarpon*, it was observed that application at 2 WAP was more favorable in the derived savanna, while the application at AAS was favorable in the rainforest. This result is in line with the findings of Hayashi et al. (2008).

Fertilizer treatments at both locations had no significant effect on the uptake of phosphorus as shown in Table 3. Following the same trend with yield, a fertilizer rate of 20 kg N ha^{-1} resulted in the highest uptake. The highest P uptake was also observed in the derived savanna compared to the rainforest. This can be attributed to the fact that soils in the rainforest are richer in nutrients compared to those in the derived savanna, which are fragile and low in organic matter content (Abiala et al., 2014). Hence, there was a higher response to fertilizer treatments in the derived savanna compared to the rainforest zone. Although the two fertilizer application times showed no significant differences, application at 2 WAP was favorable for higher P uptake in the derived savanna, while AAS was favorable in the rainforest. This can be attributed to the varying climatic conditions that exist across ecological zones.

Table 2. Effect of time and fertilizer rates on fresh yield of *Solanum macrocarpon* at the two agroecologies.

	DERIVED SAVANNA			RAINFOREST		
Fertilizer rate (kg ha^{-1})	T1 →	T2 kg ha^{-1}	Mean ←	T1 →	T2 kg ha^{-1}	Mean ←
0	333b	1750b	1042	604b	417b	511
20	4583a	3792ab	4188	1104ab	1229ab	1167
40	1417ab	3458ab	2438	1833a	750ab	1292
60	1333ab	4750a	3042	1771ab	1292ab	1532
80	2167ab	2625ab	2396	775ab	1708a	1242
Mean	1967	3275	2621	1218	1079	1149
LSD	3137	2142	-	1038	1140	-

Means with the same letters are not significantly different from each other at $p \leq 0.05$. LSD – least significant difference, where: 0 – organic fertilizer (OF) only, 20 – OF + 20 kg N ha^{-1}, 40 – OF + 40 kg N ha^{-1}, 60 – OF + 60 kg N ha^{-1}, 80 – 80 kg N ha^{-1} only. T 1 – fresh yield at planting, T 2 – fresh yield at 2 WAP.

A slight decline in P uptake was also observed at both locations. This is in line with Agbede et al. (2010), who found that the combined application of mineral and organic manure at suboptimal rates ensured greater availability of major nutrients in the soil and increased yam leaf nutrient concentration, growth, and tuber yield compared with full rates of mineral fertilizer or organic manure alone. Ogbodo (2009) has further explained that organic matter releases organic acids, which increases the rate of P desorption and thus improves its availability and other nutrients in the soil.

Although the time of fertilizer application had no significant effect on P uptake, higher uptake, attributed to well-established root hairs and well-decomposed organic material, was observed in the derived savanna with the application at 2 WAP while higher P uptake was obtained at AAS in the rainforest zone, owing to higher precipitation and soil type.

Table 3. The effect of fertilizer rate and time of application on the availability of soil P to *S. macrocarpon*.

	DERIVED SAVANNA			RAINFOREST		
Fertilizer rate (kg ha^{-1})	T1	T2	Mean	T1	T2	Mean
	→	kg ha^{-1}	←	→	kg ha^{-1}	←
0	0.02a	0.64a	0.33	0.05a	0.03a	0.04
20	3.50a	2.21a	2.85	0.13a	0.27a	0.20
40	0.32a	1.45a	0.88	0.38a	0.08a	0.23
60	0.33a	2.44a	1.38	0.36a	0.16a	0.26
80	0.56a	0.80a	0.67	0.11a	0.30a	0.21
Mean	0.95	1.51	1.23	0.21	0.17	0.19
LSD	3.30	1.86		0.34	0.33	

Means with the same letter are not significantly different from each other at $p \leq 0.05$, where: 0 – organic fertilizer (OF) only, 20 – OF + 20 kg N ha^{-1}, 40 – OF + 40 kg N ha^{-1}, 60 – OF + 60 kg N ha^{-1}, 80 – 80 kg N ha^{-1} only; T 1 – phosphorus availability at planting, T 2 – phosphorus availability at 2 WAP.

Table 4 shows the effect of fertilizer rate and time of application on the availability of soil S to *S. macrocarpon*. The fertilizer rate had no significant effect on S uptake by the vegetable. Sulphur uptake increased with increasing fertilizer rate, but the highest uptake occurred at 20 kg N ha^{-1}, while the control had the lowest uptake by *S. macrocarpon*.

Table 4. The effect of fertilizer rate and time of application on the availability of soil S to *S. macrocarpon*.

	DERIVED SAVANNA			RAINFOREST		
Fertilizer rate (kg ha^{-1})	T1	T2	Mean	T1	T2	Mean
	→	kg ha^{-1}	←	→	kg ha^{-1}	←
0	0.11b	0.49b	0.30	0.18a	0.07ab	0.12
20	1.26a	1.30a	1.28	0.32 a	0.37ab	0.35
40	0.52ab	1.00ab	0.76	0.51 a	0.21ab	0.36
60	0.45ab	1.33a	0.89	0.47 a	0.31ab	0.39
80	0.65ab	0.68ab	0.66	0.23 a	0.43a	0.33
Mean	0.60	0.96	0.57	0.34	0.28	0.31
LSD	0.82	0.65		0.33	0.31	

Means with the same letters are not significantly different from each other at $p \leq 0.05$, where: 0 – organic fertilizer (OF) only, 20 – OF + 20 kg N ha^{-1}, 40 – OF + 40 kg N ha^{-1}, 60 – OF + 60 kg N ha^{-1}, 80 – 80 kg N ha^{-1} only; T 1 – sulphur availability at planting, T 2 – sulphur availability at 2 WAP.

The time of fertilizer application had no significant effect on the uptake of S at either location. The application at 2 WAP was favorable for S uptake in the derived savanna, while AAS was favorable for the uptake of S in the rainforest. A slight decline in S uptake, similar to P uptake, was observed with the application of 80 kg N ha^{-1}, though this was not significantly different from 60 kg N ha^{-1}. This result is in line with the findings of Islam et al. (2011), who observed that higher nutrient uptake (N, P, K and S) by radish-stem-amaranth was significantly influenced by the integrated treatment of organic and inorganic fertilizers. Moreover, Wilkinson et al. (2000) and Fageria (2009) explained that the addition of nitrogen can increase P concentration in plants by increasing root growth and by increasing the ability of roots to absorb and translocate P. Additionally, the acidifying effect of N fertilizers could enhance N concentration in plants (Malhi et al., 1988) and P solubility in soil (Power and Prasad, 1997), which improves photosynthetic efficiency and nitrogen metabolism by enhancing the synthesis of new chloroplast thylakoids (Menghini et al., 1998). These effects result in increased assimilation of P and S (Osman, 2013).

Conclusion

This study concluded that using microdosing technology, a fertilizer rate of 20 kg N ha^{-1}, was optimal for *Solanum macrocarpon* production and the uptake of P and S in southwest Nigeria. The time of fertilizer application had no significant effect on yield or uptake of P and S by *T. occidentalis*. This study demonstrated that combination of fertilizer microdosing with the application of organic fertilizer was a more sustainable alternative for achieving optimal yield of fluted pumpkin and sustainable fluted pumpkin production, in contrast to the excessive use of fertilizers by farmers. Further research is required on other underutilized indigenous vegetables in Africa to establish the effectiveness of microdosing for all such crops.

Acknowledgements

The authors are grateful to the Foreign Affairs, Trade and Development Canada (DFATD) and the International Development Research Centre (IDRC) for the project research grant number 107983. This study was part of the Microdosed Vegetable (MICROVEG) Research.

References

Abiala, M.A., Odebode, A.C., Adeoye, G.O., Hsu, S., & Blackood, C.B. (2014). Soil Chemical Dynamics in Maize Field of Southwestern Nigeria. *American-Eurasian Journal of Agriculture and Environmental Science*, *13*, 234-243.

Adebisi-Adelani, O., Olajide-Taiwo, F.B., Adeoye, I.B., & Olajide-Taiwo, L.O. (2011). Analysis of production constraints facing Fadama vegetable farmers in Oyo State, Nigeria. *World Journal of Agricultural Sciences*, *7*, 189-192.

Adepetu, J.A. (1990). Soil test data interpretation in soil testing programme. Paper presented at National Workshop on soil testing service for efficient fertilizer use in Nigeria. Moor Plantation, Ibadan.

Adepetu, J.A., Adetunji, M.T., & Ige, D.V. (2014). Essential nutrients in soil/plant system. In J.A Adepetu, M.T. Adetunji & D.V. Ige (Eds.), *Soil Fertility and Crop Nutrition*. (pp. 202-345). Jumak Publishers, Ibadan, Nigeria.

Adetunji, M.T., & Adepetu, J.A. (1987). Status and distribution of sulphur fractions in soils of southwestern Nigeria. *Nigerian Journal of Science, 24*, 137-140.

Agbede, T.M., Oladitan, T.O., Alagha, S.A., Ojomo, A.O., & Ale, M.O. (2010). Comparative evaluation of poultry manure and NPK fertilizer on soil physical and chemical properties, leaf nutrient concentrations, growth and yield of yam (*Discorea rotundata* Poir) in southwestern Nigeria. *World Journal of Agricultural Sciences*, *6*, 540-546.

Ajibola, B.O., Komolafe, S.E., & Akangbe, J.A. (2015). Constraints faced by women vegetable farmers in Kwara State, Nigeria and its Agricultural practices. *Jordan Journal of Agricultural Science*, *11*, 995-1006.

Akintoye, H.A., Olaniyan, A.B., & Olasanmi, B. (2006). Effect of different sources of nitrogen on growth and yield of *Solanum macrocarpon* in derived savanna of Nigeria. *Journal of Agronomy*, *5*, 182-185.

Bagayoko, M., Maman, N., Palé, S., Sirifi, S., Taonda, S.J.B., & Traore, S. (2011). Microdose and N and P fertilizer application rates for Pearl millet in West Africa. *African Journal of Agricultural Research*, *6*, 1141-1150.

Bouyoucous, G.H. (1962). Hydrometer Method Improved for Making Particle Size Analysis of Soils. *Agronomy Journal*, *54*, 464-465.

Bremner, J.M. (1996). Total Nitrogen. In: D.L. Sparks (Ed.), *Methods of Soil Analysis, Part 3, Chemical Methods,* (pp.1123-1184). Soil Science Society of America and ASA, Madison.

Ehigiator, J.O., Ariyo, A.D., & Imasuen, E.E. (2015). Soil fertility and nutritional studies on citrus, fruit and vegetable crops in Nigeria (1975 to 2005). *Nigerian Journal of Agriculture*, *Food and Environment*, 11, 103-114.

Fageria, N.K. (2009). *The use of nutrients in crop plants*. Boca Raton, Florida: CRC Press.

Fertilizer suppliers association of Nigeria, (FEPSAN) (2014), 4, 1-4. (www.fepsannigeria.com)

Hayashi, K., Abdoulaye, T., Gerard, B., & Bationo, A. (2008). Evaluation of application timing in fertilizer micro-dosing technology on millet production in Niger. *West Africa Nutrient Cycling Agroecosystem*, *80*, 257-265.

ICRISAT (2009). Fertilizer microdosing-Boosting production in unproductive lands. Access online at www.icrisat.org/impacts/impacts-stories/icrisat-is-fertilizer microdosing.

Idowu, M.K. (2010). Effect of fertilizer use and gender of farmers on soil /plant nitrogen and crude protein content of vegetable amaranth in Osun State, Nigeria. *Acta Agronomica Nigeriana, 10*, 102-111.

Idowu, M.K., Oyedele, D.J., Adekunle, O.K., Akinremi, O.O., & Eilers, B. (2014). Effects of planting methods and seed density on vegetable yield and nutrient composition of *Solanum macrocarpon* and *Solanum scabrum* in southwest Nigeria. *Food and Nutrition Sciences*, *5*, 1185-1195.

Islam, M.M., Karim, A.J., Jahiruddin, M.S., Nik M., Majid, M., Mustaque, M.G., Ahmed, M., & Hakim, M.A. (2011). Effects of organic manure and chemical fertilizers on crops in the radish-stem amaranth Indian spinach cropping pattern in homestead area. *African Journal of Crop Science*, 5, 1370-1378.

Jones, C., & Jacobsen, J. (2009). Fertilizer placement and timing. A case course from Montana state university extension continuity education series, Bozeman. In: Nutrient management module 11, 1-15.

Kuo, S. (1996). Phosphorus. In D.L. Sparks (Ed.) *Methods of soil analysis: Part 3, Chemical methods*. (pp. 87-100). Madison: Soil Science Society of America.

Malhi, S.S., Nyborg, M., Jahn, H.G., & Penney, D.C. (1988). Yield and nitrogen uptake of rapeseed (*Brassica campestris* L.) with ammonium and nitrate. *Plant and Soil*, *105*, 231-240.

Menghini, A., Pocceshi, N., Venani, G., & Palladini, T. (1998). Effect of nitrogen fertilization on photosynthesis rate, nitrogenous metabolites and asarone accumulation in triploid Acorus calamus L. leave. *Flavour and Fragrance Journal*, *13*, 319-323

Nafiu, A.K., Togun, A.O., Abiodun, M.O., & Chude, V.O. (2011). Effects of NPK fertilizer on growth, dry matter production and yield of eggplant in Southwestern Nigeria. *Agriculture and Biology Journal of North America*, *2*, 1117-1125.

Ncube, B., Dimes, J.P., Twomlow, S.J., Mupangwa, W., & Giller, K.E. (2007). Participatory on-farm trials to test response of maize to small doses of manure and nitrogen in smallholder farming systems in semi-arid Zimbabwe. *National Cycling in Agroecosystems*, *77*, 53-67

Nigerian Canada Vegetable project (NICANVEG) (2014). Scaling up of synergized indigenous vegetables and fertilizer micro-dosing. Innovations for food security and family economic development. www.microveg.org

Ogbodo, E.N. (2009). Effect of Crop Residue on Soil Chemical Properties and Rice Yields on an Ultisol at Abakaliki, Southeastern Nigeria. *American-Eurasian Journal of Sustainable Agriculture, 3*, 422-447.

Omotoso, S.O., & Akinrinde, E.A. (2013). Effect on nitrogen fertilizer on some growth, yield and fruit quality parameters in pineapple (*Ananas comosus* L. Merr.) plant at Ado-Ekiti Southwestern, Nigeria. *International Research Journal of Agricultural Science and Soil Science*, *3*, 11-16.

Osman, K.H. (2013). *Soils-Principles, properties and management.* Dordrecht: Springer.

Piper, C.S. (1944). *Dry ashing. Soil and plant analysis*. New York: Inter-science Publishers Incorporation.

Plant Resources of Tropical Agriculture (2004). Plant Resources of Tropical Africa: Vegetables, PROTA Foundation, Netherlands/Backhuys Publishers, Leiden, Netherlands/CTA Wageningen, Netherlands.

Power, J.F., & Prasad, R. (1997). *Soil fertility management for sustainable agriculture*. CRC Press, London.

Sobulo, R.A., & Adepetu, J.A. (1987). Soil testing and fertilizer formulation for crop production in Nigeria. In: Towards efficient fertilizer use and development in Nigeria. Federal ministry of Agriculture Lagos.

Sanginga, N., & Woomer, P.L. (2009). Integrated soil fertility management in Africa: Principles, practices, and developmental process. Tropical Soil Biology and Fertility Institute of the International Center for Tropical Agriculture, 13-112.

Tabatabai, M.A. (1974). A Rapid Method for Determination of Sulfate in Water Sample. Article in *Environmental letters, 7*, 237-243.

Thomas, G.W. (1996). Soil pH and Soil Acidity. In D.L. Sparks (Ed.), *Methods of Soil Analysis, Part 3, Chemical Methods,* (pp. 475-490). Madison: SSSA and ASA.

Twomlow, S., Rohrbach, D., Dimes, J., Rusike, J., Mupangwa, W., Ncube, B., Hove, L., Moyo, M., Mashingaidze, N., & Mahposa, P. (2010). Micro-dosing as a pathway to Africas green revolution: Evidence from broad-scale on-farm trials. *Nutrient Cycling in Agroecosystem*, *88*, 3-15.

Walkey, A.C., & Black, T.A. (1934). Estimation of soil organic carbon by chromic acid titration method. *Journal of Soil Science*, *47*, 29-38.

Wilkinson, S.R., Grunes, D.L., & Sumner, M.E. (2000). Nutrient interaction in the soil and plant nutrition. In M.E Sumner (Ed.), *Handbook of Soil Science*. (pp. 89-112). Boca Raton: CRC Press.

Received: July 20, 2025
Accepted: December 10, 2025

UTICAJI MIKRODOZA ĐUBRIVA NA DOSTUPNOST FOSFORA I SUMPORA U ZEMLJIŠTU ZA *SOLANUM MACROCARPON* U JUGOZAPADNOJ NIGERIJI

Ifeoluwa A. Oluwaponle[1], Francis T. Olatoberu[1*], Mary K. Idowu[1], Durodoluwa J. Oyedele[1], Omotayo R. Akinremi[1], Ojo K. Adekunle[2] i Odunayo C. Adebooye[2]

[1]Department of Soil Science and Land Resources Management, Obafemi Awolowo University, Ile-Ife, Nigeria
[2]Department of Crop Production and Protection, Obafemi Awolowo University, Ile-Ife, Nigeria

R e z i m e

Ovo istraživanje imalo je za cilj da proceni uticaj doze đubriva i vremena primene na prinos, kao i da utvrdi dostupnost fosfora (P) i sumpora (S) u zemljištu u usevu *S. macrocarpon*. Eksperiment je sproveden u zoni savane (Ogbomoso) i kišne šume (Ileša) u jugozapadnoj Nigeriji. Tretmani su bili raspoređeni u kombinaciji faktora i postavljeni po dizajnu podeljenih parcela (engl. *split-plot design*) sa četiri ponavljanja. Glavne parcele činile su doze đubriva od 0, 20, 40, 60 i 80 kg N ha^{-1} (bez organskog đubriva), dok je vreme primene uree (pri sadnji i dve nedelje nakon sadnje) predstavljalo potparcele. Testirani usev bio je *S. macrocarpon*. Sveža masa biljaka, kao i usvajanje P i S, određivani su pri prvoj berbi. Rezultati su pokazali da je doza đubriva od 20 kg N ha^{-1} dovela do statistički značajno viših prinosa i većeg usvajanja P i S u zoni savane (4,2 t ha^{-1}) i kišne šume (1,2 t ha^{-1}). Primena dve nedelje nakon sadnje dala je veće prinose (3,3 t ha^{-1}) u zoni savane, dok je primena pri sadnji dala najviši prinos (1,2 t ha^{-1}) u zoni kišne šume. Iako vreme primene đubriva nije imalo uticaja na prinos sveže mase i dostupnost hranljivih materija, istraživanjem se zaključilo da je kombinacija 60 kg N ha^{-1} uz 5 t ha^{-1} optimalna kombinacija đubriva za proizvodnju *S. macrocarpon* u jugozapadnoj Nigeriji.

Ključne reči: *Solanum macrocarpon*, fosfor, sumpor, sveža masa, đubrivo, mikrodoza.

Primljeno: 20. jula 2025.
Odobreno: 10. decembra 2025.

[*]Autor za kontakt: e-mail: tolatoberu@oauife.edu.ng

Journal of Agricultural Sciences (Belgrade) https://doi.org/10.2298/JAS2504397Z
Vol. 70, No. 4, 2025 UDC: 633.854.78
Pages 397-417 Original scientific paper

THE MICROBIAL ACTIVITY AND PHYTOSANITARY CONDITION OF SUNFLOWER CROPS DEPENDING ON THE LEVELS OF BIOLOGIZATION OF CULTIVATION TECHNOLOGY

Oleksandr G. Zhuikov, Sergiy O. Lavrenko*, Nataliia M. Lavrenko, Juliana S. Kotovska, Oleksandr O. Kazanok and Gennadiy V. Karashchuk

Kherson State Agrarian and Economic University, Kherson, Ukraine

Abstract: The research was carried out from 2018 to 2021. The field experiments were conducted in four replications by using the split-plot design method. The study evaluated the following cultivation technology elements: A – sunflower hybrid: A1 – PR64F66 F_1; A2 – Tunca F_1; B – cultivation technology: B1 (traditional); B2 (biologized I); B3 (biologized II); B4 (organic); B5 (extensive). The research showed that during the growing season, under intensive sunflower cultivation technology, both the total colonization of the arable soil layer of the research plot and the amount of microflora by certain most principal groups decreased considerably compared to the variants where some elements of biologization or their complex application (organic cultivation technology) were implemented by 6.1–40.9%. The application of modern insecticides of organic origin in sunflower plant protection under biologized and organic cultivation technologies allows controlling a whole array of the most harmful phytophages and is not inferior to synthetic insecticides in effectiveness. The exception is the protection of the crop against owlet moth larvae, which, because of their biological and ecological characteristics, require an insecticide with more systemic properties, which are not characteristic of organic preparations with few exceptions. Biological preparations had no residual insecticidal or repellent effect on major crop pollinators. The application of pre- and post-emergence harrowing with harrows and rotary hoes and inter-row tillage in the system of the crop protection against weeds as a component of biologized and organic technologies for sunflower cultivation is as effective as soil and post-emergence synthetic herbicides.

Key words: sunflower, hybrid, biologization, microorganisms, disease.

*Corresponding author: e-mail: lavrenko.sr@gmail.com

Introduction

Sunflower (*Helianthus annuus* L.) is a strategic oilseed crop of global importance in the agro-industrial sector, valued for its high-quality oil and nutritional value. However, its cultivation faces significant phytosanitary risks and is continually threatened by several soil-borne pathogens, including fungi such as *Sclerotinia sclerotiorum*, *Verticillium dahliae*, *Plasmopara halstedii*, and various species of *Fusarium* and *Phytophthora*. These pathogens lead to diseases such as root rot, wilt, and stem rot, which cause significant annual crop losses and economic damage. Combating these phytosanitary problems is extremely challenging, as the pathogens persist in the soil for long periods, and chemical control methods are often ineffective, environmentally harmful, and increasingly restricted (Tkalenko, 2015; Zhuykov et al., 2020; Zhuikov et al., 2022a; Brent and Hollomon, 1995).

The most common methods for improving the phytosanitary status of sunflower crops are: strict adherence to crop rotation, which reduces pathogen accumulation and improves soil health; implementation of a scientifically grounded plant protection system, involving chemical and biological preparations; adherence to the plant nutrient regime, which strengthens the plants' immune system; and cultivation of disease- and pest-resistant varieties and hybrids (Patika, 2001; Bazaluk et al., 2022; Zhuykov et al., 2024a; Bazaliy et al., 2019).

In the search for stable and effective protection protocols or for limiting spread, the soil microbiome is the main frontier for improving plant health and productivity. Soil is not just an inert growing medium but a complex ecosystem containing diverse microorganisms that directly influence the phytosanitary status of agricultural crops. Within this microbiome, specific functional groups play a key role in disease suppression and promoting plant growth. Thus, the use of antagonistic microorganisms through inoculation (*Pseudomonas*, *Bacillus*, *Trichoderma*) suppresses pathogens through competition, antibiosis, or parasitism. Symbiotic relationships with plant roots are also formed, improving the uptake of nutrients and water and increasing plant resistance to stress factors such as drought, frost, and the phytotoxic effects of pesticides (Zhuikov et al., 2022b; Vavrinevich et al., 2013; Zhuykov et al., 2024b).

The current studies by the Ukrainian and foreign scientists emphasize the inhibiting impact of reactants and metabolites of synthetic pesticides (mainly, fungicidal and bactericidal preparations) on the total amount and activity of soil microbiota (Aksenov, 2001; Bayrak, 2008; Volkogon and Dimova, 2010; Tkachuk, 2014; Pashkevich, 2009). The vast majority of modern groups of the above-mentioned pesticides are not selective in their effects on pathogenic and beneficial microflora. Therefore, while they control the amount of pathogenic agents in agricultural crops, they also pose a serious potential risk of bactericidal effects on microorganisms that directly participate in soil formation, perform mineralizing, nitrogen-fixing, ammonifying, and cellulose-decomposing functions, and act as antagonists to pathogenic microbiota (Anishin, 2012; Kysil, 2005; Klimenko, 2015; Brent and Hollomon, 1995).

If sunflower production is intensified, the intensity of the above-mentioned negative processes may increase, especially when sunflowers are returned too early to the same field in crop rotation, or when repeated planting or monocropping is practiced on farms in the region. The resulting increase in pesticide loads per hectare of sunflower fields creates more unfavorable conditions for the normal activity of microorganisms in the arable soil layer.

We present the results of the experimental research on the dynamics of micro-biological soil activity intensity under different sunflower cultivation technologies, focusing on the main groups of micro-organisms involved in soil formation processes and responsible for different aspects of soil fertility formation.

Ammonifying microorganisms, also known as saprogenic bacteria, belong to a group of microorganisms that perform ammonification – the decomposition of organic nitrogen-containing (nitric) substances, releasing ammonia. They play a role in nitrogen cycling and plant nutrition. Ammonification occurs under both aerobic and anaerobic conditions. Aerobic and anaerobic microorganisms, decomposing protein, urine, chitin, organic fertilizers, humus, and similar materials can be ammonifying microorganisms. If, during the ammonification of proteins containing sulphur, hydrogen sulphide, indole and skatole are produced, this process is called putrefaction, and the microorganisms responsible are saprogenic bacteria. In addition to saprogenic bacteria, ammonification is also carried out by urobacteria, actinomycetes, and fungi. As a result of the activity of ammonifying microorganisms, the poorly available nitrogen in organic compounds from plant and animal residues is converted into a form accessible to plants. Ammonia released during ammonification is neutralized by soil acids producing ammonium salts, or nitrifying bacteria oxidize it to nitrogen (nitrate) and nitric (nitrite) acids. Most ammonifying microorganisms use protein as a source of carbon and energy, provided that there are no other substrates (such as sugars, spirits, or organic acids). Bacteria of the genus *Proteus*, as well as representatives of the genera *Bacillus*, *Pseudomonas*, and *Clostridium*, largely use proteins. Soil bacteria *Bacillus pasteurii* perform ammonification of carbamide. Representatives of the genus *Clostridium* decompose nitrogen-containing compounds to produce amines, further oxidizing other bacteria under aerobic conditions, releasing ammonia.

Oligonitrophiles are microorganisms, usually soil organisms, capable of growing under conditions with a small amount of bound nitrogen in the environment. Many of these organisms are diazotrophs, meaning they can fix atmospheric nitrogen.

Actinomycetes are prokaryotic, mycelial, gram-positive microorganisms that inhabit soil. As soil microorganisms, actinomycetes play an important ecological role. However, they attract researchers' attention mainly as one of the most important subjects in biotechnology. More than 60% of biologically active compounds are of microbial origin and two-thirds of antibiotics are metabolites of actinomycetes. Of these, 80% are synthesized by representatives of the genus *Streptomyces*. They also produce amino-acids, proteins, ferments, and other compounds. Nowadays, the search for new natural compounds with valuable characteristics, synthesized by actinomycetes, remains relevant. Actinomycetes are also important in agriculture due to their antagonistic characteristics and their ability to decompose compound substrates and degrade xenobiotics. The microbiological method for plant protection, which involves using actinomycetes and their metabolic products to suppress the development of phytopathogenic microorganisms, has significant potential.

Cellulose-decomposing bacteria are microorganisms, capable of decomposing cellulose. Important aerobic cellulose decomposers include representatives of the genera *Cytophaga* (*C. hutchinsonii*), *Sporocytophaga* (*S. mixococcoides*), *Sorangium* (*S. cellulosum*), *Archangium* (*A. gephyra*) and *Pseudomonas* (*P. fluorescens var. cellulosa*). However, the major role in cellulose decomposition under aerobic conditions is played by the fungi *Fusarium* and *Chaetomium*. Cellulose is also decomposed by *Aspergillus fumigatus*, *A. nidulans*, *Botrytis cinerea*, *Rhizoctonia solani*, *Trichoderma viride*, *Chaetomium globosus* and *Myrothecium verrucaria*.

Nitrifying bacteria are autotrophic microorganisms that obtain energy for their life activity by oxidizing ammonia to nitrates, which are known to be the most available form of nitrogen for plants.

Denitrifying bacteria convert nitrates to molecular nitrogen. All are aerobic and can oxidize organic matter using atmospheric oxygen, but under anaerobic conditions, they use the oxygen in nitrates as an electron acceptor. These bacteria are found in soil, water, and water body silt.

Nitrogen-fixing bacteria are capable of absorbing molecular nitrogen directly from the atmosphere. After these bacterial cells die, nitrogen returns to the ecosystem in a form available to plants. Without nitrogen-fixing bacteria, nitrogen available to plants would be washed out to the oceans, converted to its molecular form, and released into the atmosphere, resulting in the loss of soil fertility. The most widespread nitrogen-fixing bacteria are Rhizobium species, which form symbiotic relationships with the root systems of legume crops.

Material and Methods

Field trials on sunflower cultivation technology were conducted during 2018–2021 in the non-irrigated lands of the Farm "Vera" in the Hola Prystan district of the Kherson region. The experimental plots were located at the latitude 46°20'16.11"N, longitude 32°17'31.38"E, at an elevation of 9 m above the sea level.

The soil of the experimental plots was classified as dark-chestnut medium-loamy, and moderately saline, with a humus content of 2.34–2.60%. The content of mobile forms of mineral nutrients was as follows: nitrogen – 1.7–2.0 mg-eq per 100 g of soil; phosphorus – 4.9–6.5 mg-eq per 100 g of soil; potassium – 28–36 mg-eq per 100 g of soil. The pH ranged from 6.9 to 7.2. The soil has moderate natural fertility, which mainly depends on its nitrogen content.

The field experiments were conducted in four replications using the split-plot design method. The study focused on evaluating the following cultivation technology elements: A – sunflower hybrid: A1 – sunflower hybrid PR64F66 F_1 (bred by Pioneer); A2 – sunflower hybrid Tunca F_1 (bred by Limagrain); B – the level of biologization of the cultivation technology: B1 (traditional) – a traditional intensive zonal cultivation technology recommended by the originator for the conditions of the Southern Steppe of Ukraine, using mineral fertilizers and chemical plant protection products (PPP) to maximize the genetic potential of the hybrid; B2 (biologized I) – an intensive technology in which the plant care system replaces mineral fertilizers with biological fertilizers approved for use in organic farming. The multifunctional preparation TM "Eco-Growth" was used as an organic fertilizer; B3 (biologized II) – an intensive technology in which the plant care system replaces mineral fertilizers with biological preparations approved for use in organic farming, and herbicides are replaced with mechanical weed control operations. The preparations "ENZIM-Agro", Gaubsin-FORTE, and Viridin (Trichodermin) were used as biological fungicides. The insecticide-acaricides TM "ENZIM-Agro" Entocid (Metarizin) and Aktarofit were used as biological insecticides; B4 (organic) refers to a technology in which the crop care system is based solely on the use of biological preparations (both fertilizers and pesticides); B5 (extensive) is an extensive (minimal) technology of crop cultivation, in which the system of crop care consists only of mechanical operations to control weeds, without using chemical or biological fertilizers and plant protection products.

The experimental plots were arranged using the split-block method. The total area of the experimental field was 1.2 ha, the total area of each quartic plot was 672 m², and the registered plot was 560 m². The experiment was replicated four times. Overall, the layout of the two-factor field experiment and the arrangement of the research plots followed this pattern.

The characteristics of the experimental hybrid: PR64F66 F_1: the originator company – Pioneer® (USA), simple two-lined highly oleic, the maturity group – medium-early (111–115 days), the actual production yield – 30.8 c/ha, the plant height – below the average (146 cm), convex seeds, the color – black-gray, the inflorescence – flat capitulum, the diameter – 15.4 cm, oil content – 51.1–52.3%, protein content – 16.0–17.2%, the weight of 1,000 seeds – 67 g. Disease and stress resistance: very high resistance to drought, excellent cold resistance, high resistance to lodging, resistance to 7 races of *Orobanche cumana* (A–G), resistance to various types of cinerea (white, ashy, dry, root), and tolerance to phomosis and phomopsis; Tunca F_1: the originator company – Limagrain® (France), simple two-lined hybrid, the maturity group – medium-early (110 days), the actual production yield – 29.5 c/ha, the plant height – medium (150 cm), elongated seeds, the color – black-gray, the inflorescence – flat capitulum, the diameter – 15.9 cm, oil content – 50.6–51.7%, protein content – 16.2–17.0%, the weight of 1,000 seeds – 73 g. Disease and stress resistance: high resistance to drought, excellent cold resistance, resistance to lodging, resistance to 7 races of *Orobanche cumana* (A–G), resistance to various types of cinerea (white, ashy, dry, root), and tolerance to phomosis and phomopsis.

During the research, we followed the generally accepted methods for conducting field experiments and performing laboratory experiments. The experiments included appropriate observations, measurements and analysis of soil and plant samples. All the records and observations were made in two non-contiguous replications.

The agricultural techniques used in the experiments, provided that the specified technological operation or its gradation was not a factor studied according to the experimental design, had the following pattern: winter wheat served as a pre-crop. After its harvest, disking was performed to a depth of 10–12 cm with the BDT-7. Fourteen days after the final disking, the stubble was plowed to a depth of 22–24 cm, followed by leveling with the KPE-3.8 (8–10 cm), and double pre-sowing tillage with the Lemken Compactor S unit. According to a preliminary agreement with the regional representatives of the companies that developed the sunflower hybrids, the crop seeds without pre-sowing incrustation with a fungicidal-insecticidal composition were purchased for the experiment. Pre-sowing treatment was carried out independently: in the intensive and biologized I technology variants, seeds were treated with a mixture of Cruiser 6 l/t (thiamethoxam 350 g/l) and Maxim 1 l/t (fludioxanil 25 g/l), in the biologized II and organic technology variants, seeds were treated with a mixture of biological preparations (Table 1) at the recommended rates, using 10 l/t of the working liquid. Mineral fertilizers (ammonium nitrate and granular superphosphate) were applied in the intensive and biologized II technology variants at the calculated rate of $N_{54}P_{46}$, average over the research years (40% of nitrogen and 100% of phosphorus for basic tillage, 60% of nitrogen for pre-sowing tillage). In the organic technology variant, biological fertilizers were used at the recommended rates. Sunflower seeds were sown in the middle of spring at a soil temperature of 6–7°C at a depth of 5 cm using the wide-row method, with a row spacing of 0.7 m and a seeding rate of 55 thousand units/ha, using a SUPN-8 seeder, followed by post-sowing soil rolling with KKSH-3 rollers.

Table 1. The characteristics of biological preparations used in the variants of the experiment.

Preparation	Content	Methods and rates of application
Organic fertilizer "Eco-Growth"	Strains of the culture *Bacillus thermophiles*, *Bacillus subtilis*, phosphorus-mobilizing, nitrifying bacteria and chelate micro-fertilizer (51 g/l N, 12.0 g/l K_2O, 58 g/l MgO, 50 g/l SO_3, 6.5 g/l B, 12.5 g/l Cu, 12.4 g/l Fe, 12.0 g/l Mn, 0.2 g/l Mo, 6.4 g/l Zn, 0.1 g/l Co, 66.4 g/l amino acids, 67.8 g/l organic acids (succinic, malic, tartaric and citric), 3.3 g/l humic acids, 0.58 g/l fulvic acids, 0.0055 g/l phytohormones, 0.049 g/l of polysaccharides, vitamins, cytokinins, gibberellin compounds) pre-sowing seed treatment – 2 l/t; vegetative foliar feeding – 2 l/ha	pre-sowing seed treatment – 2 l/t; vegetative foliar feeding – 2 l/ha
Bio-fungicide Gaubsin-FORTE	Two strains of *Pseudomonas aureofaciens* with a cell titer of at least 4×10^9 CFU/ml	plant vegetative spraying – 2 l/ha
Biofungicide Viridin (Trichodermin)	Spores and mycelium of fungi of the genus *Trichoderma* spp. with a titer of not less than 1×10^8 CFU/ml and metabolic products – biologically active substances; pre-sowing seed treatment – 5 l/t; vegetative spraying of plants – 2 l/ha	pre-sowing seed treatment – 5 l/t; plant vegetative spraying – 2 l/ha
Biofungicide Entocid (Metaryzyn)	Spores of entomopathogenic fungi – not less than 2×10^8 CFU/ml	soil spraying for pre-sowing treatment – 5 l/ha
Biofungicide Actarofit	Complex of natural avermectins produced by the beneficial soil fungus Streptomyces avermitilis (abamectin – 50%, emamectin – 50%). The total content of toxins is not less than 1.8%	plant spraying – 0.2 l/ha

Source: Own description based on materials provided by manufacturers.

The care of sunflower plants involved the measures protecting the crop against a complex of pests when the economic threshold was exceeded. In the intensive and biologized I technology variants, weed control was achieved by applying the soil herbicide Triflurex at the rate of 3 l/t (triflurex 480 g/l) and the post-emergent herbicide Select at 2 l/ha (kletodim 120 g/l). In the biologized II, organic and extensive variants, weed control was carried out using mechanical methods, including pre- and post-emergent harrowing with weeders and rotary hoes, as well as inter-row tillage. Disease protection in the intensive and biologized I technology variants consisted of two vegetative treatments with the fungicide Amistar Extra at 1 l/ha (azoxystrobin 200 g/l + cyproconazole 80 g/l). In the biologized II and organic variants, treatments were performed with biofungicides (Table 1). Pest protection in the intensive and biologized I technology variants consisted of two vegetative treatments with the Ampligo 150 ZC insecticide at 0.3 l/ha, containing chlorantraniliprole 100 g/l and lambda-cyhalothrin 50 g/l. In the biologized II and organic technology variants, treatments were performed with bio-insecticides.

Vegetative plant treatment was carried out twice at the phase of sunflower development “3 pairs of true leaves” and “capitulum formation”. The rate of working fluid consumption in all the cases was 250 l/ha, with the preparations and tank mixture applied simultaneously 30 minutes before treatment. The crop was harvested by direct combining at the stage of full seed maturity using the self-propelled grain harvester John Deere 9660 STS. The data obtained were adjusted to basic moisture (7%) and 100% purity.

Sampling, preparation, and storage of soil samples for the investigation of microbiota were conducted in accordance with DSTU ISO 10381-6-2001 (DSTU ISO 10381-6-2001, 2006).

In the samples collected from the experimental plots, the abundance of the main ecological-trophic groups of microorganisms was determined by microbiological methods (Conrad, 1996; Gerhardt, 1981; Volkogon et al., 2010; Volkogon et al., 2011) by seeding diluted soil suspensions onto nutrient media. The abundance of the following groups of microorganisms was determined: ammonifiers – microorganisms that predominantly use organic compounds as sources of nitrogen and carbon (their abundance was determined by seeding aqueous dilutions of the studied soil onto agarized meat-peptone medium); immobilizers of mineral nitrogen – microorganisms that assimilate predominantly mineral nitrogen compounds (if mineral fertilizers are absent in the soil, these microorganisms begin to develop after the ammonification of organic compounds occurs); their abundance was determined by seeding soil dilutions onto agarized starch-ammonia medium; nitrogen fixers – bacteria capable of assimilating nitrogen from the air, whose abundance was determined by the method of soil crumb overgrowth on semi-liquid nitrogen-free Ashby’s medium, followed by testing for the ability of nitrogen fixation (gas chromatography test for acetylene reduction); denitrifiers – bacteria capable of reducing nitrates to N_2O, NO, and N_2, whose abundance is determined by seeding soil dilutions into liquid Giltay’s medium with KNO_3 and after incubation in a thermostat, testing for nitrate reduction is performed using the Griess reagent (nitrate test); pedotrophs – microorganisms capable of growing on soil agar, whose abundance was determined on agarized aqueous soil extract. These indicators are often used as an equivalent to the total abundance of microorganisms in the soil; micromycetes (microscopic fungi) – abundance was determined by seeding soil dilutions onto acidified agarized Czapek’s medium or onto wort-agar; cellulolytic bacteria – abundance was determined by seeding soil dilutions into liquid Imshenetsky-Solntseva medium with strips of filter paper. The results were expressed as the number of CFU per 1 g of absolutely dry soil. The potential activity of soil-biological processes was also determined. This activity was measured in soil samples by creating optimal temperature, moisture, and an excess of nutrient sources, resulting in obtaining an indicator of the maximum possible level of activity for the studied process.

Accountings of soil and plant pests were conducted with consideration of modern systems of soil tillage, application of fertilizers and plant protection products (Demenko and Yemets, 2020). During pest sampling from the soil, square samples of 0.25 m^2 (50×50 cm) were laid out. Soil from each sample was removed layer by layer: the first layer to a depth of 5 cm, and each subsequent layer to a depth of 10 cm. Insects were collected, counted and identified separately for each layer. Phytophage accounting was conducted by counting individuals per 1 m^2 or by the number of damaged plants (at the early stages of crop development). Observations were made before and after the application of the insecticide, as well as at 5, 10, and 20 days post-application, in clear, sunny weather between 11:00 and 13:00. Cabbage flea beetles were counted using measuring frames with an area of 0.25 m^2 at 16 points on the plot. The species composition of phytopathogens was determined visually using an atlas, and their distribution was assessed by the percentage of damaged plants and the percentage of damaged area of the assimilation apparatus at 10 points on the plot. The intensity of flowering plant visitation by honey bees was measured using glue traps.

The experimental data for sunflower were analyzed using the standard procedure of ANOVA within the MS Excel software. The significance of the differences was confirmed at the 95% reliability level.

Results and Discussion

The experimental data show that during the growing season, under intensive sunflower cultivation technology, both the total colonization of the arable soil layer in the research plot and the total amount of microflora in the main groups decreased significantly compared to the variants where some elements of biologization were used or where their combined application was implemented (organic cultivation technology) (Table 2).

Due to a lack of negative pesticide pressing on the agrocenosis and the additional supply of CFU by certain groups of soil microbiota, during the period of observation, there was a positive trend in the number of microorganisms in the variants of biologized I and II and organic technologies for sunflower cultivation. Organic management practices have a positive impact on microbial population sizes, as confirmed by the results of other studies. Specifically, organic farming systems lead to significantly greater microbial biomass (by 59%) and activity (by 19–84%, depending on the indicator) compared to conventional systems (Lori et al., 2017). Long-term organic farming increases both the quantity and diversity of microbes (Tsentilo, 2019). This indicates a more stable and resilient ecosystem capable of performing plant-beneficial functions more effectively (Hartmann et al., 2015; Geisseler and Scow, 2014).

On average, according to factor A, from the stage of “the first set of true leaves” to the stage “complete seed maturity”, the total colonization of 1 g of completely dry soil by aerobic species increased as follows: under biologized I – by 8.3%, biologized II – by 6.7%, organic – by 8.0%; ammonifying species – by 6.1%, 6.2% and 5.7%, respectively; oligo-nitrophiles – by 14.7%, 12.9% and 10.9%; nitrophiles – by 18.5%, 17.9% and 19.2%; cellulose-decomposing – by 40.9%, 28.0% and 28.0%; nitrifying – by 23.9%, 26.7% and 28.9%. For the group of actinomycetes, we observed a decrease in soil colonization during the growing season in the biologized and intensive technology variants, which is considered a positive effect, since this group is mostly represented by pathogenic species that cause crop diseases, particularly in sunflower (Table 2).

Table 2. Dynamics of micro-biological activity of 1 g of completely dry soil under different sunflower cultivation technologies, CFU/g dry soil (average for 2018–2021).

Cultivation technology	Stage of plant development						
	First set of leaves						
	aerobic species, mln.	ammonifying, mln.	oligo-nitrophiles, mln.	actinomycetes, mln.	nitrophiles, mln.	cellulose-decomposing, thous.	nitrifying, thous.
Traditional	17.5	16.6	12.9	1.0	15.1	1.3	7.1
Biologized I	18.9	17.0	16.2	1.1	15.0	1.3	8.3
Biologized II	19.5	17.2	16.9	1.0	15.6	1.7	8.5
Organic	19.6	17.6	17.2	1.1	15.4	1.8	8.6
Extensive	18.0	16.9	12.5	1.1	13.0	1.1	7.5
Cultivation technology	Stage of plant development						
	Complete maturity						
	aerobic species, mln.	ammonifying, mln.	oligo-nitrophiles, mln.	actinomycetes, mln.	nitrophiles, mln.	cellulose-decomposing, thous.	nitrifying, thous.
Traditional	10.3	11.3	8.9	0.7	9.7	0.7	5.1
Biologized I	20.6	23.0	19.0	0.9	18.4	2.2	10.9
Biologized II	20.9	23.3	19.4	0.8	19.0	2.3	11.6
Organic	21.3	23.7	19.3	0.9	19.2	2.5	12.1
Extensive	11.9	14.2	10.7	0.6	11.8	0.8	5.9

Note: average values for both tested hybrids. All the experimental data obtained showed significant differences ($P < 0.05$).

Conventional technologies suppress the development of microbiota, as clearly shown in our research. The results obtained in studies (Tian et al., 2015) confirm that high doses of nitrogen can inhibit certain microbial groups, particularly cellulose-decomposing bacteria and actinomycetes, due to soil acidification. This indirectly explains why biologized systems perform best in this regard.

Analysis of the dynamics of soil microbiological activity across the variants of traditional and extensive cultivation technologies showed a drop in the number of

CFU for all groups, except for actinomycetes. This process was more intense under the traditional cultivation technology, which can be explained by the application of synthetic pesticides that inhibit soil microbiota.

Since sunflower has traditionally held a leading position among industrial oil crops in our country, all innovations concerning the crop cultivation technology (firstly, intensification) have been actively implemented by agricultural commodity producers over the past 20–30 years (Bazaliy et al., 2015; Butenko, 2003). However, the scientific community and some conscientious producers have expressed concern about excessive pesticide pressure on agrocenoses and the inefficient use of production inputs, especially the most expensive components: mineral fertilizers and plant protection products (Zhuykov et al., 2020; Lukhmenev, 2015; Thomas and Kravchuk, 1981).

The current trend toward partial or complete biologization of plant production technology has also become popular in sunflower cultivation. Recently, the issue of reducing the application of synthetic plant protection products and mineral fertilizers in sunflower raw material production both in scientific and production aspects has been a topic of discussion, scientific debates and production experiments (Bursela, 1995; Palamarchuk et al., 2012; Patika, 2001; Gritsev, 2015). However, analysis of the modern scientific journals allows the conclusion that, in most cases, their authors study certain factors of biologization of the crop production only fragmentarily (almost exclusively the application of mono- and poly-functional plant growth regulators, immunomodulators, and antistressants) (Sendetsky, 2017; Tarariko and Lychuk, 2014; Tkalenko, 2015).

The application of non-synthetic fungicides and insecticides in sunflower cultivation, despite its limited popularity as a protection measure, has not been thoroughly examined in the modern scientific literature, though it is more common in crop production practice (Bazaliy et al., 2019; Vavrinevich et al., 2013; Roberts, 1981). The current interest in microbial fertilizers as a means to increase the efficiency of plant uptake of macro- and meso-elements of mineral nutrition has also extended to sunflower cultivation technology. The use of chelate complexes in mineral nutrition systems has become a focus of scientific research among Ukrainian and foreign researchers (Bulygin et al., 2007; Buryak et al., 2014).

As interest in organic products on the domestic and foreign markets has risen, sunflower seeds and processed products (oil and oil cake) with organic status have become the most expensive lots. However, comprehensive domestic organic technology for the crop cultivation has not yet been developed due to unresolved issues with weed control (Ryazanov and Shevchuk, 2018; Tsikov and Matyukha, 2006; Malidža et al., 2000).

Ultimately, the analysis of the current state of research by scientists indicates an almost complete lack of reliable information regarding the comprehensive application of various methods of alternative protection of sunflower against a complex of harmful organisms within a unified system, the priority of certain groups (fungicidal and insecticidal protection), the complete rejection of synthetic pesticides and mineral fertilizers, and the cultivation of the crop based on organic technology (Ponomarenko et al., 2017; Tsandur et al., 2014).

Phytophage control in the research focused on the most harmful groups: wireworms (larvae of the species *Agriotes obscurus* and *Agriotes lineatus*), thrips (larvae of the species *Thrips tabaci*) and owlet moths (larvae of the species *Helicoverpa armigera* and *Agrotis segetum*) (Table 3).

Table 3. Registration of the most harmful phytophages in sunflower crops depending on the level of biologization of cultivation technology (average for 2018–2021).

Hybrid (factor A)	Cultivation technology (factor B)	Phytophages		
		Wireworm species (damaged seeds per linear meter)	Tobacco thrips (individuals per plant)	Owlet moth species (individuals per plant)
PR64F66 F1	Traditional	0.22	1.12	0.27
	Biologized I	0.18	1.07	0.20
	Biologized II	0.37	1.16	0.46
	Organic	0.31	1.15	0.42
	Extensive	0.84	2.33	2.64
Tunca F1	Traditional	0.19	1.15	0.22
	Biologized I	0.20	1.11	0.17
	Biologized II	0.29	1.09	0.50
	Organic	0.27	1.17	0.41
	Extensive	0.90	2.80	2.97
LSD_{05}	For average (main) effects	Factor A – 0.07; Factor B – 0.04	Factor A – 0.04; Factor B – 0.08	Factor A – 0.07; Factor B – 0.11
	For partial differences	Factor A – 0.12; Factor B – 0.10	Factor A – 0.08; Factor B – 0.10	Factor A – 0.05; Factor B – 0.04

The experiment demonstrates that replacing synthetic insecticides with organic preparations can provide comparable efficacy against key sunflower pests. Other researchers support this view. For instance, a trial conducted in Serbia using the product ATTRACAP® (Metarhizium brunneum CB15) compared to synthetic insecticides (Buteo Start 480 FS, Lumiposa, Force 20 CS, and Force 1.5 G) showed that the biological preparation ATTRACAP® achieved efficacy comparable to synthetic insecticides at low pest density. Moreover, the use of the biopreparation helped reduce the environmental impact (Gvozdenac et al., 2022).

The experiment revealed that, based on the index of the plant damage caused by wireworm larvae, the experiment variants in which the synthetic insecticidal seed protectant was replaced with an organic preparation were not inferior to either the control variant or the variant using biologized I technology, which also used a chemical preparation. The extensive technology variant of the crop cultivation, in which no insecticidal protectant was applied, was considerably inferior to the above variants, with seed damage from pests observed on 8.4–9.0 seeds per 10 linear meters of a row, representing 22–25% of the population.

A similar tendency was observed when analyzing the damage to sunflower plants caused by tobacco thrips larvae, which are agents of viral diseases. Both variants of biologized cultivation technology and organic technology were not inferior to traditional (intensive) technology, but extensive cultivation technology was considerably based on the indexes of plant damage caused by the pest larvae: there were 2.3–2.8 larvae per each plant.

The most dangerous pests for the generative part of sunflower yield – cotton and winter owlet moth larvae – were most harmful in the variant where neither synthetic nor organic insecticidal preparations were applied. On the plots, where extensive crop cultivation technology was implemented, each capitulum contained 2.6–2.9 larvae, which inevitably affected the crop hybrid yields. Maximal control of this pest was achieved with traditional intensive cultivation technology (the average index equaled 0.22–0.27 pieces per plant) and biologized I technology, where synthetic insecticidal preparations were also applied (0.17–0.20 pieces per plant, respectively). The technology variants using organic insecticides (biologized II and organic) were somewhat less effective in controlling owlet moth larvae: the average number of pests equaled 0.46–0.50 and 0.41–0.42 pieces per plant, respectively. This can be explained by the residual systemic effect of organic insecticidal preparations, which is less specialized compared to synthetic insecticides.

Research on the intensive use of biological control has shown that regions within the Brazilian agricultural sector that actively employ biological protection methods achieved a higher technical efficiency score of 0.863, compared to 0.823 in regions using traditional methods (Rodrigues et al., 2023).

During the research, we observed both epiphytotic and sporadic manifestations of the following fungal diseases in sunflower agrocenoses: phomosis (*Phoma helianthi*), phomopsis (*Phomopsis helianthi*), white rot (*Sclerotinia sclerotiorum*), grey rot (*Botrytis cinerea*), downy mildew (*Plasmopara halstedii*), septoriosis (*Septoria helianthi*), and brown rust (*Puccinia helianthi*). The extent of plant damage caused by these disease agents, depending on cultivation technology, is shown in Table 4.

Research confirms that organic and biologized technologies can be effective in controlling sunflower diseases, proving not inferior to conventional methods. However, their success depends on an integrated approach, including crop rotation, the selection of resistant hybrids, and careful monitoring. Extensive technology (without the application of protective agents) leads to significant pathogen buildup and yield loss (Tsikov and Matyukha, 2006; Tsandur et al., 2014; Zhuykov et al., 2024b; Siviter et al., 2023).

Table 4. Sunflower plant damage caused by the agents of fungal diseases depending on the level of biologization of cultivation technology (average for 2018–2021).

Hybrid (factor A)	Cultivation technology (factor B)	Plant damage, points						
		Phomosis (*Phoma helianthi*)	Phomopsis (*Phomopsis helianthi*)	White rot (*Sclerotinia sclerotiorum*)	Grey rot (*Botrytis cinerea*)	Downy mildew (*Plasmopara halstedii*)	Septoriosis (*Septoria helianthi*)	Brown rust (*Puccinia helianthi*)
PR64F66 F1	Traditional	0.7	1.4	1.2	1.5	0.6	1.7	2.2
	Biologized I	0.5	1.5	1.1	1.7	0.4	1.9	2.1
	Biologized II	0.9	1.3	1.5	1.2	0.4	1.4	2.2
	Organic	0.7	1.0	1.2	1.2	0.4	1.6	2.0
	Extensive	2.3	2.7	3.1	2.4	0.8	3.3	3.5
Tunca F1	Traditional	0.9	1.0	1.2	1.0	0.4	2.0	2.0
	Biologized I	0.7	1.2	1.4	1.0	0.5	2.1	1.7
	Biologized II	1.2	1.0	1.5	1.5	0.4	1.9	2.5
	Organic	0.9	1.1	1.2	1.6	0.7	1.8	2.4
	Extensive	2.5	2.2	3.3	2.2	0.6	3.5	3.8
LSD_{05}	For average (main) effects	Factor A – 0.27; Factor B – 0.40						
	For partial differences	Factor A – 0.22; Factor B – 0.31						

Analysis of the above data shows that, in terms of fungicidal effectiveness, organic preparations used in the sunflower protection system under biologized II and organic technologies were not inferior to synthetic compounds used in biologized I and traditional intensive technologies. The crop cultivation using extensive technology (without application of fungicidal preparations) showed a considerably higher degree of plant damage by phytopathogens (mainly, by phomopsis, white and grey rot, septoriosis, and brown rust). The manifestation of the latter was 3.5–4.0 points in some years, which had a crucial impact on the crop productive characteristics. The issue of sunflower protection against pests and diseases by means of biological preparations is not as acute nowadays as it was 4–5 years ago. Agricultural producers have sufficient domestic and foreign organic insecticides and fungicides. However, under current conditions, weed control in the agrocenosis of the crop cultivated using organic technology is possible only through agrotechnical measures – mainly mechanical soil tillage with harrows and rotary roes.

According to the results of our research, these methods of mechanical weed control in sunflower crops proved to be highly efficient and, when implemented timely and properly, were not inferior in their effect on major weeds to chemical protection measures taken in the variants of traditional intensive and biologized I technologies (Table 5).

Table 5. Dynamics of weediness in sunflower hybrid crops depending on the level of biologization of cultivation technology (average for 2018–2021).

Hybrid (factor A)	Cultivation technology (factor B)	Development stage					
		First set of true leaves		Formation of a capitulum		Seed maturation	
		annual, pcs/m^2	perennial, pcs/m^2	annual, pcs/m^2	perennial, pcs/m^2	annual, pcs/m^2	perennial, pcs/m^2
PR64F66 F1	Traditional	0.3	0.4	4.2	2.9	7.4	5.1
	Biologized I	0.2	0.5	4.0	2.5	6.5	2.4
	Biologized II	0.6	0.5	1.9	1.0	1.7	0.9
	Organic	0.6	0.4	1.8	1.3	2.0	1.4
	Extensive	4.6	2.7	8.4	5.1	10.4	5.5
Tunca F1	Traditional	0.3	0.5	4.4	3.1	6.5	3.3
	Biologized I	0.3	0.3	4.4	3.0	7.2	3.2
	Biologized II	0.5	0.3	1.4	1.1	1.9	1.6
	Organic	0.3	0.7	1.7	0.9	2.1	1.3
	Extensive	4.1	2.2	8.8	4.4	9.3	4.0
LSD_{05}	For average (main) effects	Factor A – 0.16; Factor B – 0.34					
	For partial differences	Factor A – 0.11; Factor B – 0.19					

Our experience in using rotary hoes and harrows in the biologized sunflower weed control system shows that these operations should be performed only in that part of a day when the crop turgor is minimal and the plant is maximally resistant to mechanical damage (noon hours under high air temperature and solar insolation). The machine operating speed should not exceed 5–8 km/h, depending on the crop development stage.

At the initial stages of ontogenesis (before the first set of true leaves), there was no essential difference in weediness among sunflower hybrid crops under intensive (traditional), biologized, and organic cultivation technologies. The number of annual and perennial weeds on the plots treated with soil herbicide and on the plots where plant protection was achieved through pre- and post-emergence harrowing was 0.3–0.7 pcs/m^2, respectively. In contrast, at the initial stages, the variant with the extensive crop cultivation technology had more weeds in the crops, with the number of annual species at 4.1–4.6 pcs/m^2, and perennial species at 2.2–2.7 pcs/m^2. The phytotoxic impact of soil and post-emergent herbicides on weeds was observed in the traditional cultivation technology variant up to the stage of the 6th–7th sets of true leaves. Starting from the stage of capitulum formation, an increase in the number of harmful herbaceous species was recorded. The intensive cultivation technology and biologized I technology variants were inferior to the biologized II and organic cultivation technology variants in terms of the index of weediness, where harrowing was alternated with inter-row tillage with covering. At the stage of seed filling, when the habit of sunflower plants prevented inter-row tillage without damaging the plants, the index of weediness (mainly due to annual late species) began to increase, though not as sharply as in the variants where chemical herbicides were applied (intensive and biologized I technologies), and especially not as much as in the absence of weed control (extensive technology). Currently, scientists and agricultural producers have no clear viewpoint concerning the negative impact of synthetic pesticides (mainly insecticidal-acaricidal preparations) on the activity of insect pollinators in sunflower agrocenoses. As a typical entomophilous cross-pollinated crop, sunflower requires a certain number of entomofauna representatives capable of fully pollinating the female flowers in a capitulum. Honey bees (*Apis mellifera*) are the primary pollinators in this regard. Therefore, some researchers emphasize that elements of modern intensive technologies – particularly plant protection measures applied in the second half of crop development – negatively affect bee visitation during the flowering stage (Castor et al., 2025; Lavrenko et al., 2024; Siviter et al., 2024; Siviter et al., 2021). Others are convinced that the situation is not so serious, referring to modern achievements of agro-chemical companies in developing products that are relatively harmless to this species and do not have repellent characteristics (Siviter et al., 2023; Brown et al., 2016; Linguadoca et al., 2021; Siviter et al., 2018). Considering that disruption of sunflower entomophilous pollination can result in up to 40% of seeds missing from a capitulum and, consequently, yield losses of 20–25%, we conducted research on the intensity of honey bee visits to sunflower plants in the experimental variants. The results of our research indicate that the intensity of honey bee visits to flowering inflorescences of the crop was considerably higher in the variants where elements of biologization were applied to the insecticidal crop protection system (replacing synthetic insecticides with biological preparations) than in the variants where chemical plant protection products were used against entomophages (traditional intensive and biologized I cultivation technologies) (Figure 1).

On average, in biologized variants, there were 4.5 bees per crop inflorescence, while only 1.5 bees were observed on plants where bio-insecticides were not used, indicating a considerable repellent impact of the synthetic preparations applied. In addition, we observed a few dead honey bees in the variants of intensive and biologized sunflower cultivation technologies, suggesting not only repellent but also residual insecticidal effects of the modern insecticidal preparations on beneficial entomofauna. In the variant with extensive cultivation technology, bee visitation of inflorescences was less intense, which can be explained by slightly lower nectar secretion and earlier cessation of flowering in these plants.

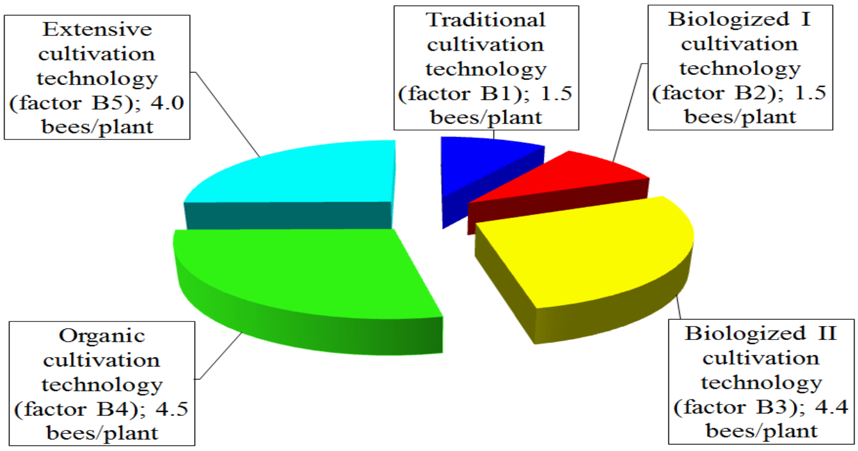


Figure 1. Intensity of honey bee visits to sunflower plants during the flowering stage, depending on cultivation technology (average for 2018–2021, bees per plant).

Conclusion

During the growing season, under conditions of intensive sunflower cultivation technology, the total colonization of the soil arable layer in the research plot and the amount of microflora in the main groups considerably decreased – by 6.1–40.9% in comparison with the variants where some elements of biologization or their complex application were implemented (organic cultivation technology).

The application of modern insecticidal preparations of organic origin in sunflower plant protection under biologized and organic cultivation technologies allows controlling a whole array of the most harmful phytophages and is not inferior to synthetic insecticides in effectiveness. The exception is the crop protection against owlet moth larvae, which, because of their biological and ecological characteristics, require an insecticidal preparation with more systemic properties that are generally not characteristic of organic preparations, with few exceptions. We observed no residual insecticidal or repellent impacts of biological preparations on major crop pollinators – honey bees as their attendance of flowering inflorescences was three times higher than in the variants of intensive and biologized I technologies.

Fungicide protection of sunflower plants, based on organic preparations, is as efficient and effective as protection systems based on synthetic fungicides: the hybrid damages caused by the most widespread phytopathogens did not differ depending on the type of preparations. Special control in sunflower agrocenosis under any cultivation technology is required for the agent of brown rust, which is inclined to secondary infestation because of climate conditions such as dry and windy weather.

Mechanical soil tillage as a method of the crop protection against weeds is an effective alternative to herbicide use. The application of pre- and post-emergence harrowing, rotary hoes, and inter-row tillage within the crop protection systems as a component of biologized and organic technologies for sunflower cultivation, is as effective as the use of soil and post-emergence synthetic herbicides. It is even more effective by the control of the second and third waves of late spring weed species in the second half of the plant development.

References

Aksenov, I.V. (2001). Agrocenosis and sunflower yield. *Scientific and technical bulletin of the Institute of Oilseeds UAAS*, *6*, 113-123.

Anishin, L.A. (2012). Plant growth regulators: doubts and facts. *Offer*, 5, 64-65.

Bayrak, N.V. (2008). Influence of non-root fertilization with REACOM on the system of plant photosynthesis. *Bulletin of Kharkiv National University named after V.N. Karazin, Series: Biology, 8*, 137-141.

Bazaliy, V.V., Zinchenko, O.I., & Lavrinenko, Yu.O. (2015). *Crop production*. Kherson: Green D.S.

Bazaliy, V.V., Domaratsky, Ye.O., & Kozlova, O.P. (2019). Influence of growth stimulants and biofungicides on the architecture of different sunflower morphobiotypes. *Research and Production Journal: Engineering and Technology*, *2* (111), 24-28.

Bazaluk, O., Havrysh, V., Nitsenko, V., Mazur, Y., & Lavrenko, S. (2022). Low-Cost Smart Farm Irrigation Systems in Kherson Province: Feasibility Study. *Agronomy*, *12* (5), 1013.

Brent, K.J., & Hollomon, D.W. (1995). *Fungicide resistance in crop pathogens: how can it be managed?* Brussels: GIFAP.

Brown, M.J.F., Dicks, L.V., Paxton, R.J., Baldock, K.C.R., Barron, A.B., Chauzat, M.-P., Freitas, B.M., Goulson, D., Jepsen, S., Kremen, C., Li,J., Neumann, P., Pattemore, D.E., Potts, S.G., Schweiger, O., Seymour, C.L., & Stout, J.C. (2016). A horizon scan of future threats and opportunities for pollinators and pollination. *PeerJ*, *4*, e2249.

Bulygin, S.Yu., Demishev, L.F., Doronin, V.A., Zarishnyak, A.S., Pashchenko, Ya.V., Turovsky, Yu.E., Fateev, A.I., Yakovenko, M.M., & Kordin, A.I. (2007). *Microelements in agriculture*. Dnepropetrovsk: Sich.

Bursela, M. (1995). Modern agroecological and social aspects of chemicalization of agriculture. *Proposal*, *1-2*, 17-18.

Buryak, Y.I., Ogurtsov, Y.E., Chernobab, O.V., & Klimenko, I.I. (2014). Effectiveness of plant growth regulators and microfertilizers in sunflower seed production. *Bulletin of the Central Executive Committee of the APV of the Kharkiv region*, *16*, 20-25.

Butenko, A.O. (2003). Influence of mineral nutrition on the productivity of sunflower varieties and hybrids in the north-eastern region of Ukraine. *Bulletin of Sumy NAU*, *4*, 139-141.

Castor, R.E.D.S, Martins, V., & Silva, E.C.M.D. (2025). Impacts of flupyradifurone on the midgut and brain of the neotropical social bee *Scaptotrigona postica* and its behavioral effects. *Environmental Toxicology and Pharmacology*, *118*, 104772.

Conrad, R. (1996). Soil microorganisms as controllers of atmospheric trace gases (H_2, CO, CH_4, OCS, N_2O and NO). *Microbiological Reviews*, *60* (4), 609-640.

Demenko, V.M., & Yemets, O.M. (2020). *Agricultural entomology: a textbook*. Sumy: SNAU, Ukraine.

DSTU ISO 10381-6-2001 (2006). *Soil quality. Sampling.* Kyiv: Derzhspozhyvstandart Ukrainy.

Geisseler, D., & Scow, K.M. (2014). Long-term effects of mineral fertilizers on soil microorganisms – A review. *Soil Biology and Biochemistry*, *75,* 54-63.

Gerhardt, P. (1981). *Manual of Methods for General Bacteriology*. Washington, DC: American Society for Microbiology.

Gritsev, D.A. (2015). Features of the formation of the sunflower crop when grown under different weed control systems. *Agrarian Bulletin of the Black Sea, 76,* 31-40.

Gvozdenac, S., Milovac, Ž., Vidal, S., Crvenković, Z.L., Papuga, I.Š., Franeta, F., Ovuka, J., & Cvejić, S. (2022). Comparison of Chemical and Biological Wireworm Control Options in Serbian Sunflower Fields and a Proposition for a Refined Wireworm Damage Assessment. *Agronomy*, *12*, 758.

Hartmann, M., Frey, B., Mayer, J., Mäder, P., & Widmer, F. (2015). Distinct soil microbial diversity under long-term organic and conventional farming. *The ISME Journal*, *9* (5), 1177-1194.

Klimenko, I.I. (2015). Influence of plant growth regulators and microfertilizers on seed yield of sunflower lines and hybrids. *Breeding and seed production*, *107,* 183-188.

Kysil, V.I. (2005). *Agrochemical aspects of greening of agriculture*. Kharkiv: Drukarnia №13.

Lavrenko, S., Korbych, N., Vedmedenko, O., & Lyubenko, O. (2024). The Effects of Climate Change on Agroecosystems, Including Changes in Honey Bee Populations (Chapter 6). *In* L. Kuzmych *(Ed.) Balancing Water-Energy-Food Security in the Era of Environmental Change*. (pp. 111-146). IGI Global.

Linguadoca, A., Rizzi, C., Villa, S., & Brown, M.J.F. (2021). Sulfoxaflor and nutritional deficiency synergistically reduce survival and fecundity in bumblebees. *Science of the Total Environment*, *795*, 148680.

Lori, M., Symnaczik, S., Mäder, P., De Deyn, G., & Gattinger, A. (2017). Organic farming enhances soil microbial abundance and activity - A meta-analysis and meta-regression. *PLOS ONE*, 12 (7), e0180442.

Lukhmenev, V.P. (2015). Influence of fertilizers, fungicides and growth regulators on sunflower productivity. *News of the Orenburg State Agrarian University*, *1* (51), 41-46.

Malidža, G., Škorić, D., & Jocić, S. (2000). Imidazolinone - resistant sunflower (*Helianthus annuus*): Inheritance of resistance and response towards selected sulfonylurea herbicide. *Proceedings of 15th International Sunflower Conference,* (pp. 42-47). Toulouse, France.

Palamarchuk, V.D., Polishchuk, I.S., Yermakova, L.M., & Kalenskaya, S.M. (2012). *Systems of modern intensive technologies.* Vinnytsia: FOP Rogalska I.O.

Pashkevich, E.B. (2009). Biological substantiation of creation and features of application of biological products containing *Bacillius subtilis* for protection of plants from phytopathogens. *Problems of Agrochemistry and Ecology*, *2*, 41-47.

Patika, V.P. (2001). Search for microorganisms and processing of new environmentally friendly drugs. *Bulletin of Odessa National University. Biology*, *6* (4), 228-230.

Ponomarenko, S.P., Gritsayenko, Z.I., Babayants, O.V., & Terek, O.I. (2017). World achievement of Ukrainian scientists for agrarian farmers (multicomponent biostimulators of plant development with bioprotective effect. Kyiv: Agrobiotech.

Roberts, D.A. (1981). *Fundamentals of plant protection*. Moscow: Kolos.

Rodrigues, L.C.C., Fortini, R.M., & Neves, M.C.R. (2023). Impacts of the use of biological pest control on the technical efficiency of the Brazilian agricultural sector. *International Journal of Environmental Science and Technology*, *20*, 1-16.

Ryazanov, S.F., & Shevchuk, O.A. (2018). Scope and ecotoxic assessment of chemical plant protection products. *Plant Protection*, *8*, 102-117.

Sendetsky, V.M. (2017). Influence of growth regulators on sunflower yield during cultivation in Western Forest-Steppe conditions. *Scientific Bulletin of NULES of Ukraine*, *Series: Agronomy*, *269*, 53-61.

Siviter, H., Brown, M.J.F., & Leadbeater E. (2018). Sulfoxaflor exposure reduces bumblebee reproductive success. *Nature*, *561* (7721), 109-112.

Siviter, H., Bailes, E.J., Martin, C.D., Oliver, T.R., Koricheva, J., Leadbeater, E., & Brown. M.J.F. (2021). Agrochemicals interact synergistically to increase bee mortality. *Nature*, *596* (7872), 389-392.

Siviter, H., Fisher, A., Baer, B., Brown, M.J.F., Camargo, I.F., Cole, J., Le Conte, Y., Dorin, B., Evans, J.D., Farina, W., Fine, J., Fischer, L.R., Garratt, M.P.D., Giannini, T.C., Giray, T., Li-Byarlay, H., López-Uribe, M.M., Nieh, J.C., Przybyla, K., Raine, N.E., Ray, A.M., Singh, G., Spivak, M., Traynor, K., Kapheim, K.M., & Harrison, J.F. (2023). Protecting pollinators and our food supply: understanding and managing threats to pollinator health. *Insectes Sociaux*, *70* (11), 5-16

Siviter, H., DeVore, J., Gray, L.K., Ivers, N.A., Lopez, E.A., Riddington, I.M., Stuligross, C., Jha, Sh., & Muth, F. (2024). A novel pesticide has lethal consequences for an important pollinator. *Science of the Total Environment*, *952*, 175935.

Tarariko, Yu.O., & Lychuk, G.I. (2014). Stimulators of plant growth in the system of organic farming. *Bulletin of Agrarian Science*, *5*, 11-15.

Thomas, S.I., & Kravchuk, V.D. (1981). *Microfertilizers and sunflower harvest.* Chisinau: Shtiintsa.

Tian, W., Wang, L., Li, Y., Zhuang, K., Li, G., Zhang, J., Xiao X., & Xi, Y. (2015). Responses of microbial activity, abundance, and community in wheat soil after three years of heavy fertilization with manure-based compost and inorganic nitrogen. *Agriculture, Ecosystems & Environment*, *213*, 219-227.

Tkachuk, O.O. (2014). Environmental safety and prospects for the use of plant growth regulators. *Bulletin of Vinnytsia Polytechnic Institute*, *3*, 41-44.

Tkalenko, G. (2015). Biological drugs in plant protection. Special number "Modern agricultural technologies and the use of biological products and growth stimulants", 6-14.

Tsandur, M.O., Druzyak, V.G., Yanyuk, N.A., & Khariponchuk, T.I. (2014). Employed couples as a basic element of organic farming. *Bulletin of Agrarian Science*, *9*, 5-9.

Tsentilo, L.V. (2019). Biological activity of soil under different systems of sunflower fertilization and soil cultivation. *Tavria Scientific Bulletin*, *108*, 117-122.

Tsikov, V.S., & Matyukha, L.P. (2006). *Weeds: pests and protection system.* Research and production publication. Dnipro: ENEM.

Vavrinevich, O.P., Omelchuk, S.T., & Bardov, V.G. (2013). Estimation of modern assortment and volumes of fungicides application in agriculture of Ukraine as a component of state social and hygienic monitoring. *Preventive Medicine*, *4*, 95-103.

Volkogon, V.V., & Dimova, S.B. (2010). Influence of microbial preparations on assimilation of nutrients by cultivated plants. *Bulletin of Agricultural Science*, *5*, 25-28.

Volkogon, V.V., Nadkernychna, O.V., &, Tokmakova, L.M. (2010). *Experimental soil microbiology*: Monograph. Kyiv: Agrarian Science.

Volkogon, V.V., Zaryshnyak, A.S., & Hrynyk, I.V. (2011). *Methodology and practice of using microbial preparations in technologies of growing agricultural crops*. Kyiv: Agrarian Science.

Zhuikov, O., Kyrylov, Yu., & Lavrenko, S. (2022a). The efficiency of sunflower cultivation on different levels of biologization. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 22* (2), 807-814.

Zhuikov, O., Lavrenko, S., Lavrys, V., & Lavrenko, N. (2022b). Quantitative and qualitative indexes of the functioning of photosynthetic apparatus of ornamental sunflower plants with different seeding rates under conditions of the Southern Steppe of Ukraine. *AgroLife Scientific Journal, 11* (2), 261-266.

Zhuykov, O.G., Ushkarenko, V.O., Burdiuh, O.O., Lavrenko, S.O., & Lavrenko, N.M. (2020). Photosynthetic activity and productivity of sunflower hybrids in organic and traditional cultivation technologies. *AgroLife Scientific Journal*, *9* (1), 374-381.

Zhuykov, O., Lavrenko, S., Khodos, T., & Ursal, V. (2024a). The productivity of sareptsky mustard depends on the sowing rate and the level of biologization of the crop growing technology. *Journal of Ecological Engineering*, *25* (7), 246-255.

Zhuykov, O.G., Lavrenko, S.O., Lavrys, V.Yu., & Kotovska, J.S. (2024b). Formation of economically valuable traits by hybrids of the sunflower (*Helianthus annuus ornamentalis (Multiflorus)*) under organic growing technology. *International Journal of Agricultural Technology, 20* (6), 2605-2618.

Received: March 23, 2022
Accepted: September 13, 2022

MIKROBNA AKTIVNOST I FITOSANITARNI USLOVI U USEVU SUNCOKRETA U ZAVISNOSTI OD NIVOA BIOLOGIZACIJE TEHNOLOGIJE GAJENJA

Oleksandr G. Zhuikov, Sergiy O. Lavrenko*, Nataliia M. Lavrenko, Juliana S. Kotovska, Oleksandr O. Kazanok i Gennadiy V. Karashchuk

Kherson State Agrarian and Economic University, Kherson, Ukraine

R e z i m e

Istraživanje je sprovedeno u periodu od 2018.-2021. godine. Poljski ogledi su sprovedeni u četiri ponavljanja primenom metode dizajna sa podeljenim parcelama (engl. *split-plot design method*). U studiji su ocenjivani sledeći elementi tehnologije gajenja: A – hibrid suncokreta: A1 – PR64F66 F_1; A2 – Tunca F_1; B – tehnologija gajenja: B1 (tradicionalna); B2 (biologizovana I); B3 (biologizovana II); B4 (organska); B5 (ekstenzivna). Istraživanje je pokazalo da je tokom vegetacionog perioda, pri primeni intenzivne tehnologije gajenja suncokreta, došlo do značajnog smanjenja kako ukupne kolonizacije obradivog sloja zemljišta na oglednoj parceli, tako i količine mikroflore od strane određenih najvažnijih grupa, u poređenju sa varijantama u kojima su primenjeni neki elementi biologizacije ili njihova kompleksna primena (organska tehnologija gajenja) za 6,1–40,9%. Primena savremenih insekticida organskog porekla u zaštiti suncokreta, pri biologizovanoj i organskoj tehnologiji gajenja, omogućava suzbijanje čitavog niza najštetnijih fitofaga i po efikasnosti nije inferiorna u odnosu na sintetičke insekticide. Izuzetak predstavlja zaštita useva od larvi sovice, koje, zbog svojih bioloških i ekoloških osobina, zahtevaju insekticid sa izraženijim sistemskim svojstvima, koja nisu karakteristična za organske preparate, uz nekoliko izuzetaka. Biološki preparati nisu imali rezidualni insekticidni ili repelentni efekat na glavne oprašivače useva. Obrada drljačama i rotacionim motičicama pre i posle nicanja, kao i međuredna obrada u sistemu zaštite useva od korova, kao komponenta biologizovane i organske tehnologije gajenja suncokreta, jednako je efikasna kao primena zemljišnih insekticida i sintetičkih herbicida posle nicanja.

Ključne reči: suncokret, hibrid, biologizacija, mikroorganizmi, bolesti.

Primljeno: 23. marta 2022.
Odobreno: 13. septembra 2022.

*Autor za kontakt: e-mail: lavrenko.sr@gmail.com

Journal of Agricultural Sciences (Belgrade)
Vol. 70, No. 4, 2025
Pages 419-433

https://doi.org/10.2298/JAS2504419T
UDC: 633.853:[632.4:582.282.151
633.853:575.2
Original scientific paper

SCREENING OF RAPESEED (*BRASSICA NAPUS*) GENOTYPES AGAINST *ALTERNARIA* BLIGHT

Papiya Clara Toppo[1*], Sk. Md. Mobarak Hossain[1], Md. Mahfuzul Hasan[2], Md. Mamunur Rashid[3], Afsana Hossain[2], Jannatun Nahar Jui[4] and Fatima Karim[1]

[1]Department of Plant Pathology, Faculty of Agriculture, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh
[2]Department of Horticulture, Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh
[3]Department of Agronomy, Faculty of Agriculture, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh
[4]Department of Agronomy, Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

Abstract: *Alternaria* blight is a destructive fungal disease that infects rapeseed leaves and siliquae. The purpose of this study is to evaluate the disease severity of various mustard genotypes and to identify the superior rapeseed genotypes that are resistant to *Alternaria* blight. Twelve rapeseed genotypes were investigated. At 45, 55, and 65 days after sowing (DAS), genotype NAP16061 showed the lowest disease severity (12.43%, 15.06%, and 11.06%, respectively). NAP16001 had the fewest diseased pods (1.000, 1.133, and 1.700, respectively) at 45, 55, and 65 DAS, respectively. In terms of the quantities of healthy pods, NAP16001, NAP16068, and NAP16068 performed better. BARI SH13 had the lowest total numbers of leaves plant^{-1} and percent leaf area, while NAP16061 had the smallest average spot size on leaves. The greatest plant height was observed in NAP16066. Positive loadings for disease susceptibility parameters such as disease severity, percent disease severity, percent leaf area diseased, and diseased leaves plant^{-1} were observed in PC1. NAP16066, NAP16025, and NAP16001 showed a negative relationship with PC1, indicating resistance to *Alternaria* blight. Genotypes such as NAP16082 and NAP16068 were also negatively oriented along PC2, and exhibited moderate resistance, requiring further assessment. Cluster II includes the most sought-after genotypes with resistance to *Alternaria* blight disease, which clustered with NAP16001 and NAP16066.

Key words: *Brassica napus*, genotypes, mustard, PCA and hierarchical cluster, rapeseed.

[*]Corresponding author: e-mail: claratoppo52@gmail.com

Introduction

Mustard crops, which belong to the genus *Brassica* under the family Brassicaceae, are among the common primary oilseed crops in Bangladesh. Rapeseed (*Brassica napus*), now commonly referred to as canola, is one of the most extensively cultivated oilseeds worldwide, especially in the Indian subcontinent (Goyal et al., 2020). In Bangladesh, mustard is a crucial oilseed crop, known locally as 'Sharisha', and along with grains, is vital in Bangladesh to the country agriculture for ensuring security and agricultural success (Laboni et al., 2024). It is intensively cultivated throughout the winter season (October–February), accounting for approximately 60% of total oilseed production and more than 80% of total oilseed production (Miah et al., 2015; BER, 2022). The crop is well-suited to nearly all of the country's agroclimatic zones. In addition to its utilization as an oil commodity, it is also employed as a condiment due to its medicinal properties (Thirumavalavan, 2025). The flavor of damaged perishable commodities, such as fruits, vegetables, dairy products, and meat, can be improved by adding *B. napus*, which contains pungent compounds, such as allyl isothiocyanate, which increase sensory acceptance (Liang et al., 2023; Torrijos et al., 2023). In comparison to other countries, rapeseed yields are particularly low in Bangladesh. *Brassica* spp. cultivation was conducted on approximately 814,288.54 acres of land, resulting in the production of 396,594.28 metric tons of mustard. However, the average mustard and rapeseed production in 2020–2021 was only 487.04 kg acre^{-1} (BBS, 2021). In the fiscal year 2021–2022, mustard and rapeseed were the topmost planted oilseed crops in Bangladesh, covering 610,000 hectares and producing 822 thousand metric tons (Arafat, 2022).

Rapeseed, the third-largest source of edible oil after soybean and palm, contains approximately 38–46% on a dry weight basis of total oil and a high erucic acid content ranging between 40 and 47% (Mannekote et al., 2018; Chakroborty et al., 2025). Oil of *Brassica napus* is an important source of energy in human nutrition since it is free of cholesterol, which is commonly found in animal fats, and, notably, mustard oil contains crucial soluble vitamins A, D, E and K (Sharif et al., 2017), making it a popular choice for cooking and medical applications.

Several biotic and abiotic stressors can reduce the amount and quality of mustard crops, and among the biotic agents, *Alternaria brassicae* and *Alternaria brassicicola* are the main causal organisms of *Alternaria* leaf blight (Sharma et al., 2018). Of the two seed-borne fungal pathogens, only *A. brassicicola* has caused considerable yield losses of up to 70% (Gupta et al., 2020). In the initial stage, the *Alternaria* fungus develops dark brown lesions on leaves, stems, and siliquae that progressively limit photosynthetic activity, accelerate senescence, and subsequently hamper productivity (Nowakowska et al., 2019). The pathogen is significantly affected by weather, with the highest disease prevalence occurring during wet seasons and in regions with considerable rainfall. *A. brassicae* can impact host species at all developmental stages, including the seed stage (Meena et al., 2010).

Disease-related mustard crop losses have an impact on the edible oil market prices of Bangladesh (Ahmed et al., 2018). Farmers in Bangladesh store their seeds using traditional practices, which lead to a major infestation of different fungi. *Alternaria* pathogens infect the varieties released in Bangladesh for farming (Hossain et al., 2018). However, the occurrence and severity of disease in the various released types in Bangladesh have received little attention. To provide superior genotypes for the successful rapeseed production, it is critically important to screen the resistant genotypes against the key diseases, such as *Alternaria* blight of rapeseed, and evaluate the effect of the disease on different rapeseed genotypes.

Material and Methods

Experimental setup

The experiment was conducted throughout the Rabi season from November 2021 to February 2022 on the farm of the Bangladesh Agricultural Research Institute, Rajbari, Dinajpur. The laboratory tests were conducted in the Post-graduation Laboratory, Department of Plant Pathology, Hajee Mohammad Danesh Science and Technology University, Dinajpur. The experimental site is situated in the subtropical zone, and the Dinajpur district of Bangladesh receives an average annual rainfall of 1542.10 mm. The area has a subtropical climate, with considerable rainfall from May to September and less precipitation from October to April (Yesmin et al., 2023; Bashir et al., 2025; Hasan et al., 2025; Rahman et al., 2024). Throughout the experiment, temperature, rainfall, and relative humidity data were collected from the meteorological station in Dinajpur, Bangladesh, and presented in Figure 1.

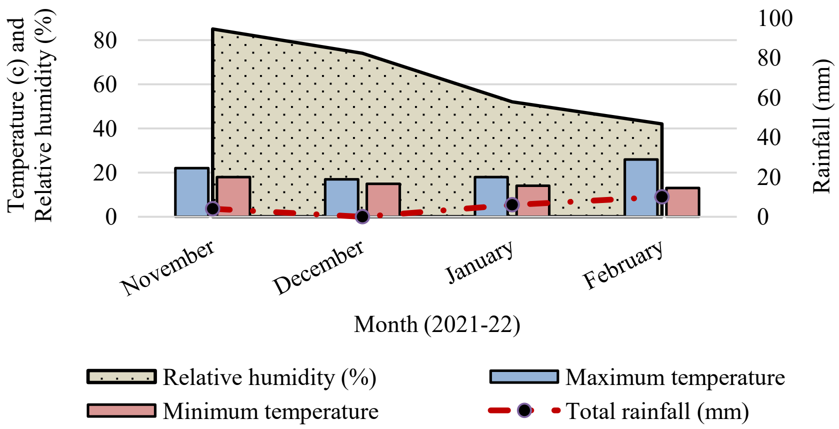


Figure 1. Monthly (November 2021 – February 2022) measurements of maximum and minimum temperatures, relative humidity, and rainfall in the Dinajpur District of Bangladesh (Data Source: Meteorological Station of Dinajpur, Bangladesh).

The soil in the experimental region was sandy loam (65% sand, 30% silt, and 5% clay). It had an acidic pH of 5.5 to 6.5 and limited water retention capacity. The initial soil study found 0.514% organic carbon and 0.04% total nitrogen. The soil contains 56 ppm of available phosphorus, 0.27 meq/100 g of exchangeable potassium, and 9.90 ppm of available sulphur (Sultana et al., 2025).

Field layout was completed following final land preparation. The experiment was designed in a randomized complete block design (RCBD) with three replicates. This study evaluated 12 mustard (*Brassica napus*) genotypes, including NAP0876, NAP16001, NAP16025, NAP16041, NAP16061, NAP16064, NAP16066, NAP16068, NAP16081, NAP16082, BARI SH8, and BARI SH13, collected from the Oilseed Research Centre (ORC) in Gazipur, Bangladesh, as planting materials. The entire field was divided into three blocks, each containing all the treatments once. The unit plot size was 3.6 m × 1.75 m, resulting in a total of 36 plots for the investigation. The distance between blocks was 1 m, and the spacing between individual plots was 0.5 m to facilitate intercultural operations and minimize border effects. The experimental field was prepared using appropriate tillage methods to provide a fine and well-aerated seedbed conducive to rapeseed cultivation. The land was initially plowed two to three times with a power tiller or country plow to achieve the desired soil tilth (Howlader et al., 2024). Each plowing was succeeded by laddering to fragment clods, equalize the soil, and enhance uniform moisture distribution. The final ground preparation resulted in a smooth, level area that was suitable for rapeseed seed germination and seedling establishment. Rapeseed seeds were seeded on 14 November 2019 and were harvested in March 2020.

Identification of *Alternaria* leaf blight

Alternaria leaf blight disease was characterized by the appearance of spots on plant parts such as leaves, stems, and siliquae. This kind of blight disease was distinguished by necrotic pinhead-like lesions surrounded by circular chlorotic regions or patches on leaves and siliquae (Tripathi et al., 2025). After observing the visual symptoms at 45, 55, and 65 DAS in the experimental field, the affected plant samples were covered with paper or poly bags and sent to the Laboratory of Plant Pathology, Hajee Mohammad Danesh Science and Technology University, for isolation, laboratory culture, and confirmation of *Alternaria brassicae* and *Alternaria brassicicola*.

Harvesting of crops and data collection

Five plants were randomly selected from each plot and tagged for data collection. When 80% of the plants showed signs of maturity, such as straw-colored leaves, stems, and siliquae, the crop was harvested for seed yield. At maturity, plants were collected by uprooting.

Data collection procedure

Plant height was measured in centimeters using a meter scale at both the vegetative and reproductive stages, and the average was recorded for each replication. Data were also collected as the average of five randomly selected plants from each plot. Plant height was measured from the ground surface to the top of the main shoot, with the mean height given in centimeters.

Five plants per plot were selected and tagged for the collection of data. The data on the number of total leaves were recorded at 45, 55 and 65 DAS by visual observation. The data on the number of total diseased leaves were recorded at 45, 55 and 65 days after sowing by visual observation from the five tagged plants per plot. The data on the number of healthy and diseased pods were also recorded by visual observation.

Average spot size on leaves was measured at 45, 55, and 65 DAT following sowing using a centimeter (cm) scale. The data on percent diseased leaf area were collected using visual scale observation of symptoms, and diseased leaf area data were recorded. The percentage of diseased leaves was estimated using the procedure below:

$$\% \text{ Leaf area diseased} = \frac{\text{Infected leaf area diseased}}{\text{Total leaf area}} \times 100 \quad (1)$$

Disease severity was calculated by using the “0–5” scale (Conn et al., 1990). Disease severity was calculated using the following formula (Karim et al., 2024):

$$\% \text{ Disease severity} = \frac{\text{Sum of all disease rating}}{\text{Total number of ratings} \times \text{Maximum disease rating}} \times 100 \quad (2)$$

Statistical analysis

The acquired data for the various parameters were compiled and tabulated. Statistical analysis was conducted using the Statistrix-10 application. The treatment means were compared using the least significant difference (LSD) test.

Results and Discussion

Plant height (cm)

The height of the plants exhibited significant variation among all 12 evaluated genotypes. At 45 DAS, the tallest plants measured 86.9 cm in NAP16066, followed by 82.76 cm in BARI SH8. At 55 DAS, the tallest plant height was noticed in NAP16066 (87.66 cm), followed by BARI SH8 (83.56 cm) (Figure 2). At 65 DAS, the tallest plant height recorded was 87.66 cm in NAP16066, followed by 83.60 cm in BARI SH8 and 78.53 cm in NAP16001 (Figure 2).

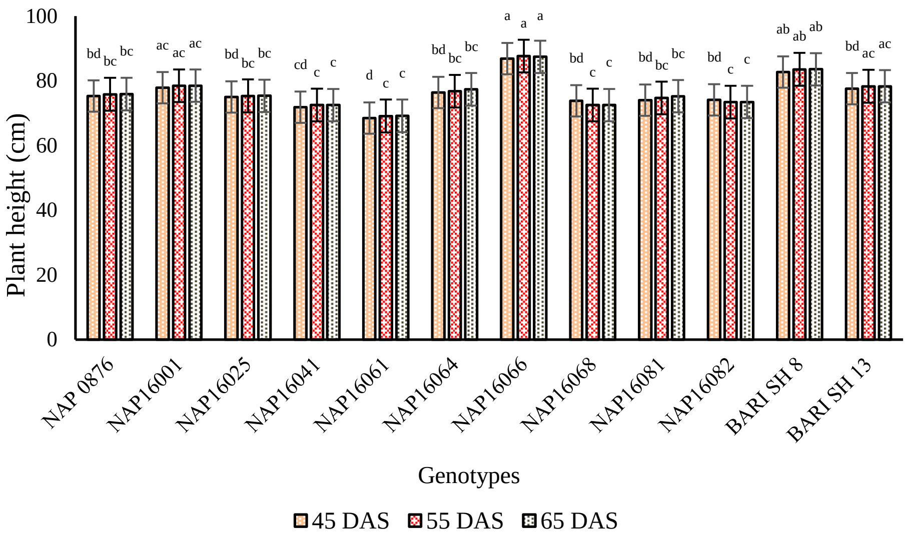


Figure 2. Plant height (cm) of 12 genotypes of *Brassica napus* recorded at different dates after sowing.

Number of total leaves plant^{-1}

The number of total leaves per plant varied considerably among the genotypes. At 45 DAS, the greatest number of leaves was recorded in BARI SH13 (12.67), (12.67), which was similar to NAP16064 (11.33). At 55 DAS, the highest number of leaves was again recorded in BARI SH13 (13.43) (Table 1). At 65 DAS, the highest number of leaves was recorded in NAP16061 (12.80), which was similar to BARI SH13 (11.03) and NAP16064 (10.93) (Table 1).

Table 1. Total number of leaves plant^{-1} and diseased leaves plant^{-1}of 12 genotypes of *Brassica napus* recorded at different dates after sowing.

Genotypes	Total number of leaves plant^{-1}			Diseased leaves plant^{-1}		
	45 DAS	55 DAS	65 DAS	45 DAS	55 DAS	65 DAS
NAP 0876	6.87 d	7.56 h	7.92 f	2.400 ef	2.920 ef	3.400 h
NAP16001	9.00 c	9.34 g	8.73 ef	3.120 d	3.920 d	4.510 f
NAP16025	9.457 c	9.81 fg	5.22 g	2.790 de	2.990 e	3.940 g
NAP16041	11.21 b	12.11 bd	10.87 bc	3.100 c	4.790 c	5.670 d
NAP16061	11.24 b	12.64 ac	12.80 a	2.780 de	3.390 d	3.950 g
NAP16064	11.33 b	12.47 ad	10.93 bc	4.020 c	4.400 cd	5.640 d
NAP16066	9.40 c	10.27 eg	9.25 de	3.950 c	4.830 c	5.630 d
NAP16068	11.05 b	10.653 ef	10.03 bd	5.580 a	6.810 a	7.930 a
NAP16081	10.77 b	11.36 ce	9.74 ce	4.800 b	5.840 b	5.100 e
NAP16082	10.47 b	11.28 de	9.29 de	4.870 b	5.840 b	6.860 b
BARI SH 8	11.20 b	13.21 ab	10.61 bc	4.390 bc	4.840 c	6.200 c
BARI SH 13	12.67 a	13.43 a	11.03 b	1.200 f	2.410 f	2.840 i
%CV	2.98	3.94	4.19	4.26	4.06	2.64
$LSD_{0.05}$	0.9102	1.2964	1.1954	0.4657	0.5279	0.3996

Means with the same letter within a column do not differ significantly at the 5% level of probability.

Number of diseased leaves plant^{-1}

The number of diseased leaves substantially varied among the genotypes. At 45 DAS, the lowest number of diseased leaves was recorded in BARI SH 13 (1.200), which was similar to NAP0876 (2.400) (Table 1). At 55 DAS, the minimum number of diseased leaves (2.410) was observed in BARI SH13. At 65 DAS, BARI SH13 again had the minimum number of diseased leaves (3.400), which was similar to NAP0876 (0.40) and NAP16025 (3.940) (Table 1).

Average spot size on leaf

The number of average spot sizes on the leaf differed substantially across genotypes at all data collection dates. At 45 DAS, the genotype with the smallest average spot size was NAP16061 (0.23 cm), followed by NAP16081 (0.62 cm) (Figure 3). At 55 DAS, the genotype with the smallest average spot size was observed in NAP160610 (0.23 cm), which was similar to BARI SH8 (0.56 cm). At

65 DAS, NAP16061 again had the smallest average spot size (0.23 cm), followed by NAP16064 (0.70 cm) (Figure 3).

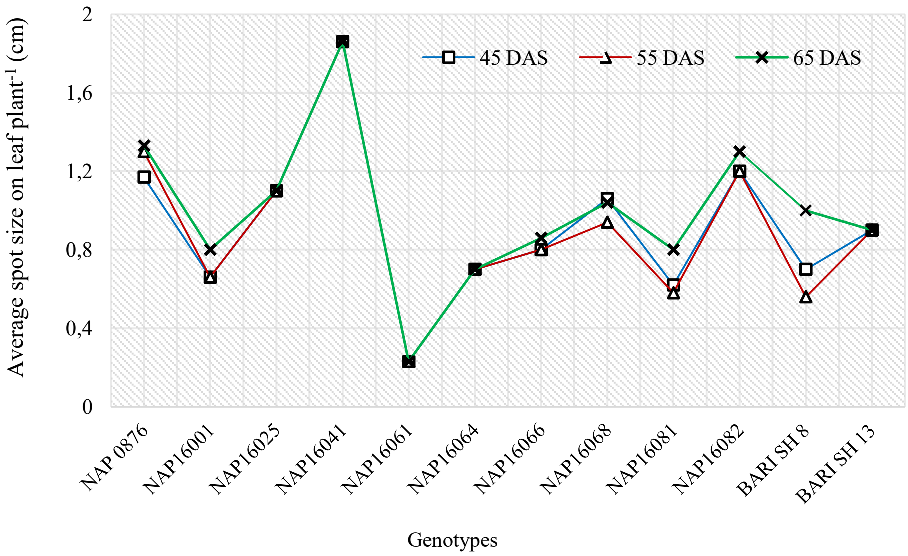


Figure 3. Average spot size on leaf plant^{-1} of 12 genotypes of *Brassica napus* recorded at different dates after sowing.

Percent leaf area diseased

Percent leaf area diseased varied significantly among the 12 genotypes of *Brassica napus*. At 45 DAS, NAP16061 had the lowest percentage of diseased leaf area (3.697%), which was comparable to BARI SH13 (3.700%), and NAP16064 (4.187%) (Table 2). At 55 DAS, the lowest percent disease leaf area was measured in NAP 16061 (5.477%), which was similar to BARI SH13 (6.321%), NAP16064 (6.610%) and NAP16041 (6.700%). At 65 DAS, NAP16061 again had the lowest percentage of diseased leaf area (3.167%) (Table 2).

Disease severity

The percent disease severity varied significantly among the 12 genotypes of *Brassica napus*. The minimal disease severity (12.56%) was observed at NAP 16061 (12.43%), followed by NAP16064 (12.56%) at 45 DAS (Table 2). At 55 DAS, NAP16061 showed minimum disease severity (15.06%), comparable to BARI SH13 (15.16%). At 65 DAS, NAP16061 performed better in the case of disease severity (11.06%), followed by BARI SH8 (24.00%) (Table 2).

Table 2. Percent leaf area diseased and disease severity (%) of 12 genotypes of *Brassica napus* recorded at different dates after sowing.

Genotypes	Percent leaf area diseased			Disease severity (%)		
	45 DAS	55 DAS	65 DAS	45 DAS	55 DAS	65 DAS
NAP 0876	9.143 d	9.53 e	13.96 e	20.50 f	21.86 f	27.09 i
NAP16001	9.743 c	11.40 c	16.11 cd	21.80 e	23.00 e	27.03 i
NAP16025	9.627 c	10.03 d	16.40 c	27.03 b	28.40 c	33.00 e
NAP16041	5.633 g	6.700 i	10.15 h	22.93 d	24.533 d	31.60 f
NAP16061	3.697 i	5.477 k	3.167 i	12.43 h	15.06 g	11.06 k
NAP16064	4.187 h	6.610 i	10.76 g	12.56 h	22.20 f	31.00 g
NAP16066	14.68 b	16.567 b	21.69 b	22.03 e	30.10 b	36.55 b
NAP16068	16.68 a	18.98 a	22.70 a	39.30 a	32.50 a	41.86 a
NAP16081	7.830 e	8.700 f	13.70 e	23.03 d	24.50 d	29.86 h
NAP16082	7.620 f	8.050 g	12.95 f	24.53 c	21.93 f	35.03 c
BARI SH 8	5.600 g	7.080 h	10.03 h	20.50 f	23.10 e	24.53 j
BARI SH 13	3.700 i	6.320 j	15.78 i	13.90 g	15.16 g	33.86 d
%CV	1.47	0.97	1.76	1	1.06	1.12
$LSD_{0.05}$	0.2031	0.1584	0.4152	0.3652	0.4267	0.5423

Means with the same letter within a column do not differ significantly at the 5% level of probability.

Number of healthy pods plant^{-1}

The number of healthy pods per plant differed substantially across all rapeseed genotypes. At 45 DAS, NAP16081 had the highest number of healthy pods (33.91), which was comparable to NAP16001 (27.53) and BARI SH8 (25.50) (Table 3). At 55 DAS, the genotype with the highest number of healthy pods was NAP16068 (53.00), followed by NAP16066 (43.00). At 65 DAS, the genotype with the highest number of healthy pods was NAP16066 (102.83), followed by NAP16064 (99.00), NAP16001 (88.27), and BARI SH13 (86.87) (Table 3).

Number of diseased pods plant^{-1}

The number of diseased pods per plant differed substantially across all rapeseed genotypes. At 45 DAS, NAP16001 had the fewest diseased pods (1.000), which was comparable to NAP16025 (1.400), NAP16064 (1.796), and NAP16066 (2.166) (Table 3). At 55 DAS, NAP16001 had the lowest number of diseased pods (1.133), which was comparable to NAP16025 (1.733), NAP16064 (2.133), and NAP16068 (2.500). At 65 DAS, NAP16001 had the fewest diseased pods (1.700), close to NAP16025 (2.000) (Table 3).

Table 3. Number of healthy and diseased pods per plant of 12 genotypes of *Brassica napus* recorded at different dates after sowing.

Genotypes	Number of healthy pods per plant			Number of diseased pods plant^{-1}		
	45 DAS	55 DAS	65 DAS	45 DAS	55 DAS	65 DAS
NAP 0876	18.6 h	19.33 k	51.53 a	3.4 b	3.7667 b	3.8533 de
NAP16001	27.533 b	38.66 d	88.27 h	1 g	1.1333 g	1.7 i
NAP16025	24.7 d	25.66 i	68.38 c	1.4 fg	1.7333 f	2 h
NAP16041	21.5 g	23.16 j	51.50 g	4.00 a	4.3743 a	5.2333 a
NAP16061	23.37 e	36.33 ef	69.99 h	2.6233 cd	3.2667 c	3.76 def
NAP16064	16.767 i	35.66 f	99.00 g	1.7967 ef	2.1333 e	2.8333 g
NAP16066	22.287 e	43.00 b	102.83 a	2.1667 de	2.89 d	3.62 ef
NAP16068	25.417 c	53.00 a	77.6 e	2.5 cd	3.3 c	3.863 de
NAP16081	33.907 a	41.33 c	73.47 f	2.8333 c	3 cd	3.4667 f
NAP16082	18.787 h	29.00 h	80.00 d	3.3667 b	3.7667 b	4 d
BARI SH 8	25.5 c	31.00 g	77.93 de	3.63 ab	3.9 b	4.45 c
BARI SH 13	22 fg	37.00 e	86.87 c	3.8033 ab	4.3067 a	4.79 b
CV	1.66	1.74	1.78	10.19	6.04	4.84
$LSD_{0.05}$	1.793	2.124	2.3374	0.4677	0.3201	0.2974

Means with the same letter within a column do not differ significantly at the 5% level of probability.

Principal component analysis (PCA)

Principal component analysis (PCA) indicated significant variance between genotypes in terms of disease-related and agronomic parameters (Figure 4). The first two principal components (PCs) explained 60.7% of the total variation, with PC1 accounting for 39.33% and PC2 for 21.37%. PC1 showed a positive loading of disease susceptibility traits such as disease severity (DS), percent disease severity (PDS), percent leaf area diseased (PLAD), and diseased leaves per plant (DP). Genotypes including BARI SH8, BARI SH13, NAP16081, and NAP16064 were positioned in the same manner, indicating higher disease susceptibility (Figure 4). Plant attributes, such as healthy pods per plant (HPP) and plant height (PH), were negatively linked with PC1, indicating a negative correlation with disease susceptibility. Genotypes involving NAP16066, NAP16025, and NAP16001 were concentrated in this region, showing disease resistance. The number of diseased pods (NDP) was similarly significantly associated with PC1, confirming this difference. PC2 (21.37% of the variance) exhibited additional differences between genotypes. Traits such as leaf per plant (LP) and DS were strongly correlated with PC2, but percent leaf area diseased (PLAD) and PDS had smaller impacts. NAP16082 and NAP16068 were found in the negative PC2 region, whereas NAP16061 was very susceptible (Figure 4).

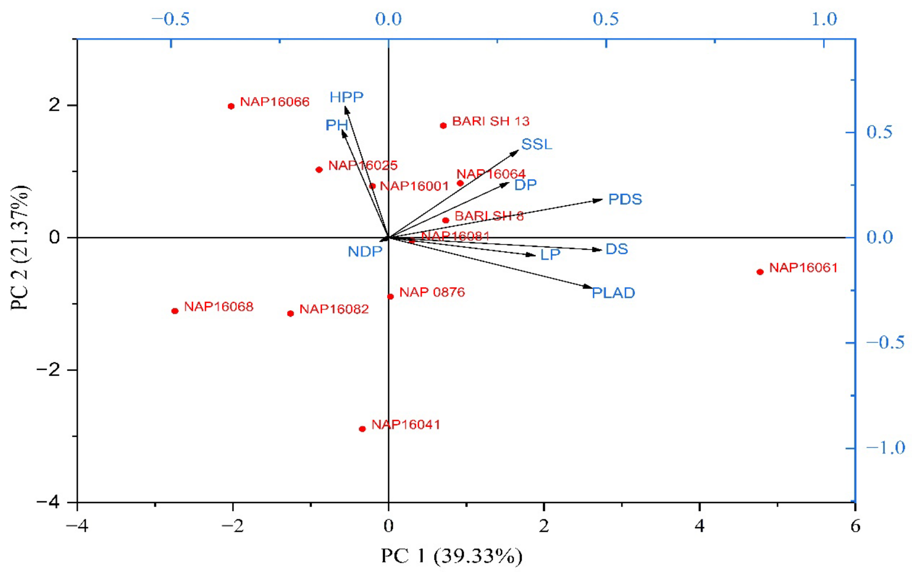


Figure 4. Expression of principal component analysis (PCA) across the genotypes.

Hierarchical cluster analysis (HCA)

The hierarchical clustering dendrogram illustrates the genetic relationships among the screened genotypes, providing insights into their diversity (Figure 5). The genotypes were divided into separate clusters based on genetic similarities. Cluster I contained NAP0876 and NAP16041, showing a strong genetic relationship. Cluster II was formed up of NAP16001 and NAP16066, with BARI SH13 as a subgroup. Cluster III possessed the genetically identical NAP16081 and NAP16082. Cluster IV included NAP16064 and NAP16025, which formed a moderately associated group. Finally, cluster V featured BARI SH8 and NAP16061, implying a genetic connection between these two genotypes. The clustering pattern demonstrated significant genetic heterogeneity among the tested genotypes (Figure 5).

The most significant and devastating disease of rapeseed is leaf blight, which is widely disseminated. Among the 12 genotypes studied, none were free of *Alternaria* infection; however, disease severity varied between genotypes. Talukdar and Das (2015) assessed rapeseed and mustard genotypes for resistance to *Alternaria* disease under field conditions in Assam, India, concluding that none of the genotypes exhibited strong resistance to *Alternaria* blight in rapeseed and mustard. The results showed that the highest plant height was observed in NAP16066, while the lowest disease severity was observed in NAP16061, BARI

SH13, and BARI SH8. BARI SH13 genotypes performed better in terms of the total number of leaves, diseased leaves, and percent leaf area diseased. The highest number of healthy pods was observed in NAP16001, NAP16066, and NAP16068, while the fewest diseased pods were noted in NAP16001. Significant diversity in disease resistance was identified among rapeseed genotypes through PCA, providing valuable insights for genotype selection (Ilieva et al., 2019). *Alternaria* blight resistance was observed in genotypes that were negatively associated with PC1, including NAP16066, NAP16025, and NAP16001. Similarly, NAP16082 and NAP16068, which were positioned negatively along PC2, showed modest resistance, requiring further investigation. Conversely, BARI SH8, NAP16064, and NAP16081 were significantly correlated with DS, PDS, and PLAD, suggesting that these genotypes were highly susceptible. Furthermore, NAP16041, situated at the extreme lower end of PC2, exhibited a novel disease tolerance mechanism, rendering it an appealing candidate for further investigation. NAP16066, NAP16025, and NAP16001 have been identified as potentially disease-resistant genotypes, underscoring their potential for use in screening programs. In contrast, genotypes particularly susceptible to *Alternaria* blight, such as NAP16061 and BARI SH8, showed poor disease resistance. In addition, the partitioned variance across these dimensions was accounted for by the significant contributions of multiple qualities to various principal components, as demonstrated by the research conducted by Neeru et al. (2015), Saleem et al. (2017) and Godara et al. (2022). These results underscore the effectiveness of PCA as a strategy for screening rapeseed genotypes for resistance to *Alternaria* blight.

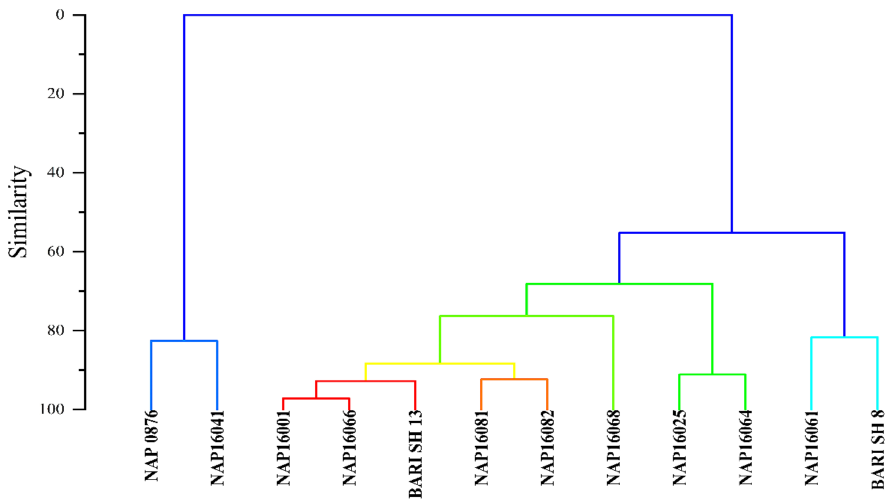


Figure 5. Hierarchical cluster analysis (HCA) dendrogram illustrating relationships among the genotypes.

The hierarchical clustering analysis effectively grouped the studied genotypes based on genetic similarity, providing valuable insights into their genetic relationships and diversity (Pathaichindachote et al., 2019). The observed clustering pattern demonstrated a high level of genetic variety, which is essential for mustard screening. The significant genetic association between NAP0876 and NAP16041 in cluster I revealed a high level of similarity, implying an individual disease tolerance mechanism. Similarly, in cluster II, the most desired genotypes, which were robust in resistance to *Alternaria* blight disease, clustered with NAP16001 and NAP16066. Cluster III (NAP16081 and NAP 16082) and cluster IV (NAP16068 and NAP16025) showed substantial resemblance, indicating that these genotypes were moderately to highly resistant to *Alternaria* blight. Finally, cluster V contained BARI SH8 and NAP16061, demonstrating a genetic association between the two genotypes that were most susceptible to *Alternaria* blight in this study. These findings are in alignment with Ghosh et al. (2019) and Blagojević et al. (2020).

Conclusion

The results showed that *Alternaria* blight resistance was suggested by genotypes that were negatively connected to PC1, such as NAP16066, NAP16025, and NAP16001. In a similar manner, NAP16082 and NAP16068, which were negatively oriented along PC2, demonstrated moderate resistance, requiring further investigation. NAP16066, NAP16025, and NAP16001 have been identified as possibly disease-resistant genotypes, highlighting their suitability for screening programs. Cluster I was significantly comparable, showing a particular disease tolerance mechanism, but cluster II contained the most desired genotypes with high resistance to *Alternaria* blight disease, clustering with NAP16001 and NAP16066.

Acknowledgments

The authors convey their gratitude to the official personnel of the Agricultural Research Station, Bangladesh Agricultural Research Institute (BARI), Rajbari, Dinajpur-5200 for the technical assistance and support.

References

Ahmed, M., Tonu, N. N., Hornaday, K., Aminuzzaman, F.M., Chowdhury, M.S.M., & Islam, M.R. (2018). Effect of chemical seed treatment and BAU-Biofungicide on *Alternaria* blight (*Alternaria brassicae*) of mustard. *Agricultural Sciences*, *9* (5), 566-576.

Arafat, Y. (2022). Mustard Production in Bangladesh: Status, Prospects and Challenges1. Doctoral dissertation, Bangabandhu Sheikh Mujibur Rahman Agricultural University.

Bashir, M.U.H.A., Haque, T., Howlader, N.C., Hasan, M.M., Siddiki, M.H., Sarkar, M.A.H., Rashid, M.A.M., & Sarker, S. (2025). Molybdenum and methods of application in relation to growth and yield of cabbage (*Brassica oleacea* Var *capitata* L.). *Journal of Agricultural Sciences and Engineering*, *7* (1), 19-31. DOI: https://doi.org/10.48309/jase.2025.503480.1069

BBS (2021). Statistical year book of Bangladesh. Bangladesh Bureau of Statistics. Statistic Division, Ministry of Planning, Govt. of the People's Republic of Bangladesh.

BER (2022). Bangladesh Economic Review, Finance Division, Ministry of Finance, Government of the People’s Republic of Bangladesh.

Blagojević, J.D., Vukojević, J.B., & Ivanović, Ž.S. (2020). Occurrence and characterization of *Alternaria* species associated with leaf spot disease in rapeseed in Serbia. *Plant pathology*, *69* (5), 883-900. DOI: https://doi.org/10.1111/ppa.13168

Chakroborty, N., Kabir, M.A., Hossen, M.M., Afrin, J., Islam, M.M., & Robin, A.H.K. (2025). Species-Specific Variation in Oil Content and Fatty Acid Profiles of Short-Duration Rapeseed and Mustard. *ACS Food Science & Technology*, *5* (3), 1082-1090. DOI: https://doi.org/10.1021/acsfoodscitech.4c00894

Conn, K.L., Tewari, J.P., & Awasthi, R.P. (1990). A disease assessment key for Alternaria blackspot in rapeseed and mustard. *Canadian plant disease survey*, *70* (1), 19-22.

Ghosh, S., Mazumder, M., Mondal, B., Mukherjee, A., De, A., Bose, R., Das, S., Bhattacharyya, S., and Basu, D. (2019). Morphological and SSR marker-based genetic diversity analysis of Indian mustard (*Brassica juncea* L.) differing in *Alternaria brassicicola* tolerance. *Euphytica*, *215* (12), 206. DOI: https://doi.org/10.1007/s10681-019-2523-1

Godara, P., Kumar, S., & Kumar, D. (2022). Evaluation of Genetic Variation in Indian mustard (*Brassica Juncea* L Czern and Coss) Using Multivariate Techniques. *Journal of Agriculture Research and Technology*, *47* (3), 344. DOI: https://doi.org/10.56228/JART.2022.47315

Goyal, A., Tanwar, B., Sihag, M.K., Kumar, V., Sharma, V., & Soni, S. (2021). Rapeseed/Canola (*Brassica napus*) Seed. In: Tanwar, B., Goyal, A. (Eds.) *Oilseeds: Health Attributes and Food Applications.* Springer, Singapore. https://doi.org/10.1007/978-981-15-4194-0_2

Gupta, S., Didwania, N., & Singh, D. (2020). Biological control of mustard blight caused by Alternaria brassicae using plant growth promoting bacteria. *Current Plant Biology*, *23*, 100166. DOI: https://doi.org/10.1016/j.cpb.2020.100166

Hasan, M.M., Hossain, M.M., Haque, T., Basunia, A.K., & Howlader, N.C. (2025). Morpho-biochemical evaluation of three sugar apple (*Annona squamosa* L.) genotypes. *International Journal of Horticultural Science and Technology*, *12* (2), 189-198. DOI: https://doi.org/10.22059/ijhst.2024.369325.744

Hossain, M.A., Habib, A., Islam, M.S., & Khokon, M.A.R. (2018). Validation of inoculation test and screening for resistance sources of mustard-rapeseed cultivars in Bangladesh against *Alternaria brassicicola*. *Current Agriculture Research Journal*, *6* (1), 8-19. DOI: http://dx.doi.org/10.12944/CARJ.6.1.02

Howlader, N. C., Hossain, M. M., Rabbani, M. G., Basunia, A. M., Hasan, M. M., and Umme Saima, U. (2024). Effect of irrigation intervals on the growth, yield and fruit quality of lemon (*Citrus limon* L.). *Plant Physiology and Soil Chemistry*, *4* (1), 20-25. DOI: http://doi.org/10.26480/ppsc.01.2024.20.25

Ilieva, V., Markova Ruzdik, N., Mihajlov, L., and Ilievski, M. (2019). Assessment of agro-morphological variability in rice using multivariate analysis. *Journal of Agriculture and Plant Sciences, 17* (1), 79-85.

Karim, F., Hossain, S.M.M., Hasan, M.M., Howlader, N.C., & Bhuiyan, M.M.A. (2024). Biological control of foot and root rot disease of pea by using formulated product of *Trichoderma*. *Journal of Agricultural Sciences (Belgrade)*, *69* (2), 181-196. DOI: https://doi.org/10.2298/JAS2402181K

Laboni, S.H., Chowdhury, A.K.M.M.B., Bahadur, M.M., Islam, M.R., Hasan, M.M., & Howlader, N.C. (2024). Effect of Different Fertilizer Combinations and Gibberellic Acid (GA3) on Yield Attributing Traits of Mustard: Fertilizer Combinations and GA3 on Yield Attributes of Mustard. *Journal of the Bangladesh Agricultural University*, *22* (2), 185-192. DOI: https://doi.org/10.3329/jbau.v22i2.74552

Liang, M., Wang, R., Wu, Y., Xin, R., Guan, W., & Liu, Y. (2023). Comparative Analysis of Volatile Flavor Compounds in Seven Mustard Pastes via HS-SPME–GC–MS. *Molecules*, *28* (14), 5482. DOI: https://doi.org/10.3390/molecules28145482

Mannekote, J.K., Kailas, S.V., Venkatesh, K., & Kathyayini, N. (2018). Environmentally friendly functional fluids from renewable and sustainable sources-A review. *Renewable and sustainable energy reviews*, *81* (2), 1787-1801. DOI: https://doi.org/10.1016/j.rser.2017.05.274

Meena, P.D., Awasthi, R.P., Chattopadhyay, C., Kolte, S.J., & Kumar, A. (2010). *Alternaria* blight: a chronic disease in rapeseed-mustard. *Journal of Oilseed Brassica*, *1* (1), 1-11.

Miah, M.M., Afroz, S., Rashid, M.A., & Shiblee, S.A.M. (2015). Factors affecting the adoption of improved varieties of mustard cultivation in some selected sites of Bangladesh. *Bangladesh Journal of Agricultural Research*, *40* (3), 363-379. DOI: https://doi.org/10.3329/bjar.v40i3.25411

Neeru, N., Thakral, N.K., Ram, A.R.A., & Amit, S.A.S. (2015). Evaluation and classification of Indian mustard (*Brassica juncea* L.) genotypes using principal component analysis. *Journal of Oilseed Brassica, 6*, 167-174.

Nowakowska, M., Wrzesińska, M., Kamiński, P., Szczechura, W., Lichocka, M., Tartanus, M., Kozik, E.U., & Nowicki, M. (2019). *Alternaria brassicicola–Brassicaceae pathosystem*: insights into the infection process and resistance mechanisms under optimized artificial bio-assay. *European Journal of Plant Pathology*, *153*, 131-151. DOI: https://doi.org/10.1007/s10658-018-1548-y

Pathaichindachote, W., Panyawut, N., Sikaewtung, K., Patarapuwadol, S., & Muangprom, A. (2019). Genetic diversity and allelic frequency of selected Thai and exotic rice germplasm using SSR markers. *Rice Science*, *26* (6), 393-403. DOI: https://doi.org/10.1016/j.rsci.2018.11.002

Rahman, M.T., Hasan, M.A., Hasan, M.M., Howlader, N.C., & Tusar, M.R.S. (2024). Impact of supplemental irrigation and organic manure on growth and yield performance of rice variety BRRI dhan103 under terminal drought condition in Aman season. *Bulgarian Journal of Crop Science*, *61* (5), 21-31. DOI: https://doi.org/10.61308/UQNM4090

Saleem, N., Jan, S.A., Atif, M.J., Khurshid, H., Khan, S.A., Abdullah, M., Jahanzaib, M., Ahmed, H., Ullah, S.F., Iqbal, A., Naqi, S., Ilyas, M., Ali, N., & Rabbani, M.A. (2017). Multivariate based variability within diverse Indian mustard (*Brassica juncea* L.) genotypes. *Open Journal of Genetics*, *7* (02), 69. DOI: https://doi.org/10.4236/ojgen.2017.72007.

Sharif, M.A.R., Haque, M.Z., Howlader, M.H.K., & Hossain, M.J. (2016). Effect of sowing time on growth and yield attributes of three mustard cultivars grown in Tidal Floodplain of Bangladesh. *Journal of the Bangladesh Agricultural University*, *14* (2), 155-160. DOI: https://doi.org/10.3329/jbau.v14i2.32689

Sharma, P., Samkumar, A., Rao, M., Singh, V.V., Prasad, L., Mishra, D.C., Bhattacharya, R., & Gupta, N.C. (2018). Genetic diversity studies based on morphological variability, pathogenicity and molecular phylogeny of the *Sclerotinia sclerotiorum* population from Indian mustard

(*Brassica juncea*). *Frontiers in Microbiology*, *9*, 1169. DOI: https://doi.org/10.3389/fmicb.2018.01169

Sultana, A., Hossain, S.M.M., Hasan, M.M., Howlader, N.C., Paul, S., Yesmin, M.S., & Hossain, A. (2025). Bio-control management of foot and root rot disease of lentil as impacted by different formulations of *Trichoderma* product. *Journal of Oasis Agriculture and Sustainable Development*, *7* (2), 1-12. DOI: https://doi.org/10.56027/JOASD.102025

Talukdar, D., & Das, B.C. (2015). Screening of Rapeseed and mustard genotypes against *Alternaria* blight disease and its development of in the field condition in Assam. *International Journal of Scientific Research*, *4* (5), 717-720.

Thirumavalavan, M. (2025). An Overview of Black Mustard (*Brassica nigra* L.): Important Facts, Constituents, Health Benefits, Profuse Therapeutic Applications, and Adverse Effects: A Mini Review. *Journal of Food Science*, *90* (11), e70653. DOI: https://doi.org/10.1111/1750-3841.70653

Torrijos, R., Righetti, L., Cirlini, M., Calani, L., Manes, J., Meca, G., & Dall’Asta, C. (2023). Phytochemical profiling of volatile and bioactive compounds in yellow mustard (*Sinapis alba*) and oriental mustard (*Brassica juncea*) seed flour and bran. *LWT*, *173*, 114221. DOI: https://doi.org/10.1016/j.lwt.2022.114221

Tripathi, R., Purohit, R., Tewari, A. K., & Kala, S. (2025). Insights into silique to seed infection, survival in seed and PCR based detection threshold establishment of *Alternaria brassicae* in the Indian mustard seeds. *Australasian Plant Pathology*, *54*, 265-274. DOI: https://doi.org/10.1007/s13313-025-01038-1

Yesmin, M.S., Islam Sikder, M.S.I., Hossain, M.S., Hasan, M.M., & Howlader, N.C. (2023). Effect of organic seed priming on yield and yield attributing traits of chickpea (*Cicer arietinum* L.) in drought prone area. *Agriculture Extension in Developing Countries*, *1* (1), 38-42. DOI: https://doi.org/10.26480/aedc.01.2023.38.42

Received: April 11, 2025
Accepted: November 15, 2025

PROCENA GENOTIPOVA ULJANE REPICE (*BRASSICA NAPUS*) NA OTPORNOST PROTIV CRNE PEGAVOSTI

Papiya Clara Toppo[1*], Sk. Md. Mobarak Hossain[1], Md. Mahfuzul Hasan[2], Md. Mamunur Rashid[3], Afsana Hossain[2], Jannatun Nahar Jui[4] i Fatima Karim[1]

[1]Department of Plant Pathology, Faculty of Agriculture, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh
[2]Department of Horticulture, Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh
[3]Department of Agronomy, Faculty of Agriculture, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200, Bangladesh
[4]Department of Agronomy, Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh

R e z i m e

Crna pegavost (alternarioza) je razorna gljivična bolest koja inficira listove i ljuske uljane repice. Cilj ovog istraživanja bio je da se oceni intenzitet oboljevanja kod različitih genotipova kupusnjača i da se identifikuju superiorni genotipovi uljane repice otporni na crnu pegavost. Ispitano je dvanaest genotipova uljane repice. Naime, 45, 55 i 65 dana nakon setve (DNS), genotip NAP16061 je pokazao najmanji intenzitet oboljevanja (12,43%, 15,06% odnosno 11,06%). Genotip NAP16001 je imao najmanji broj zaraženih ljuski (1,000, 1,133 odnosno 1,700) 45, 55 odnosno 65 dana nakon setve. U pogledu broja zdravih ljuski, bolji su bili genotipovi NAP16001, NAP16068 i NAP16068. Genotip BARI SH 13 imao je najmanji ukupan broj listova po biljci i najmanji procenat lisne površine, dok je genotip NAP16061 imao najmanju prosečnu veličinu pega na listovima. Najveća visina biljaka je zabeležena kod genotipa NAP16066. Pozitivna opterećenja za parametre osetljivosti na bolest, kao što su intenzitet oboljevanja, procenat intenziteta oboljevanja, procenat zaražene lisne površine i broj zaraženih listova po biljci, primećene su kod prve glavne komponente (engl. *principal component 1 – PC1*). Genotipovi NAP16066, NAP16025 i NAP16001 pokazali su negativnu povezanost sa prvom glavnom komponentom, što ukazuje na otpornost na crnu pegavost.

Ključne reči: *Brassica napus*, genotipovi, gorušica, PCA i hijerarhijski klaster, uljana repica.

Primljeno: 11. aprila 2025.
Odobreno: 15. novembra 2025.

*Autor za kontakt: e-mail: claratoppo52@gmail.com

Journal of Agricultural Sciences (Belgrade) https://doi.org/10.2298/JAS2504435K
Vol. 70, No. 4, 2025 UDC: 639.3.082.454:597.552.56(497.6)
Pages 435-449 Original scientific paper

FECUNDITY AND LENGTH-WEIGHT RELATIONSHIP OF THE BROODSTOCK OF BROWN TROUT (*SALMO TRUTTA* M. *FARIO*) FROM CULTIVATED CONDITIONS IN THE BANJA LUKA REGION

Jelena R. Klječanin[1] and Nebojša M. Savić[2*]

[1]Ministry of Agriculture, Forestry and Water Management of the Republic of Srpska, Department for the Provision of Professional Services in Agriculture, Srpskih sokolova 1, Doboj, Bosnia and Herzegovina
[2]University of Banja Luka, Faculty of Agriculture, Bulevar vojvode Petra Bojovića 1A, Banja Luka, Bosnia and Herzegovina

Abstract: Research on the fecundity and length-weight relationship of the broodstock of farmed brown trout (*Salmo trutta* m. *fario*) was carried out in the salmonid hatcheries Klašnik and Šiprage in the Banja Luka region. The aim of the study was to determine the fecundity of females and the length-weight relationship of female and male brown trout from two salmonid hatcheries in the Banja Luka region. Thirty females and thirty males per hatchery were analyzed. The age of the females in the Klašnik hatchery was 3^+ to 4^+ years old, and the males were 1^+ years old, while in the Šiprage hatchery, both the females and males were aged 4^+ to 6^+ years. Egg samples from each female were photographed, and the number and the diameter of eggs in each sample were determined using the "ImageJ" program. A significant correlation ($p < 0.01$) was found between weight, total length, standard length, and body height of females and males from both hatcheries. Total fecundity was significantly lower in females from the Klašnik hatchery (2589±650.85 eggs) than in females from the Šiprage hatchery (4618±1541.54 eggs), which had higher body weight. No significant difference ($p > 0.05$) was found in the relative fecundity, weight and diameter of eggs of females from the Klašnik hatchery (2220±583.71 eggs/kg; 0.097±0.014 g/egg and 5.176±0.232 mm/egg) and the Šiprage hatchery (2343±801.65 eggs/kg; 0.095±0.02 g/egg and 5.267±0.457 mm/egg). Positive allometric growth ($b > 3$) was found in females from the Šiprage hatchery, while negative allometric growth ($b < 3$) was found in other cases.

Key words: fecundity, egg weight, egg diameter, condition factor, brown trout.

[*]Corresponding author: e-mail: nebojsa.savic@agro.unibl.org

Introduction

Brown trout (*Salmo trutta* m. *fario*) can be found in areas from northern Norway and northeastern Russia to the Atlas mountain range in North Africa, and from Iceland to Afghanistan (Bernatchez 2001; Elliott, 1994). Kottelat and Freyhof (2007) state that brown trout is native to the northwestern part of Europe, from Spain to the Barents Sea in Russia, and has been introduced to other parts of Europe. Brown trout is an autochthonous fish species of Bosnia and Herzegovina. Due to its slower growth, brown trout is less commonly farmed commercially in Bosnia and Herzegovina (Savić, 2023). There are brown trout hatcheries whose main goal is to obtain fry for stocking streams and rivers. To breed the broodstock, it is necessary to provide good conditions for the breeding environment, nutrition, breeding technology, and other factors (Savić et al., 2018).

Brown trout, like other fish species, is characterized by high fecundity. Hoitsy et al. (2012) state that the total fecundity of brown trout ranges from 500 to 8000 eggs per female. Total fecundity increases with increasing body weight and female age (Ojanguren et al., 1996), due to increased body cavity size and available energy (Jonsson and Jonsson, 1997). A number of authors have investigated the fecundity of brown trout (Estay et al., 2004; Şahin et al., 2010; Rasool and Jan, 2013; Kocabas and Bascinar, 2016; Rawat et al., 2017; and others). The relative fecundity of brown trout ranges from 1500 to 3500 eggs/kg of female (Hoitsy et al., 2012), which is higher than that of some other salmonids, such as brook trout and rainbow trout (Hao and Yifeng, 2009; Barylo et al., 2019), but lower than that of huchen (Marić, 2005). As the age of females increases, the relative fecundity of brown trout declines (Estay et al., 2004).

The average diameter of a brown trout egg is about 5 mm, depending on the size of the female's body (Ojanguren et al., 1996). In most salmonids, the egg diameter increases with increasing body weight (Jonsson et al., 1996; Dębowski et al., 2005). There are no significant differences in the size and number of eggs among brown trout of the same age, and the body length of brown trout is the main indicator of the size and number of eggs (Lobon-Cervia et al., 1997).

The condition factor (CF) of the fish is based on the length and weight of the fish body, and these same parameters are used to determine the body growth of the investigated fish population (Jan et al., 2018). When analyzing the length-weight relationship, the regression coefficient (b) is determined, which indicates the growth of the fish (Ricker, 1975; Sangun et al., 2007), and for most fish, it falls within $2.5 < b < 3.5$ (Froese, 2006). The condition factor (CF) indicates the influence of the external environment on fish (Dekić et al., 2016), and within a population, it depends on the genetics and stage of fish development (Treer et al., 2014).

In Bosnia and Herzegovina, there have been no significant studies on the fecundity and length-weight relationship of the broodstock of brown trout, and the results of this study may encourage future research in these areas. This approach can contribute to improving the choice of females for the broodstock (Ihut et al., 2015). The aim of this study was to determine the fecundity and length-weight relationship of female and male brown trout from two salmonid hatcheries in the Banja Luka region.

Material and Methods

The research was conducted at two salmonid hatcheries in the Banja Luka region of Bosnia and Herzegovina, Klašnik (44°43'28.51°N, 17°9'21.07°E, 176 m above sea level) and Šiprage (44°28'26.21°N, 17°35'35.14°E, 620 m above sea level). The Klašnik hatchery is supplied with water from a spring located next to the hatchery facility, and the water temperature on the day of spawning was 10°C. The Šiprage hatchery is supplied with water from the Crkvena River (the source is about 6 km from the hatchery), and the water temperature on the day of spawning was 6°C.

Brown trout (*Salmo trutta* m. *fario*) spawning took place during the 2021/2022 spawning season (end of December – Klašnik and beginning of November – Šiprage). Thirty females and thirty males were analyzed per hatchery, for a total of 120 brown trout (60 females and 60 males) from two hatcheries. In the Klašnik hatchery, females were 3^+ to 4^+ years old and males were 1^+ years old. In the Šiprage hatchery, both females and males were 4^+ to 6^+ years old. An anesthetic (2-phenoxyethanol, 2.5 ml/10 liters of water) was used during spawning in the Klašnik hatchery, while no anesthetic was used in the Šiprage hatchery. Before spawning, the weight (g) of female and male brown trout was determined using a CAS (computing scale) digital scale, with a capacity of 5 kg. Total and standard body length (cm) and body height (cm) were then measured using an ichthyometer.

After determining the mentioned characteristics, the spawning procedure began. After squeezing the eggs of one female into a dry, empty container, the total weight of eggs obtained from each female was measured using a CAS digital scale. A sample of 50–70 eggs was taken from the total weight of eggs of each female, and the sample weight was determined using a Denver DL-501 digital scale with a 0.5 kg capacity and 0.1 g accuracy. The egg samples were photographed, and the images were saved on a computer and used to count the eggs with the "ImageJ" program. The total fecundity of females was determined using the Equation (1).

$$F = \frac{W_t}{W_s} \times N \qquad (1)$$

F – fecundity, N – number of eggs in the sample, W_t – total weight of eggs and W_s – weight of eggs in the sample.

The relative fecundity of females was determined by dividing the total number of eggs by the body weight of each female. The average egg weight was determined based on the number and weight of eggs in the sample. After counting the eggs, their diameter was measured using the "ImageJ" program from a sample of 30 eggs per female (900 eggs from 30 females from the Klašnik hatchery and 900 eggs from 30 females from the Šiprage hatchery). The length-weight relationship is determined according to the exponential function in Equation (2).

$$W = aL^b \tag{2}$$

W – weight of fish (g); a – regression constant; b – regression coefficient; L – length (cm).

This relationship is transformed into logarithmic form (Ricker, 1975), as shown in Equation (3).

$$\text{Log } W = \text{Log } a + b \text{ Log } L \tag{3}$$

b < 3 indicates negative allometric growth, b = 3 indicates isometric growth, and b > 3 indicates positive allometric growth.

The condition factor (CF) is determined by Equation (4).

$$CF = \frac{BW}{L^3} \times 100 \tag{4}$$

CF – condition factor; BW – body weight (g); L – length (cm).

The statistical analysis of the data included descriptive statistics (average, minimum and maximum values, standard deviation, and coefficient of variation), Pearson's correlation coefficient, regression, and significance testing of mean differences (univariate analysis of variance, t-test, and Duncan's test) using the MS Excel program and SPSS16.

Results and Discussion

The age and body weight of female and male brown trout in the Šiprage hatchery were similar, but differed in the Klašnik hatchery. Descriptive statistics for the morphometric characteristics of the analyzed brown trout individuals are presented in Table 1.

The analysis of morphometric characteristics (TL, SL, H, and W) of female and male brown trout from the Klašnik and Šiprage hatcheries revealed a strong correlation ($p < 0.01$) among the analyzed parameters. In females from both the Klašnik and Šiprage hatcheries, the highest correlation was found between TL and SL ($r = 0.930$; $r = 0.889$). In the Klašnik hatchery, the lowest correlation was between TL and H ($r = 0.689$), while in the Šiprage hatchery, the lowest was between SL and H ($r = 0.767$). In males from the Klašnik hatchery, the highest correlation was found between W and SL ($r = 0.859$). In the Šiprage hatchery, the highest correlation was between TL and SL ($r = 0.995$). The lowest correlation in the Klašnik hatchery was between TL and H ($r = 0.674$), while in the Šiprage hatchery, the lowest correlation was between W and H ($r = 0.808$).

Table 1. Morphometric characteristics of the broodstock of brown trout from the Klašnik and Šiprage hatcheries.

Hatcheries	n	Sex		W (g)		TL (cm)	SL (cm)	H (cm)
				Before spawning	After spawning			
Klašnik	30	♀	x̄	1449.27	1200.50	48.31	43.18	11.71
			SD	314.37	271.62	4.59	3.97	0.83
			min	950.00	756.00	40.60	36.00	10.00
			max	2235.00	1827.00	57.30	50.70	13.40
			CV	21.69	22.63	9.49	9.20	7.11
	30	♂	x̄	298.27	-	30.08	24.79	6.30
			SD	91.99	-	3.26	3.19	12.25
			min	147.00	-	23.50	19.30	4.90
			max	518.00	-	36.40	31.70	7.80
			CV	30.84	-	10.84	12.85	0.77
Šiprage	30	♀	x̄	2555.27	2100.93	50.98	45.82	13.08
			SD	946.01	773.77	5.71	5.50	2.34
			min	1106.00	868	40.40	36.70	9.50
			max	3912.00	3278	59.90	55.10	18.80
			CV	37.02	36.83	11.21	12.00	17.86
	30	♂	x̄	2661.37	-	50.68	45.84	12.93
			SD	757.11	-	5.85	5.84	1.61
			min	1245.00	-	42.70	37.80	10.30
			max	3751.00	-	58.80	54.20	17.20
			CV	28.45	-	11.54	12.73	12.47

W – body weight of female (g); TL – total length (cm); SL – standard length (cm); H – body height (cm); SD – standard deviation; CV – coefficient of variation.

The difference in the total fecundity of females from the Klašnik and Šiprage hatcheries (Table 2) resulted from the higher age and weight of the females from the Šiprage hatchery. According to Ojanguren et al. (1996), total fecundity increases with increasing body weight and female age. Rasool and Jan (2013) report that the total fecundity of farmed brown trout (weight 517 g) averages 1281 eggs. Rawat et al. (2017) reported that the fecundity of brown trout (weight – 235–1140 g) caught in the river was 454–1052 eggs/female and was positively correlated with weight ($r = 0.653$) and length ($r = 0.859$).

There was no significant difference ($p > 0.05$) in the relative fecundity of females from the Klašnik and Šiprage hatcheries. Rasool and Jan (2013) reported that the relative fecundity of brown trout (weight 517.06 g) averaged 2560 eggs. Sahin et al. (2010) reported that the relative fecundity of brown trout females (3–5 years old) from cultivated conditions in northeastern Turkey was 2259±947 eggs/kg. Jan and Jan (2017) state that the relative fecundity of farmed brown trout (weight – 250–750 g) is 891–1570 eggs/kg of female. The coefficients of variation for total and relative fecundity of females from the Šiprage hatchery were higher (as a result of greater variation in body weight) compared to females from the

Klašnik hatchery. Variations in reproductive characteristics in brown trout are the result of wide distribution and the different conditions of their habitat and breeding environment (Dieterman et al., 2016).

The relative ratio of the total weight of eggs to the weight of brown trout females from the Klašnik hatchery averaged 17.30%:82.70%, and in the Šiprage hatchery, 17.61%:82.39%.

Table 2. Morphometric and reproductive characteristics of brown trout females from the Klašnik and Šiprage hatcheries.

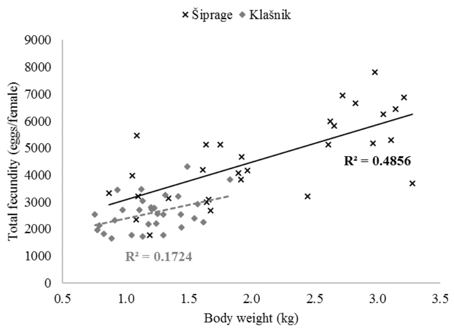
Hatchery		TL (cm)	W (g)	Total fecundity (eggs)	Relative fecundity (eggs/kg of female)	Ratio (%)		Weight of eggs (g/female)	Weight of egg (g/egg)	Diameter of egg (mm)*
						Weight of eggs	Weight of female body			
Klašnik (N = 30)	x̄	48.31	1200.50	2589	2220[a]	17.30	82.70	248.77	0.097[a]	5.176[a]
	SD	4.59	271.62	650.85	583.71	2.77	2.77	59.56	0.014	0.232
	min	40.60	756	1654	1363	11.82	76.43	127.00	0.076	4.637
	max	57.30	1827	4321	3688	23.57	88.18	408.00	0.132	5.718
	CV	9.49	22.63	25.14	26.29	16.00	3.35	23.94	14.82	4.48
Šiprage (N = 30)	x̄	50.98	2100.93	4618	2343[a]	17.61	82.39	454.33	0.095[a]	5.267[a]
	SD	5.71	773.77	1541.54	801.65	4.33	4.33	200.24	0.020	0.457
	min	40.40	868	1764	1129	8.37	71.24	109.00	0.053	4.414
	max	59.90	3278	7804	5019	28.76	91.63	804.00	0.128	6.236
	CV	11.21	36.83	33.38	34.21	24.56	5.25	44.07	20.81	8.68

TL – total length (cm); W – weight of females after spawning (g); N – number of analyzed females; *900 eggs/hatchery analyzed; [a]the same letter in superscript (observed by columns) indicates no significant difference ($p > 0.05$).

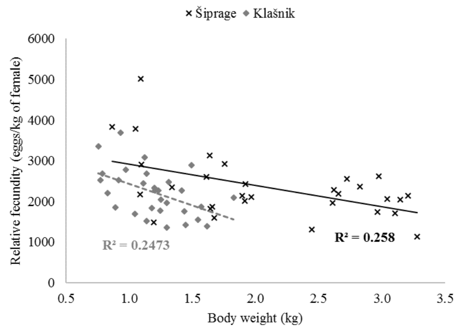
There was no significant difference ($p > 0.05$) in the diameter and weight of eggs from females at the Klašnik and Šiprage hatcheries. Similar results were reported by Sahin et al. (2010), who stated that the diameter of brown trout eggs (3–5 years old) from farming conditions in northeastern Turkey was 5.3±0.40 mm, and the average egg weight was 93.9±19.37 mg. Estay et al. (2004) reported that the diameter of brown trout eggs from farming conditions, aged three, four and five years, was 4.64±0.11 mm, 4.67±0.27 mm and 5.24±0.12 mm, similarly to the results of this research.

The correlation between total fecundity and body weight of brown trout females (Graph 1) from the Klašnik hatchery was positive but low ($R^2 = 0.1724$), while for females from the Šiprage hatchery it was moderately high ($R^2 = 0.4856$). Sahin et al. (2010) reported a highly positive correlation between body weight and total fecundity ($R^2 = 0.8665$, $p < 0.001$) in farmed brown trout females aged 3–5 years. Rasool and Jan (2013) also found a highly positive correlation between fecundity and body weight in female brown trout ($R^2 = 0.9426$).

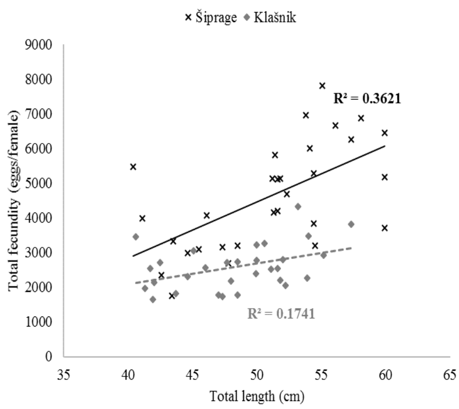
The correlation between relative fecundity and the weight of females from the Klašnik and Šiprage hatcheries (Graph 2) was low and negative ($R^2 = 0.2473$ and $R^2 = 0.258$), which indicates that relative fecundity decreases with increasing body weight, according to Dębowski et al. (2005), Çakmak et al. (2018) and Rinaldo (2020). In contrast to the results of this research, Sahin et al. (2010) report a low positive correlation between body weight and relative fecundity ($R^2 = 0.1632$, $p > 0.10$) in female brown trout aged 3 to 5 years.



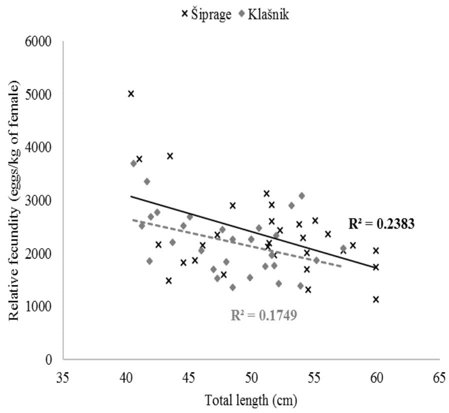
Graph 1. Relationship between total fecundity and body weight of females from the Klašnik and Šiprage hatcheries.



Graph 2. Relationship between relative fecundity and body weight of females from the Klašnik and Šiprage hatcheries.



Graph 3. Relationship between total fecundity and total length of females from the Klašnik and Šiprage hatcheries.

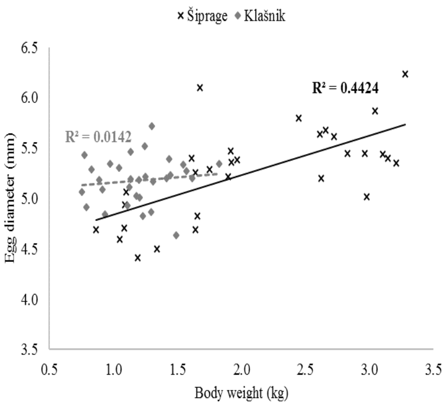


Graph 4. Relationship between relative fecundity and total length of females from the Klašnik and Šiprage hatcheries.

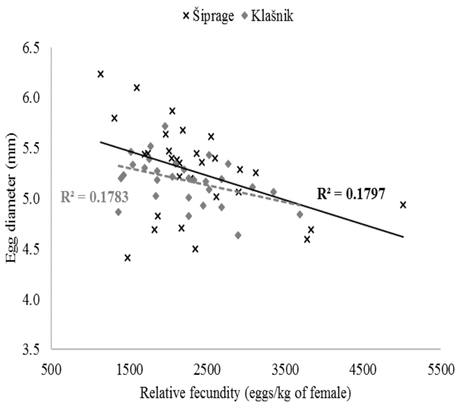
The correlation between total fecundity and total length in females from the Klašnik hatchery (Graph 3) was positive but low ($R^2 = 0.1741$). In females from the Šiprage hatchery, a positive and higher correlation was found ($R^2 = 0.3621$), while Rasool and Jan (2013) have reported that the correlation between fecundity and total length in brown trout females is highly positive ($R^2 = 0.865$).

The correlation between relative fecundity and TL of females from the Klašnik and Šiprage hatcheries (Graph 4) was low and negative ($R^2 = 0.1749$ and $R^2 = 0.2383$); as TL increases, relative fecundity decreases, according to Dębowski et al. (2005) and Rinaldo (2020).

The correlation between egg diameter and body weight of females (Graph 5) from the Klašnik hatchery was positive but low ($R^2 = 0.0142$), while it was higher for females from the Šiprage hatchery ($R^2 = 0.4424$). The diameter of the egg increases with the increase in body weight, as stated by Dębowski et al. (2005). Sahin et al. (2010) report a low negative correlation between egg diameter and body weight ($R^2 = 0.002$, $p > 0.10$) and between egg diameter and total fecundity ($R^2 = 0.0865$, $p > 0.05$). The correlation between the diameter of the egg and the relative fecundity of females (Graph 6) from the Klašnik hatchery was negative and low ($R^2 = 0.1783$), as was the case for females from the Šiprage hatchery ($R^2 = 0.1797$).



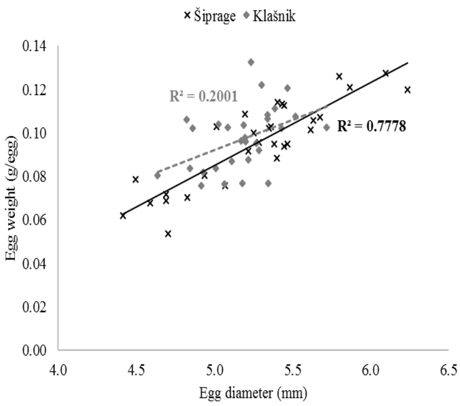
Graph 5. Relationship between egg diameter and body weight of females from the Klašnik and Šiprage hatcheries.



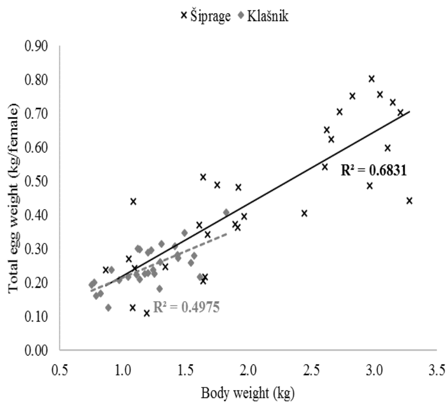
Graph 6. Relationship between egg diameter and relative fecundity of females from the Klašnik and Šiprage hatcheries.

The correlation (Graph 7) between egg weight (g/egg) and egg diameter (mm) from the Klašnik hatchery was positive and low ($R^2 = 0.2001$), while it was high ($R^2 = 0.7778$) for females from the Šiprage hatchery. The correlation (Graph 8) between total weight of eggs (kg/female) and body weight (kg) of females from the

Klašnik hatchery was R^2 = 0.4975, and for females from the Šiprage hatchery it was R^2 = 0.6831.



Graph 7. The relationship between egg weight and egg diameter in females from the Klašnik and Šiprage hatcheries.



Graph 8. The relationship between total egg weight and body weight in females from the Klašnik and Šiprage hatcheries.

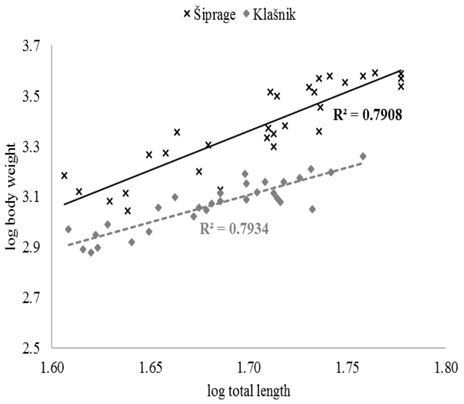
Positive allometric growth was found in females from the Šiprage hatchery, while negative allometric growth was found in males from the Šiprage hatchery, as well as in both females and males from the Klašnik hatchery (Tables 3 and 4). Several factors may contribute to the negative allometric growth of brown trout of the broodstock of males from the Šiprage hatchery, and both females and males from the Klašnik hatchery, such as selection, feed and nutrition, and environmental conditions. Rawat et al. (2014) found a highly positive correlation between length and body weight in brown trout.

Table 3. Descriptive statistics of TL and W logarithmic values, regression parameters, coefficient of correlation and coefficient of determination of brown trout from the Klašnik and Šiprage hatcheries.

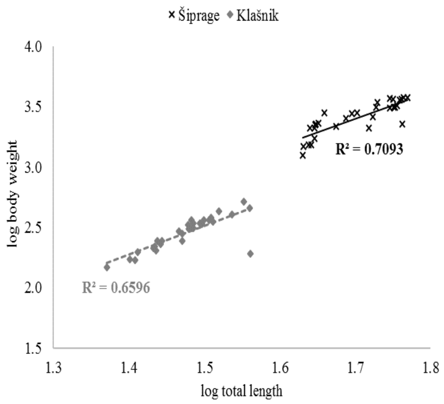
Hatchery	n	Sex	log TL (cm)			log W (g)			Regression parameters		R	R^2
			Min	Max	$\bar{x}$ ±SD	Min	Max	$\bar{x}$±SD	a	b		
Klašnik	30	♀	1.61	1.76	1.68±0.04	2.98	3.35	3.15±0.10	-0.334	2.072	0.894	0.798
	30	♂	1.37	1.56	1.48±0.05	2.17	2.71	2.45±0.14	-1.063	2.383	0.812	0.660
Šiprage	30	♀	1.61	1.78	1.70±0.05	3.04	3.59	3.38±0.17	-1.958	3.128	0.889	0.791
	30	♂	1.63	1.77	1.70±0.05	3.10	3.57	3.41±0.14	-0.424	2.250	0.842	0.709

n – number of analyzed fish; TL – total length; W – weight; SD – standard deviation; a – regression constant; b – regression coefficient.

The correlation of the logarithmic values of weight and body length of females (Graph 9) from the Klašnik and Šiprage hatcheries was positive and high (R^2 = 0.7934 and R^2 = 0.7908). For males (Graph 10) from the Klašnik and Šiprage hatcheries, the correlation was also positive and high (R^2 = 0.6596 and R^2 = 0.7093). Jan et al. (2018) report the coefficient of determination (R^2) for the relationship between log length and log weight of female brown trout as R^2 = 0.910, and for males as R^2 = 0.917.



Graph 9. Linear regression of the length-weight relationship of females from the Klašnik and Šiprage hatcheries.



Graph 10. Linear regression of the length-weight relationship of males from the Klašnik and Šiprage hatcheries.

Table 4. Length-weight relationship of brown trout from Klašnik and Šiprage hatcheries.

Hatchery	n	Sex	Growth type		
			$W = aL^b$	Log W = Log a + b Log L	
Klašnik	30	♀	$W = 0.4634L^{2.072}$	LogW = -0.334+2.072LogL	Allometric (-)
	30	♂	$W = 0.0865L^{2.383}$	LogW = -1.063+2.383LogL	Allometric (-)
Šiprage	30	♀	$W = 0.01102L^{3.128}$	LogW = -1.958+3.128LogL	Allometric (+)
	30	♂	$W = 0.376704L^{2.250}$	LogW = -0.424+2.250LogL	Allometric (-)

n – number of analyzed fish.

In the Klašnik hatchery, the regression coefficient was higher for males (b = 2.383) compared to females (b = 2.072), while in the Šiprage hatchery, the regression coefficient for females (b = 3.128) was higher than for males (b = 2.250). This partially agrees with the findings of Jan et al. (2018), who have stated that the regression coefficient (b) of brown trout from cultured conditions is slightly higher in females than in males. Rawat et al. (2014) reported that the regression coefficient (b) of male brown trout (W = 20.61–1180 g) was 3.096 and that of females (W = 24.37–1280 g) was 3.040, and the total regression coefficient (males and females) was 3.073. Tanir and Fakioğlu (2017) reported that the length-weight relationship of brown trout (W = 4.02–264.31 g) caught from multiple locations in a river in northeastern Turkey ranged from 3.0672 to 3.3158. Arslan et al. (2004) found that the growth of brown trout caught from the rivers of northeastern Turkey was isometric in spring, summer and autumn, while negative allometric growth occurred in the winter period. The observed differences in length and body weight growth of female and male brown trout broodstock from the Klašnik and Šiprage hatcheries may result from different influences. In addition to the age structure, the differences in growth could be influenced by the spawning season, nutrition, conditions of the breeding environment, lack of selection when choosing broodstock individuals, cultivation technology, and other factors.

Analysis of condition factors (Table 5) revealed significant differences (Duncan test; $p < 0.05$) between males and females. The lowest CF (1.08) was found in males from the Klašnik hatchery, while the highest CF was found in males (2.03) and females (1.85) from the Šiprage hatchery.

Table 5. Descriptive statistics of W, TL and CF of brown trout from the Klašnik and Šiprage hatcheries.

Hatchery	n	Sex	W (g)	CV	TL (cm)	CV	CF			
							$\bar{x}$±SD	min	max	CV
Klašnik	30	♀	1449.27±314.37	21.69	48.31±4.59	9.49	$1.28±0.18^{a}$	0.91	1.83	13.72
	30	♂	298.27±91.99	30.84	30.08±3.26	10.84	$1.08±0.15^{b}$	0.40	1.29	13.88
	60	♀+♂	873.77±624.14	71.43	39.20±10.00	25.51	$1.18±0.19^{a,b}$	0.40	1.83	16.29
Šiprage	30	♀	2555.27±946.01	37.02	50.98±5.71	11.21	$1.85±0.33^{c}$	1.18	2.42	17.91
	30	♂	2661.37±757.11	28.45	50.68±5.85	11.54	$2.03±0.38^{d}$	1.17	2.98	18.61
	60	♀+♂	2608.32±851.17	32.63	50.83±5.73	11.28	$1.94±0.36^{c,d}$	1.17	2.98	18.72

n – number of analyzed fish; W – body weight before spawning; CV – coefficient of variation; TL – total length; CF – condition factor; SD – standard deviation; $^{a, b, c \text{ and } d}$ different superscript letters (per column) indicate a significant difference ($p < 0.05$).

The condition factor (CF) ranged from 1.08±0.15 in males from the Klašnik hatchery to 2.03±0.38 in males from the Šiprage hatchery, according to research by Jan et al. (2018), who state that the CF of brown trout (W = 250–750 g) was above 1, which indicates a good status of farmed brown trout. The high condition factor of females and males from the Šiprage hatchery was accompanied by higher coefficients of variation, which were more pronounced compared to females and males from the Klašnik hatchery. Jan et al. (2018) stated that the highest CF of female brown trout was found in November (1.87 ± 0.08; W = 124–840 g) and the lowest in January (0.99 ± 0.10; W = 104–760. 3 g). In male brown trout, the highest CF was also determined in November (1.177 ± 0.40; W = 305–672 g) and the lowest in January (0.98 ± 0.12; W = 160–915.7 g). Rozdina et al. (2019) reported that the CF of brown trout (aged 1–5 years) caught in the river averaged 1.84, indicating a good condition of the brown trout. Ishtiyaq and Imtiaz (2019) state that the CF of rainbow trout from cultured conditions (W = 198–450 g) varies significantly by month throughout the year, ranging from 0.98 to 1.58. The pronounced variation in CF can be attributed to different factors (breeding environment, nutrition, health status, etc.). Piria et al. (2020) stated that the CF of brown trout caught in streams in Croatia ranged from 0.94 to 1.06 (TL = 7.1–32 cm). Kheyrandish et al. (2010) reported that the CF of 4^+ year-old brown trout harvested from six Caspian basin rivers was 1.24 (W = 209.5 g) and 1.37 (W = 390 g). The CF of female and male brown trout from the Šiprage hatchery was favorable and high. In females and males from the Klašnik hatchery, the CF was above 1, but significantly lower compared to individuals from the Šiprage hatchery. A significant difference in CF ($p < 0.05$) was found between female and male brown trout from the two hatcheries.

Conclusion

A significant correlation ($p < 0.01$) was found between the examined morphometric characteristics (W, TL, SL, H) of female and male broodstock of brown trout from the Klašnik and Šiprage hatcheries. The total fecundity of females from the Klašnik hatchery was lower than that of the females from the Šiprage hatchery, which is due to the greater age and body weight of the female brown trout from the Šiprage hatchery. No significant difference ($p > 0.05$) was found in the relative fecundity of females from the Klašnik and Šiprage hatcheries. The correlation between total fecundity, weight, and body length of females from the Klašnik and Šiprage hatcheries was positive; with an increase in body length and weight, total fecundity also increased. The correlation between relative fecundity, weight, and body length of females from the Klašnik and Šiprage hatcheries was negative, indicating that relative fecundity decreased with increasing body length and weight. The ratio (%) of egg weight to body weight of brown trout females from the two hatcheries was similar. There was no significant difference ($p > 0.05$) in the average weight or diameter of the eggs from females at the Klašnik and Šiprage hatcheries. As body weight increased, egg diameter also increased, while higher relative fecundity in females was associated with smaller egg diameter.

Length-weight relationships were characterized by different allometric growth patterns. Positive allometric growth ($b > 3$) was found in females from the Šiprage hatchery, while negative allometric growth ($b < 3$) was observed in males from the Šiprage hatchery, as well as in both females and males from the Klašnik hatchery. The condition factor of females and males from both hatcheries differed significantly ($p < 0.05$) in all combinations of male and female brown trout.

References

Arslan, M., Yildirim, A., & Bektaş, S. (2004). Length-weight relationship of brown trout, *Salmo trutta*, inhabiting Kan Stream Çoruh Basin Nort-Eastern Turkey. *Turkish Journal of Fisheries and Aquatic Sciences, 4*, 45-48.

Barylo, YE.O., Loboiko, YU.V., & Barylo, B.S. (2019). Fishery-exteriors characteristics of the brooders of brown trout, rainbow trout and brook trout. Scientific Messenger of Lviv National University of Veterinary Medicine and Biotechnologies. Series: *Agricultural sciences, 21* (90), 88-92.

Bernatchez, L. (2001). The evolutionary history of brown trout (*Salmo trutta* L.) inferred from phylogeographic, nested clade, and mismatch analyses of mitochondrial DNA variation. *Evolution, 55* (2), 351-379.

Çakmak, E., Sirin, F., Düzgüneş, Z., & Parlak, R. (2018). The Age Dependent Reproductive Performance of 4th Generation Black Sea Trout (*Salmo labrax* Pallas, 1814) Females. Turkish *Journal of Fisheries and Aquatic Sciences, 19*. 10.4194/1303-2712-v19_6_05.

Dębowski, P., Dobosz, S., & Grudniewska, J. (2005). Fecundity and egg size in sea trout (*Salmo trutta* m. *trutta* L.) in pond conditions. *Archives of Polish Fisheries, 13* (2), 227-234.

Dekić, R., Savić, N., Manojlović, M., Golub, D., & Pavličević, J. (2016). Condition factor and organosomatic indices of rainbow trout (*Oncorhynchus mykiss*, Wal.) from different broodstock. *Biotechnology in Animal Husbandry*, *32* (2), 229-237.

Dieterman, D., Walker, T., Cochran, P., & Konsti, M. (2016). Reproductive Traits of Brown Trout in Two Contrasting Streams of Southeast Minnesota. North American *Journal of Fisheries Management, 36*, 465-476. 10.1080/02755947.2015.1135216.

Elliott, J.M. (1994). *Quantitative ecology and the brown trout.* Oxford Series in Ecology and Evolution, Oxford University Press, Oxford, Great Britain.

Estay, J.F., Noriega, R., Ureta, P.J., Martín, W., & Colihueque, N. (2004). Reproductive performance of cultured brown trout (*Salmo trutta* L.) in Chile. *Aquaculture Research, 35*, 447-452.

Froese, R. (2006). Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. *Journal of Applied Ichthyology*, 22, 241-253.

Hao, F., & Yifeng, C. (2009). The reproductive traits of brown trout (*Salmo trutta fario* L.) from the Yadong River, Tibet. *Environmental Biology of Fishes*, *86*, 89-96.

Hoitsy, G., Woynarovich, A., & Moth-Poulsen, T. (2012). Guide to the small scale artificial propagation of trout. The FAO Regional Office for Europe and Central Asia, Budapest.

Ihut, A., Mireşan, V., Cocan, L.D., Răducu, C., Laţiu, C., & Pop, D. (2015). Reproductive Indices of Rainbow Trout (*Oncorhynchus mykiss*) Females from a Trout Farm. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. *Animal Science and Biotechnologies*, *72*, 157-161.

Ishtiyaq, A., & Imtiaz, A. (2019). Length Weight Relationship and Condition Factor of Cultured Rainbow Trout, Oncorhynchus mykiss (Walabum, 1792). *Journal of Ecophysiology and Occupational Health, 19*, 1-4. 10.18311/jeoh/2019/22304.

Jan, M., & Jan, N. (2017). Studies on the fecundity (F), gonadosomatic index (GSI) and hepatosomatic index (HSI) of *Salmo trutta fario* (Brown trout) at Kokernag trout fish farm, Anantnag, Jammu and Kashmir. *International Journal of Fisheries and Aquatic Studies, 5* (6), 170-173.

Jan, M., Jan, N., & Ahmed, I. (2018). Length Weight Relationship (LWR) and Condition Factor (K) of Brown Trout, *Salmo trutta fario*. *Journal of Ecophysiology and Occupational Health, 18,* (3&4), 73-79. 10.18311/jeoh/2018/19992.

Jonsson, N., Jonsson, B., & Fleming, I.A. (1996). Does early growth cause a phenotypically plastic response in egg production of Atlantic salmon. *Functional Ecology, 10*, 89-96.

Jonsson, N., & Jonsson, B. (1997). Energy allocation in polymorphic brown trout. *Functional Ecology, 11*, 310-317.

Kheyrandish, A., Abdoli, A., Mostafavi, H., Niksirat, H., Naderi, M., & Vatandoost, S. (2010). Age and Growth of Brown Trout (*Salmo trutta*) in Six Rivers of the Southern Part of Caspian Basin. *American Journal of Animal and Veterinary Sciences, 5* (1), 8-12.

Kocabas, M., & Bascinar, N. (2016). Assessing Stock Reproductive Potential of *Salmorizeensis*, *Salmo trutta abanticus, Salmo trutta caspius, Salmo trutta fario* and *Salmocoruhensis* with Fecundity. *Austin Biology, 1* (3), 1015, 1-4.

Kottelat, M., & Freyhof, J. (2007). *Handbook of European freshwater fishes.* Kottelat, Cornol, Switzerland and Freyhof, Berlin, Germany.

Lobon-Cervia, J., Utrilla, G.C., Rincòn, A.P., & Amezcua, F. (1997). Environmentally induced spatio-temporal variations in the fecundity of brown trout *Salmo trutta* L.: trade-offs between egg size and number. *Freshwater Biology, 38*, 277-288.

Marić, S. (2005). Evolucijska istorija kompleksa potočne pastrmke *Salmo trutta* L. na području republike Srbije i značaj za ribarstvo. Doktorska disertacija, Univerzitet u Beogradu, Biološki fakultet.

Ojanguren, F.A., Reyes-Gavilán, G.F., & Braňa, F. (1996). Effects of egg size on offspring development and fitness in brown trout, *Salmo trutta* L. *Aquaculture, 147*, 9-20.

Piria, M., Špelić, I., Rezić, A., & Šprem, N. (2020). Morfološke značajke i kondicija potočne pastrve *Salmo trutta* Žumberačkih i Samoborskih potoka. *Journal of Central European Agriculture, 21* (2), 231-245.

Rasool, N., & Jan, U. (2013). Study on the fecundity of *Salmo trutta fario* (Brown trout) in Kashmir. *Journal of Biology and Life Science*, *4* (1), 181-193.

Rawat, S.M., Bantwan, B., Singh, D. & Gusain, P.O. (2014). Length-weight relationship and condition factor of brown trout (*Salmo trutta fario* L.) from River Asiganga, Uttarakhand (India). *Environment Conservation Journal*, *15* (3), 41-46.

Rawat, S.M., Bantwan, B., & Singh, D. (2017). Study on the fecundity of brown trout (*Salmo trutta fario* L.) in River Asiganga, Uttarkashi (Uttarakhand), India. *International Journal of Fisheries and Aquatic Studies, 167,* 167-172.

Ricker, W.E. (1975). Computation and Interpretation of Biological Statistics of Fish Populatons. Bulletin of the Fishery Research Board of Canada No 191.

Rinaldo, A. (2020). Fecundity and egg size in anadromous brown trout *Salmo trutta.* UiT The Arctic University of Norway, Department of Arctic and Marine Biology. Master's thesis in Freshwater Ecology BIO-3950.

Rozdina, D., Raikova, G., & Valkanov, R. (2019). Age-Size Composition, L-W Relationship and Condition Factor of the Brown Trout (*Salmo trutta* Linnaeus, 1758) in the River Iliyna, Bulgaria. *Current Research in Hydrology and Water Resources*: CRHR-121. DOI: 10.29011/CRHR-121.100121.

Sangun, L., Akamca, E., & Akar, M. (2007). Weight-Length Relationships for 39 Fish Species from the North-Eastern Mediterranean Coast of Turkey. *Turkish Journal of Fisheries and Aquatic Sciences*, *7,* 37-40.

Savić, N., Babić, R., Ostojić, A., & Vaško, Ž. (2018). *Dužičasta pastrmka – gajenje, tržište i ekonomika*. Banja Luka. Univerzitet u Banjoj Luci, Poljoprivredni fakultet.

Savić, N. (2023). State and perspectives of aquaculture development in Bosnia and Herzegovina. XII International Symposium on Agricultural Sciences "AgroReS 2023", 24-26, Trebinje, Bosnia and Herzegovina. Book of abstracts, p. 244.

Şahin, T., Akbulut, B., Çakmak, E., & Çavdar, Y. (2010). Reproductive Characteristics of Brown Trout (*Salmo trutta fario* L.) Reared in North-Eastern Turkey. *The Israeli journal of aquaculture = Bamidgeh*, *62,* 195-201.

Tanir, Z.Ö., & Fakioğlu, Ö. (2017). Density, Biomass and Length-Weight Relationship of Brown Trout (*Salmo trutta* Linnaeus, 1758) Population in the Çoruh River Basin, North-Eastern Anatolia, Turkey. *Journal of Limnology and Freshwater Fisheries Research, 3* (3), 129-136. https://doi.org/10.17216/limnofish.313520.

Treer, T., Šprem, N., & Piria, M. (2014). Condition of huchen (*Hucho hucho* Linnaeus, 1758) from the Croatian-Slovenian Kupa River. *Journal of Applied Ichthyology*, *30* (1), 168-171. 10.1111/jai.12309.

Received: September 5, 2024
Accepted: November 15, 2025

PLODNOST I DUŽINSKO-MASENI ODNOS MATIČNOG JATA POTOČNE PASTRMKE (*SALMO TRUTTA* M. *FARIO*) IZ GAJENIH USLOVA REGIJE BANJA LUKA

Jelena R. Klječanin[1] i Nebojša M. Savić[2*]

[1]Ministarstvo poljoprivrede, šumarstva i vodoprivrede Republike Srpske, Resor za pružanje stručnih usluga u poljoprivredi, Srpskih sokolova 1, Doboj, BiH
[2]Univerzitet u Banjoj Luci, Poljoprivredni fakultet,
Bulevar vojvode Petra Bojovića 1A, Banja Luka, BiH

R e z i m e

Istraživanje plodnosti i dužinsko-masenog odnosa matičnog jata gajene potočne pastrmke (*Salmo trutta* m. *fario*) realizovano je u salmonidnim mrestilištima Klašnik i Šiprage, region Banja Luka. Cilj rada bio je da se utvrdi plodnost ženki i dužinsko-maseni odnos ženki i mužjaka potočne pastrmke iz dva salmonidna mrestilišta u regiji Banja Luka. Analizirano je 30 ženki i 30 mužjaka po mrestilištu. Starost ženki u mrestilištu Klašnik bila je 3^+ do 4^+, a mužjaka 1^+ godinu, dok su u mrestilištu Šiprage ženke i mužjaci bili starosti 4^+ do 6^+ godina. Uzorci ikre od svake ženke fotografisani su i korišćenjem programa „ImageJ" utvrđen je broj i dijametar ikre u uzorku. Utvrđena je značajna korelacija ($p < 0{,}01$) mase, totalne dužine, standardne dužine i visine tijela ženki i mužjaka iz dva mrestilišta. Apsolutna plodnost značajno je niža kod ženki iz mrestilišta Klašnik (2589±650,85 ikre) nego kod ženki iz mrestilišta Šiprage (4618±1541,54 ikre) koje su bile veće mase tijela. Nije utvrđena značajna razlika ($p > 0{,}05$) u pogledu relativne plodnosti, mase i dijametra ikre ženki iz mrestilišta Klašnik (2220±583,71 ikre/kg; 0,097±0,014 g/ikra i 5,176±0,232 mm/ikra) i Šiprage (2343±801,65 ikre/kg; 0,095±0,02 g/ikra i 5,267±0,457 mm/ikra). Kod ženki iz mrestilišta Šiprage utvrđen je pozitivan alometrijski rast ($b > 3$), a u ostalim slučajevima negativan alometrijski rast ($b < 3$).

Ključne reči: plodnost, masa i dijametar ikre, faktor kondicije, potočna pastrmka.

Primljeno: 5. septembra 2024.
Odobreno: 15. novembra 2025.

[*]Autor za kontakt: e-mail: nebojsa.savic@agro.unibl.org

Journal of Agricultural Sciences (Belgrade)
Vol. 70, No. 4, 2025
Pages 451-462
https://doi.org/10.2298/JAS2504451N
UDC: 656.01:631
Original scientific paper

THE IMPACT OF STAKEHOLDER BEHAVIOR ON THE OPTIMIZATION OF DIGITALIZATION IN THE MOROCCAN AGRICULTURAL SUPPLY CHAIN: A PLS-BASED VERIFICATION

Imane Neggaoui*, Lamyaa Lemfarreg and Mohamed Yaouhi

Laboratory of Studies and Research in Management Sciences (LERSG),
Faculty of Legal, Economic and Social Sciences – Agdal,
Mohammed V University, Rabat, Morocco

Abstract: Digital transformation is increasingly recognized as a strategic lever to enhance the logistical performance of agricultural supply chains, particularly in emerging economies. This study investigates the effect of actors' behavior on the optimization of digitalization, by analyzing the relationship between human usage patterns, data storage and processing capacity, and agricultural logistics performance. A conceptual model grounded in the diffusion of innovation theory and the dynamic capabilities theory was tested using the PLS-SEM method on a sample of 308 stakeholders from the Moroccan agricultural sector. The empirical results reveal that actors' behavior significantly influences digital capacity, which in turn affects several key performance dimensions, including cost reduction, quality improvement, operational efficiency, market competitiveness, and the reduction of intermediary roles. These outcomes highlight the importance of human factors in driving technological adoption and suggest that successful digital transformation requires not only infrastructure and tools but also active engagement, digital literacy, and collaborative practices among supply chain participants. The study underscores the need for policies and capacity-building initiatives that empower local actors and facilitate the integration of digital solutions adapted to the realities of agricultural logistics in low- and middle-income countries. The proposed model offers practical insights applicable to other low-digital-maturity logistics contexts and contributes to the growing literature on digital innovation in agri-food systems.

Key words: digitalization, agricultural logistics, stakeholder behavior, logistics performance.

*Corresponding author: e-mail: imane_neggaoui@um5.ac.ma

Introduction

In recent years, digital transformation has emerged as a key driver of innovation in supply chains, offering new opportunities to improve logistics performance, responsiveness, and data transparency. While progress has been remarkable in industrial sectors, the agricultural sector, particularly in developing countries, still lags behind in terms of digital integration. Agricultural supply chains are often fragmented, lack technological infrastructure, and have limited data interoperability, which weakens coordination and decision-making (Gopal et al., 2024; Klerkx et al., 2019).

In Morocco, this digital divide is especially evident. Although national strategies such as Generation Green 2020–2030 aim to modernize agricultural systems, the integration of digital tools remains limited in wholesale markets, cooperatives, and distribution networks. Key technologies related to traceability, information management, and data sharing are unevenly adopted across actors, depending on their resources, knowledge, and willingness to innovate (Banque Mondiale, 2021; Haut-Commissariat au Plan [HCP], 2023, n.d.). This technological gap leads to persistent inefficiencies, overdependence on intermediaries, and difficulty meeting international standards.

Prior research has highlighted that successful digitalization requires more than infrastructure. It also depends on the human dimension, specifically, how stakeholders adopt, use, and integrate digital tools into their practices (Bag et al., 2020; Ben-Daya et al., 2019). However, there is still limited empirical research on the specific mechanisms through which stakeholder behavior influences the effectiveness of digital transformation, as well as its direct impact on overall logistics performance. Within this context, the present study addresses the following research question: How does stakeholder behavior influence the optimization of digitalization in Moroccan agricultural supply chains, and to what extent does this digitalization affect overall supply chain performance?

This study aims to address this research gap by analyzing the role of stakeholder behavior in shaping digital capacity, operationalized here as the ability to store and process information, and by assessing how this capacity affects key dimensions of agricultural logistics performance, such as cost reduction, quality improvement, efficiency, and market competitiveness. The analysis focuses on the Moroccan agricultural supply chain and uses the partial least squares structural equation modeling (PLS-SEM) method on data collected from 308 supply chain actors.

Material and Methods

This study adopts a quantitative explanatory research design to examine the influence of stakeholder behavior on digital capacity and its subsequent effect on the performance of agricultural supply chains. The proposed model is grounded in two theoretical foundations. The first is the diffusion of innovation theory, which suggests that an individual's or organization's readiness to adopt innovation depends on perceived usefulness, social influence, and ease of implementation. This theory highlights how the behavior of stakeholders – such as their openness to change, willingness to use digital tools, and training engagement – affects the pace and depth of technological adoption within supply chains (Rogers, 1983). The second is the dynamic capabilities theory, which emphasizes that organizations must continuously reconfigure internal and external competences to adapt to rapidly changing environments. In this context, the capacity to store and process data is seen as a dynamic capability that enables agricultural supply chains to respond flexibly and efficiently to market and operational demands (Teece, 2007). This theoretical grounding supports the hypothesis that behavioral readiness among stakeholders enhances the organization's digital capabilities, particularly in terms of data storage and processing, which in turn influence various dimensions of logistics performance. Within this framework, data storage and processing capacity is considered a central operational pillar of digitalization, as it reflects the actual implementation of digital systems in core supply chain processes. In this context, it represents the embodiment of digitalization itself (Orjuela-Castro et al., 2023; Dubey et al., 2019).

The study tests six hypotheses:

H1: Stakeholder behavior has a positive effect on data storage and processing capacity.

H2.1: Data storage and processing capacity positively influences cost reduction.

H2.2: Data storage and processing capacity positively influences quality improvement.

H2.3: Data storage and processing capacity positively influences the reduction of intermediary roles.

H2.4: Data storage and processing capacity positively influences transactional efficiency and flexibility.

H2.5: Data storage and processing capacity positively influences market competitiveness.

To empirically validate these relationships, data were collected through a structured questionnaire administered to actors in the fruit and vegetable supply chain operating in three Moroccan wholesale markets: Casablanca, Agadir, and Oujda. These locations were selected for their logistical significance and diversity in practices. The data collection process took place between April and June 2024 and targeted a wide range of stakeholders including wholesalers, intermediaries, retailers, and distributors. After screening, 308 valid responses were retained. The questionnaire was built using items adapted from validated scales in prior literature and measured responses on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

The construct “stakeholder behavior” captures openness to innovation, digital skills, readiness for change, use of digital tools, and collaborative practices (Rogers, 1983; Venkatesh et al., 2012). The construct “data storage and processing capacity” measures the organization’s ability to collect, store, structure, and utilize information using digital platforms, data analytics, and system integration. “Logistics performance” is conceptualized as a multidimensional construct encompassing five areas: cost reduction, quality improvement, reduction in intermediary roles, transactional efficiency and flexibility, and market competitiveness (Papadopoulos et al., 2017; Zhang et al., 2002).

The data were analyzed using SmartPLS 4 software. The analysis followed a two-step procedure: first, the evaluation of the measurement model through reliability (Cronbach’s alpha, composite reliability), convergent validity (average variance extracted), and discriminant validity (Fornell-Larcker criterion and HTMT ratios); second, the evaluation of the structural model based on path coefficients, R^2 values, f^2 effect sizes, and predictive relevance using Q^2 statistics. Hypotheses were tested using the bootstrapping method with 5,000 resamples and a significance level of 5%, which ensures robustness in the presence of non-normal data distributions and complex intervariable relationships.

Results and Discussion

To evaluate the impact of stakeholder behavior on agricultural logistics performance through digitalization, a structural model was estimated using the PLS-SEM method. This model includes, on the one hand, behavior (STK_BEH) as a predictive factor, and on the other hand, data storage and processing capacity (DSP_CAP) as the central lever of digitalization. The latter then acts upon five key dimensions of logistics performance: cost reduction, quality improvement, reduction of intermediary roles, transactional efficiency and flexibility, and market competitiveness. This model allows for the evaluation of how stakeholder behavior influences the optimization of digitalization, and how such optimization is reflected in the performance of the agricultural supply chain. Figure 1 illustrates the structure of the model.

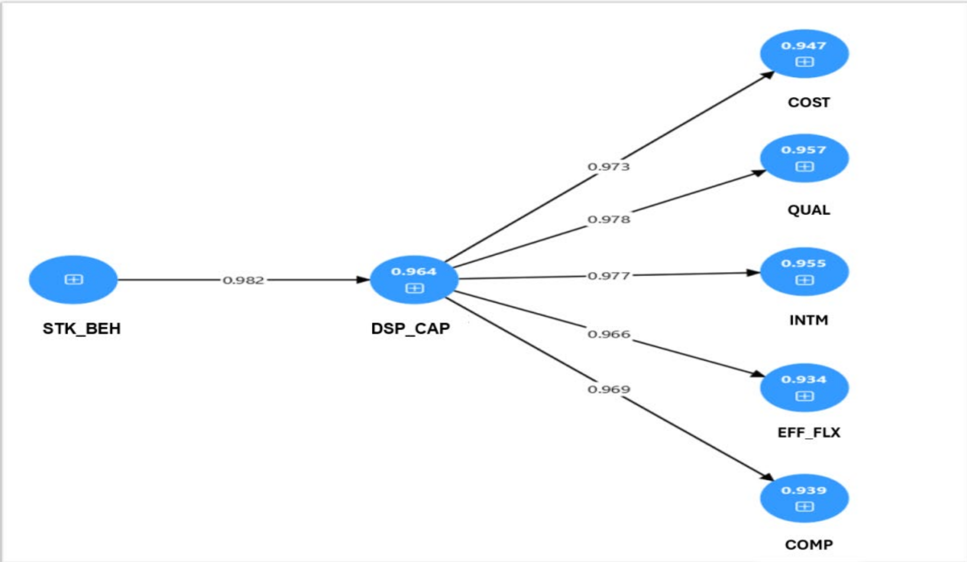


Figure 1. Structural model showing the influence of stakeholder behavior on logistics performance through data storage and processing capacity.

Test of direct effects

The analysis of direct effects was conducted using bootstrapping (5,000 subsamples, BCa confidence interval, $p < 0.05$). Table 1 presents the standardized coefficients (β), t-statistics, and associated p-values:

Table 1. Results of direct effects (PLS-SEM).

Relationship	Coefficient β	t-value	p-value	Interpretation
BEHAVIOR → DSP_CAP	0.982	229.985	0.000	Highly significant
DSP_CAP → COST	0.973	237.773	0.000	Highly significant
DSP_CAP → QUALITY	0.978	212.833	0.000	Highly significant
DSP_CAP → INTERMEDIARIES	0.977	193.115	0.000	Highly significant
DSP_CAP → EFFICIENCY_FLEXIBILITY	0.966	165.079	0.000	Highly significant
DSP_CAP → COMPETITIVENESS	0.969	154.231	0.000	Highly significant

These results confirm that stakeholder behavior had a strongly significant effect ($\beta = 0.982$; $p < 0.001$) on data storage and processing capacity, emphasizing the importance of human practices (technology use, engagement, training) in the success of digital initiatives. Hypotheses H2.1 to H2.5 have been also supported:

- H2.1: Cost reduction (β = 0.973; $p < 0.001$);
- H2.2: Quality improvement (β = 0.978; $p < 0.001$);
- H2.3: Reduction of intermediaries (β = 0.977; $p < 0.001$);
- H2.4: Improved efficiency and flexibility (β = 0.966; $p < 0.001$);
- H2.5: Enhanced market competitiveness (β = 0.969; $p < 0.001$).

These results confirm that data storage and processing capacity – used here as a proxy for the optimization of digitalization – served as a transversal operational lever that significantly influenced all major dimensions of logistics performance. In line with previous research, this capacity enables real-time information flows, enhances decision-making agility, and improves coordination between supply chain actors (Fumasoli, 2022; Kamble et al., 2020). It thus represents the functional embodiment of digital transformation within agricultural logistics, particularly in contexts where fragmented processes and limited interoperability are prevalent (Papadopoulos et al., 2017).

Coefficients of determination

The analysis of determination coefficients evaluates the proportion of variance in each dependent variable explained by its predictors. Table 2 presents the R^2 and adjusted R^2 values obtained in the final model:

Table 2. Coefficients of determination for each dependent variable.

Endogenous variable	R^2	Adjusted R^2	Interpretation
DSP_CAP	0.964	0.964	Stakeholder behavior explains 96.4% of the variance in data storage capacity
COST	0.947	0.947	Data storage capacity explains 94.7% of cost reduction
QUALITY	0.957	0.957	Data storage capacity explains 95.7% of quality improvement
INTERMEDIARIES	0.955	0.955	It explains 95.5% of the reduction in intermediary roles
EFFICIENCY_FLEX	0.934	0.934	It explains 93.4% of transactional efficiency and flexibility
COMPETITIVENESS	0.939	0.939	It explains 93.9% of market competitiveness

The results demonstrate a very high level of explained variance across all performance dimensions, confirming the strong predictive quality of the structural model (Sarstedt et al., 2014; Shmueli et al., 2016). In particular, stakeholder behavior emerged as a key determinant of effective digitalization, significantly enhancing the organization’s capacity to store and process data. This finding aligns with the view that behavioral readiness and user engagement are essential enablers of digital transformation in low-maturity contexts (Gunasekaran et al., 2017; Venkatesh et al., 2012). Furthermore, data storage and processing capacity – used here as an operational proxy for digitalization – functioned as a transversal lever that drove improvements in logistics performance, confirming previous empirical evidence from agro-food and supply chain studies (Dubey et al., 2019; Ning and Yao, 2023).

Effect size (F2)

The local effect size (F2) measures the individual contribution of each predictor variable to the explained variance of a dependent variable. Table 3 presents the effect sizes obtained.

Table 3. Local effect sizes for key relationships in the structural model.

Relationship	f^2	Interpretation
BEHAVIOR → DSP_CAP	26.985	Exceptionally strong effect of behavior on digital capacity
DSP_CAP → COST	17.798	Medium to strong effect on cost reduction
DSP_CAP → QUALITY	22.096	Medium to strong effect on quality improvement
DSP_CAP → INTERMEDIARIES	21.380	Medium to strong effect on reduction of intermediary roles
DSP_CAP → EFFICIENCY_FLEX	14.087	Medium effect on efficiency and flexibility
DSP_CAP → COMPETITIVENESS	15.322	Medium to strong effect on market competitiveness

These results confirm that data storage and processing capacity is a structural lever for performance, significantly activated by stakeholder behavior. The exceptionally high effect size observed supports the growing body of literature suggesting that successful digital transformation in supply chains depends less on the mere presence of technologies and more on how organizational actors engage with them. Recent research emphasizes that digital optimization is primarily driven by user engagement, digital culture, and collaborative practices embedded in daily operations (Kern, 2021; Queiroz et al., 2019; Wamba and Queiroz, 2020). In agricultural contexts, these dynamics are critical due to the heterogeneous digital readiness of actors and the fragmented nature of data ecosystems.

Total effects

The analysis of total effects provides a summary of all significant direct relationships within the structural model. Table 4 presents the total effects and their significance level.

Table 4. Total effects and significance of structural paths.

Relationship	Total effect (β)	Significance
BEHAVIOR → DSP_CAP	0.982	Highly significant
DSP_CAP → COST	0.973	Highly significant
DSP_CAP → QUALITY	0.978	Highly significant
DSP_CAP → INTERMEDIARIES	0.977	Highly significant
DSP_CAP → EFFICIENCY_FLEX	0.966	Highly significant
DSP_CAP → COMPETITIVENESS	0.969	Highly significant

These findings provide robust empirical support for the view that stakeholder behavior constitutes a critical driver of digital optimization within agricultural supply chains. The results demonstrate that digital capacity, understood as the ability to store, structure, and mobilize data, was not merely a technological resource but a transversal lever that significantly and consistently enhanced all key dimensions of logistics performance. This dynamic aligns with recent research emphasizing that human-centered factors such as openness to change, digital competencies, and inter-organizational collaboration are decisive in the effective deployment of digital innovations, as shown by Raj et al. (2020), Kamble et al. (2020), and Gölzer and Fritzsche (2017). The structural model confirms a strong and coherent interaction between the three core constructs of this study: stakeholder behavior, digital capacity, and performance. The highly significant influence of behavior on digitalization outcomes reinforces the idea that technological transformation in contexts such as Morocco's agricultural sector is inextricably linked to user engagement, capacity-building efforts, and organizational readiness for change.

These findings are fully consistent with the theoretical perspectives mobilized in this research. The diffusion of innovation theory (Rogers, 1983) finds clear empirical support here: it is users' attitudes, practices, and ability to adopt digital tools that determined their actual effectiveness. Our results also support the dynamic capabilities theory (Teece, 2007). Data storage and processing capacity clearly strengthened supply chain performance by reducing costs, improving quality, making transactions more efficient, and increasing competitiveness.

The relationship between stakeholder behavior, data storage and processing capacity, and logistics performance can be interpreted as a sequential activation dynamic central to digital transformation. In this framework, behavioral engagement initiated digital capacity, which subsequently generated tangible value across logistics processes. This progressive chain is particularly relevant in the Moroccan agricultural context, where levels of digital adoption vary across actors. Our findings show that when stakeholders engaged with digital tools, their behavior significantly enhanced data storage and processing capacity, which subsequently improved logistics performance. The results therefore confirm that the proposed mechanism operates effectively in a context where digital transformation is still evolving.

The strength of the obtained coefficients confirms not only statistical significance but also an underlying organizational reality. The ability to exploit data effectively is no longer a purely technical function; it acts as a transversal engine for coordination, responsiveness, and process optimization in fragmented agricultural ecosystems (Gunasekaran et al., 2017; Kamble et al., 2020; El Moutaouakil et al., 2022). However, this capacity is not autonomous: it is critically dependent on the willingness of stakeholders to collaborate, develop digital competencies, and adopt shared platforms, as highlighted by recent studies on socio-technical integration in emerging markets (Mangla et al., 2018).

Ultimately, this research contributes to the literature by confirming that digitalization in agricultural supply chains is not merely a question of deploying technologies, but a broader organizational and human transformation. In emerging economies especially, the success of such transformation relies on the activation of behavioral levers, the reinforcement of digital infrastructures, and the integration of analytics into decision-making processes. These findings reinforce previous observations on the interdependence of technological readiness and organizational maturity in enabling logistics performance (Wang et al., 2024).

Conclusion

This study has answered the central question posed in the introduction: stakeholder behavior is indeed a fundamental lever in optimizing digitalization within Moroccan agricultural supply chains. The results obtained through PLS-SEM analysis confirm that without human involvement, a shared digital culture, and willingness to adopt and integrate tools, digitalization cannot achieve its intended outcomes.

Data storage and processing capacity, considered here as the operational expression of digitalization, acted as a transversal lever across all dimensions of logistics performance: cost, quality, flow efficiency, and competitiveness. However, this capacity cannot emerge or evolve without the people who activate, understand, and improve it.

As Morocco seeks to modernize its agricultural value chains and integrate more fully into global value systems, it becomes urgent to act at the root of the problem: to train, raise awareness, support, and involve all field-level stakeholders. Public policy must go beyond infrastructure and platforms to include concrete actions focused on skill-building, trust development, and collaborative practice.

This research proposes a model that is reproducible in other sectors and countries with low digital maturity. Its message is clear: no digital transformation will succeed without human transformation. Morocco has the resources, the ambition, and now the empirical evidence to move forward. What remains is the courage to invest in people as the foundation of progress.

References

Bag, S., Wood, L. C., Xu, L., Dhamija, P., & Kayikci, Y. (2020). Big data analytics as an operational excellence approach to enhance sustainable supply chain performance. *Resources, Conservation and Recycling*, *153*, 104559. https://doi.org/10.1016/j.resconrec.2019.104559

Banque Mondiale (2021). Financing Digital Transformation in Developing Countries. Washington. https://documents1.worldbank.org/curated/en/778371636967305332/pdf/Digital-Development-Partnership-Annual-Review-2021-On-the-Path-to-Recovery.pdf

Ben-Daya, M., Hassini, E., & Bahroun, Z. (2019). Internet of things and supply chain management: A literature review. *International Journal of Production Research, 57* (15-16), 4719-4742. https://doi.org/10.1080/00207543.2017.1402140

Dubey, R., Gunasekaran, A., Childe, S.J., Blome, C., & Papadopoulos, T. (2019). Big Data and Predictive Analytics and Manufacturing Performance: Integrating Institutional Theory, Resource-Based View and Big Data Culture. *British Journal of Management, 30* (2), 341-361. https://doi.org/10.1111/1467-8551.12355

El Moutaouakil, K., Jabir, B., & Falih, N. (2022). Smart Livestock Monitoring System. In Proceedings of the International Symposium on Artificial Intelligence and the Security of New Telecommunications Systems (CIA2ST'2022). Beni Mellal, Morocco.

Fumasoli, G. (2022). Accélération de la transformation numérique inclusive des chaînes de valeur agricoles. GIZ.

Gölzer, P., & Fritzsche, A. (2017). Data-driven operations management: Organisational implications of the digital transformation in industrial practice. *Production Planning & Control, 28* (16), 1332-1343. https://doi.org/10.1080/09537287.2017.1375148

Gopal, P.R.C., Rana, N.P., Krishna, T.V., & Ramkumar, M. (2024). Impact of big data analytics on supply chain performance: An analysis of influencing factors. *Annals of Operations Research, 333* (2-3), 769-797. https://doi.org/10.1007/s10479-022-04749-6

Gunasekaran, A., Subramanian, N., & Rahman, S. (2017). Improving supply chain performance through management capabilities. *Production Planning & Control, 28* (6-8), 473-477. https://doi.org/10.1080/09537287.2017.1309680

Haut-Commissariat au Plan [HCP] (2023). Indicateurs de digitalisation du tissu économique marocain. Rabat, Morocco.

Kern, J. (2021). The Digital Transformation of Logistics: A Review About Technologies and Their Implementation Status. In M. Sullivan & J. Kern (Eds.), *The Digital Transformation of Logistics.* (pp. 361-403). Wiley. https://doi.org/10.1002/9781119646495.ch25

Kamble, S.S., Gunasekaran, A., & Gawankar, S.A. (2020). Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications. *International Journal of Production Economics, 219*, 179-194. https://doi.org/10.1016/j.ijpe.2019.05.022

Klerkx, L., Jakku, E., & Labarthe, P. (2019). A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. NJAS: *Wageningen Journal of Life Sciences, 90-91* (1), 1-16. https://doi.org/10.1016/j.njas.2019.100315

Mangla, S.K., Luthra, S., Rich, N., Kumar, D., Rana, N.P., & Dwivedi, Y.K. (2018). Enablers to implement sustainable initiatives in agri-food supply chains. *International Journal of Production Economics, 203*, 379-393. https://doi.org/10.1016/j.ijpe.2018.07.012

Ning, L., & Yao, D. (2023). The Impact of Digital Transformation on Supply Chain Capabilities and Supply Chain Competitive Performance. *Sustainability, 15* (13), 10107. https://doi.org/10.3390/su151310107

Orjuela-Castro, A. J., Orejuela-Cabrera, P. J., & Adarme-Jaimes, W. (2023). Supply Chain Network Design of Perishable Food in Surplus Periods. *International Journal on Food System Dynamics, 14* (1), 110-128. https://doi.org/10.18461/ijfsd.v14i1.e8

Papadopoulos, T., Gunasekaran, A., Dubey, R., Altay, N., Childe, S.J., & Fosso-Wamba, S. (2017). The role of Big Data in explaining disaster resilience in supply chains for sustainability. *Journal of Cleaner Production, 142*, 1108-1118. https://doi.org/10.1016/j.jclepro.2016.03.059

Queiroz, M.M., Telles, R., & Bonilla, S.H. (2019). Blockchain and supply chain management integration: A systematic review of the literature. Supply Chain Management: *An International Journal, 25* (2), 241-254. https://doi.org/10.1108/SCM-03-2018-0143

Raj, A., Dwivedi, G., Sharma, A., Lopes De Sousa Jabbour, A.B., & Rajak, S. (2020). Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective. *International Journal of Production Economics, 224*, 107546. https://doi.org/10.1016/j.ijpe.2019.107546

Rogers, E.M. (1983). *Diffusion of innovations* (3rd ed.). Free Press.

Sarstedt, M., Ringle, C.M., Smith, D., Reams, R., & Hair, J.F. (2014). Partial least squares structural equation modeling (PLS-SEM): A useful tool for family business researchers. *Journal of Family Business Strategy, 5* (1), 105-115. https://doi.org/10.1016/j.jfbs.2014.01.002

Shmueli, G., Ray, S., Velasquez Estrada, J.M., & Chatla, S.B. (2016). The elephant in the room: Predictive performance of PLS models. *Journal of Business Research, 69* (10), 4552-4564. https://doi.org/10.1016/j.jbusres.2016.03.049

Teece, D.J. (2007). Dynamic capabilities and multinational enterprise: Penrosean insights and omissions. *Management International Review, 47* (2), 175-192. https://doi.org/10.1007/s11575-007-0010-8

Venkatesh V., Thong, J.Y.L, & Xu X. (2012). Consumer Acceptance and Use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology. *MIS Quarterly, 36* (1), 157. https://doi.org/10.2307/41410412

Wamba, S.F., & Queiroz, M.M. (2020). Blockchain in the operations and supply chain management: Benefits, challenges and future research opportunities. *International Journal of Information Management, 52*, 102064. https://doi.org/10.1016/j.ijinfomgt.2019.102064

Wang, S., Ghadge, A., & Aktas, E. (2024). Digital transformation in food supply chains: An implementation framework. Supply Chain Management: *An International Journal, 29* (2), 328-350. https://doi.org/10.1108/scm-09-2023-0463

Zhang, N., Wang, M., & Wang, N. (2002). Precision agriculture—A worldwide overview. *Computers and Electronics in Agriculture, 36* (2-3), 113-132. https://doi.org/10.1016/S0168-1699(02)00096-0

Received: June 20, 2025
Accepted: December 7, 2025

UTICAJ PONAŠANJA ZAINTERESOVANIH STRANA NA OPTIMIZACIJU DIGITALIZACIJE U MAROKANSKOM POLJOPRIVREDNOM LANCU SNABDEVANJA: VERIFIKACIJA ZASNOVANA NA METODU DELIMIČNIH NAJMANJIH KVADRATA

Imane Neggaoui*, Lamyaa Lemfarreg i Mohamed Yaouhi

Laboratory of Studies and Research in Management Sciences (LERSG),
Faculty of Legal, Economic and Social Sciences – Agdal,
Mohammed V University, Rabat, Morocco

R e z i m e

Digitalna transformacija se sve više prepoznaje kao strateški instrument za unapređenje logističkih performansi poljoprivrednih lanaca snabdevanja, naročito u zemljama u razvoju. Ovo istraživanje ispituje uticaj ponašanja aktera na optimizaciju digitalizacije, analizirajući odnos između obrazaca korišćenja od strane ljudi, kapaciteta za skladištenje i obradu podataka i učinak poljoprivredne logistike. Konceptualni model zasnovan na teoriji difuzije inovacija i teoriji dinamičkih sposobnosti testiran je primenom modeliranja strukturnih jednačina metodom parcijalnih najmanjih kvadrata (engl. *PLS-SEM*) na uzorku od 308 aktera iz marokanskog poljoprivrednog sektora. Empirijski rezultati pokazuju da ponašanje aktera ima značajan uticaj na digitalne kapacitete, koji potom utiču na više ključnih dimenzija učinka, uključujući smanjenje troškova, unapređenje kvaliteta, operativnu efikasnost, konkurentnost na tržištu i smanjenje posredničkih uloga. Ovi nalazi ukazuju na značaj ljudskih faktora u podsticanju usvajanja tehnologija i sugerišu da uspešna digitalna transformacija zahteva ne samo infrastrukturu i alate, već i aktivno angažovanje, digitalnu pismenost i postojanje saradnje među učesnicima u lancima snabdevanja. Istraživanje naglašava potrebu za politikama i inicijativama za jačanje kapaciteta koje osnažuju lokalne aktere i olakšavaju integraciju digitalnih rešenja prilagođenih realnim uslovima poljoprivredne logistike u zemljama sa niskim i srednjim prihodima. Predloženi model nudi praktične uvide primenljive i u drugim logističkim kontekstima sa niskim nivoom digitalne zrelosti i doprinosi sve obimnijoj literaturi o digitalnim inovacijama u poljoprivredno-prehrambenim sistemima.

Ključne reči: digitalizacija, poljoprivredna logistika, ponašanje zainteresovanih strana, logističke performanse.

Primljeno: 20. juna 2025.
Odobreno: 7. decembra 2025.

*Autor za kontakt: e-mail: imane_neggaoui@um5.ac.ma

INSTRUCTIONS FOR AUTHORS

MANUSCRIPT SUBMISSION

By submitting a manuscript authors warrant that their contribution to the Journal is their original work, that it has not been published before, that it is not under consideration for publication elsewhere, and that its publication has been approved by all co-authors, if any, and tacitly or explicitly by the responsible authorities at the institution where the work was carried out.

Authors are exclusively responsible for the contents of their submissions, the validity of the experimental results and must make sure that they have permission from all involved parties to make the data public.

Authors wishing to include figures or text passages that have already been published elsewhere are required to obtain permission from the copyright holder(s) and to include evidence that such permission has been granted when submitting their papers. Any material received without such evidence will be assumed to originate from the authors.

Authors must make sure that all only contributors who have significantly contributed to the submission are listed as authors and, conversely, that all contributors who have significantly contributed to the submission are listed as authors.

The registration of the authors and the submission of the papers should be done via the following link: http://aseestant.ceon.rs/index.php/jas/user

Manuscripts are to be pre-evaluated at the Editorial Office in order to check whether they meet the basic publishing requirements and quality standards. They are also screened for plagiarism.

Authors will be notified by email upon receiving their submission. Only those contributions which conform to the following instructions can be accepted for peer-review. Otherwise, the manuscripts shall be returned to the authors with observations, comments and annotations.

MANUSCRIPT PREPARATION

Authors must follow the instructions for authors strictly, failing which the manuscripts would be rejected without review.

The manuscript should be written in MS-Word in .doc, .docx, format. Font Times New Roman, font size 12, single spacing, margin 2.5 cm should be used when writing the paper. Page numbering should be avoided.

Original scientific paper - The paper should report the unpublished results of original research. This paper should occupy 6 to 12 pages.

Review article - The article which contains original, detailed and critical review of research problem or area where the author has made a certain contribution, noticed by auto citation (at least 10). This article should occupy 15 to 20 pages.

Preliminary communication - Original research paper of full format, small-scale or preliminary character. It should occupy 2 to 6 pages.

The obligatory parts of each Original scientific paper and Preliminary communication are the following: Title of the paper, Name(s) of author(s), Complete postal address(es) of affiliations, Abstract, Key words, Introduction, Material and Methods, Results and Discussion, Conclusion, Acknowledgements, References and Summary in Serbian (if manuscript is submitted in English and vice versa). The obligatory parts of each Review article are the following: Title of the paper, Name(s) of author(s), Complete postal address(es) of affiliations, Abstract, Key words, Introduction, Analysis-discussion of a certain topic, Conclusion, References and Summary in Serbian (if manuscript is submitted in English and vice versa). If manuscript is written in English British version is preferred.

Title of the paper
The title of the paper should describe the content of the paper as accurately and concisely as possible. Authors are recommended to use words in the title which are suitable for indexing and browsing purposes. The title should be centred and written in capital letters. If the paper has already been announced at certain meeting as an oral presentation, under the same or similar title, the datum should be stated on it at the bottom of the first page, after the data of the corresponding author.

Authors' Names
First name, middle initial(s) and last (family) name of all authors, in the original form, should be provided. The names should be written below the title, in lower-case letters, centred and bolded. If several different affiliations need to be mentioned, using the command "insert footnote", consecutive numerals should be placed as the superscript after the respective author's name. The corresponding author should be designated with an asterisk as the superscript, after the last (family) name, and his/her e-mail address should be given under the line, at the bottom of the first page of the paper.

Authors' Affiliations
The full name and address of the institution where the author is employed should be provided. It should be centred and written immediately after the author's name. If authors belong to different institutions, the numerals should be placed as the superscript before the name of institution to provide information on the institution where each of the stated authors is employed.

Abstract
The abstract is a short informative review of the content of the paper, which should enable the reader to estimate its relevance easily and accurately. It is in the interests of the author that the abstract contains terms used for indexing and browsing purposes. The references should not be given in the abstract. The abstract should include the aim of research, the methods, the results and the conclusion. It should contain between 200 and 250 words and be placed between the name of the authors' affiliations and key words. The title of the abstract should be bolded and indented pressing the tab key. The colon should be used after the title of the abstract, and then the text of the abstract should follow without any indentation.

Key words
Key words are terms or phrases which describe best the content of the article for the needs of indexing and browsing purposes. The number of key words should be 3 to 10. They should appear below the abstract. The title of key words should be bolded and indented by pressing the tab key. The colon should be used after the title, and then the list of key words in lower-case letters should be given with the full stop at the end. Key words should be provided in Serbian and English after abstract on both languages.

Introduction
The introduction should contain all the relevant information on past researches according to the stated problem and what can be achieved by further research. Reviewing the references, the author and the year should be provided, and the mentioned author should be cited in References. The title of the introduction should be centred and bolded, written in lower-case letters, below which using one line spacing, the text of the introduction should follow, justified. Each new paragraph should be indented pressing the tab key. These rules should be applied to all parts of the paper.

Material and Methods
The material and methods should be clearly outlined explaining all applied procedures in the paper. Generally known methods should be presented briefly, and a detailed explanation should be given if there is a deviation from previously published procedures. Papers, which have an experimental character, should provide the way of statistical data processing. This part, as well as the part Results and Discussion, if needed, may comprise certain subparts, too.

Results and Discussion
In the part Results and Discussion data obtained on the basis of observation and conducted experiments should be interpreted. In the comment of the results, references should be quoted at the end of the paper, providing the comparison between the obtained results and previous knowledge of the certain area.

Conclusion
All relevant items achieved in the researched area should be mentioned in the conclusion. Listing of all results with repetition of numbers previously specified in Results and Discussion should be avoided. Conclusion should not contain references.

Acknowledgements
Acknowledgements should contain the title and the number of the project that is the title of the program within which the paper was written, as well as the name of the institution which financed the project or program. It should be placed between the conclusion and references.

References

The References section should contain only papers cited in the main text. The paper cited in the text should contain the last (family) name and the year. If the citation is comprised of one author, it is stated as Jalikop (2010) or (Jalikop, 2010). When the citation is comprised of the two authors it is stated as Sadras and Soar (2009) or (Sadras and Soar, 2009). If more than two authors are cited, after the last (family) name of the first author, the abbreviation "et al." is given, and then the year. This citation is stated as Lehrer et al. (2008) or (Lehrer et al., 2008). If more than one paper are cited simultaneously for a certain problem, they should be listed chronologically. A large number of cited papers out of brackets should be separated by comma (,) and if in brackets, by semicolon (;). If two or more papers of the same author are cited, they must be listed chronologically (1997, 2002, 2006, etc.). If a certain author appears several times for the same year, the letters are added (2005a, b, c, etc.). The citations of personal communication and unpublished papers should be avoided, except that it is an absolute necessity. Such citations should appear in the text only as (Brown, personal communication), and not in the list of References.

The references, cited in the text should be stated in the list of references in the original form, alphabetically, without numbering. If a greater number of publications of the same author is cited, then the papers where the author is the single author should first be cited and then the publications of the same author with one and then with more co-authors. If a considerable number of publications appear in any of the above mentioned categories, they should be listed chronologically (1997, 2002, 2006, etc.), and if a great number of publications is of the same year then the letters are added (2005a, 2005b, 2005c, etc.). References entry should contain: the last (family) name of the author, the first letter of the author's name, the year of publishing in the brackets, the title of the paper, the title of the journal, the volume and the number of pages (the first-the last). When the book is cited, the publisher and place of publishing should be given. The lines of each reference entry should be indented after the first line. APA - Publication Manual of the American Psychological Association citation style is used in this journal.

The examples of listing references are the following:

Periodicals

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.

Books

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

Book chapter

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.

Proceedings

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, France.

Thesis

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

Report

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

Web site

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

Summary

The summary in Serbian is given at the end of the paper and should comprise 200 to 250 words. Before the main text of the summary, as well as in English, the title of the paper, first name, middle initial(s) and last (family) name of all authors and the names and addresses of affiliations should be given. The title of the summary is centred and written separately. Below the title, the text of the summary should follow, without any indentation, and immediately after the text of the summary, the key words are given with the full stop at the end. The e-mail address of the corresponding author should be given at the bottom of the page.

Tables

Tables numbered with Arabic numerals (1, 2, etc.), followed by the title should be placed in the text using 9 font size and a maximum width of 13 cm. They should be clear, simple and unambiguous. The vertical sections should be avoided, and the number of columns should be limited so that the table is not too wide. Also, an unnecessary usage of horizontal sections should be avoided. The title of the table, single spaced above the table, justified, and with the full stop at the end should be given. The detailed explanation of abbreviations, symbols and signs used in the table should be provided below the table. Each table must be mentioned in the text.

Illustrations

All graphs, diagrams and photographs should be titled "Figure" (1, 2, etc.). They should be placed in the text. Graphs and diagrams should be computer drawn, using 9 font size and a maximum width of 13 cm, so that they can be legible and distinct after the size reduction. The overuse of colours and hues should be avoided for aesthetic reasons. The detailed legend without abbreviations for each graph and diagram should be given. The photographs must be of high quality so that they can technically be well reproduced. They should be submitted in "TIF" or "JPG" format, and they will be printed in black and white. The title of the illustration should be justified, with a full stop at the end, single spaced from the illustration and given below it. Each illustration should be mentioned in the text.

Abbreviations and units

Only standardised abbreviations should be used in the paper. Measure units should be expressed using International System of Units (SI). The abbreviations can be used for other expressions provided these expressions are stated in the full form when appear for the first time with the abbreviated form in the brackets. Values from 1 to 9 can be written in letters, but others numerically.

Nomenclature

The complete nomenclature (chemical and biochemical, taxonomical, genetic etc.) must be adjusted to international codes and commissions, such as *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* etc.

Formulae

All formulae and equations in the paper should be worked out by means of the programme "WORD Equation". An ample space should be left around the formulae for the sake of visibility. Subscripts and superscripts should be clear. Greek letters and other non-Latin symbols should be explained when they are first used. The meaning of all symbols should be given immediately after the equation where these symbols are first used. Equations should be numbered by Arabic numerals, serially in brackets, at the right-hand side. Each equation must be mentioned in the text as Eq. (1), Eq. (2), etc.

The corresponding author will be sent a free copy of the journal after it has been published.

All future associates are asked to prepare the paper according to the given instructions in order to facilitate the work of the Editorial Board. Unless the paper is prepared according to the given instructions it will not be accepted for the prospective publishing.

Editorial Board of the Journal
Journal of Agricultural Sciences

UPUTSTVO AUTORIMA

SLANJE RUKOPISA

Prilikim podnošenja rukopisa autori garantuju da rukopis predstavlja njihov originalan doprinos, da nije već objavljen, da se ne razmatra za objavljivanje kod drugog izdavača ili u okviru neke druge publikacije, da je objavljivanje odobreno od strane svih koautora, ukoliko ih ima, kao i, prećutno ili eksplicitno, od strane nadležnih tela u ustanovi u kojoj je izvršeno istraživanje.
Autori snose svu odgovornost za sadržaj ponesenih rukopisa, kao i validnost eksperimentalnih rezultata, i moraju da pribave dozvolu za objavljivanje podataka od svih strana uključenih u istraživanje.
Autori koji žele da u rad uključe slike ili delove teksta koji su već negde objavljeni dužni su da za to pribave saglasnost nosilaca autorskih prava i da prilikom podnošenja rada dostave dokaze da je takva saglasnost data. Materijal za koji takvi dokazi nisu dostavljeni smatraće se originalnim delom autora.
Autori garantuju, da su kao autori navedena samo ona lica koja su značajno doprinela sadržaju rukopisa, odnosno da su sva lica koja su značajno doprinela sadržaju rukopisa navedena kao autori. Registracija autora i prijava radova se vrši preko linka: http://aseestant.ceon.rs/index.php/jas/user
Pri prijavi rada autori treba da navedu podatke za kontakt (ime i prezime, ustanovu i E-mail adresu) najmanje tri potencijalna recenzenta. Oni treba da budu eksperti iz date oblasti istraživanja koji će obezbediti objektivnu procenu rada. Predloženi recenzenti ne bi trebalo da budu iz iste institucije iz koje su i autori rada.
Nakon prijema, rukopisi prolaze kroz preliminarnu proveru u redakciji kako bi se proverilo da li ispunjavaju osnovne kriterijume i standarde. Pored toga, proverava se da li su rad ili njegovi delovi plagirani.
Autori će o prijemu rukopisa biti obavešteni elektronskom poštom. Samo oni rukopisi koji su u skladu sa datim uputstvima biće poslati na recenziju. U suprotnom, rukopis će, sa primedbama i komentarima, biti vraćen autorima.

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.

Redakcioni odbor časopisa
Journal of Agricultural Sciences

CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

63

JOURNAL of Agricultural Sciences / editor-in-chief Snežana Oljača. - [Štampano izd.]. - Vol. 44, no. 1 (1999)- . - Belgrade : University of Belgrade, Faculty of Agriculture, 1999- (Belgrade-Zemun : Faculty of Agriculture). - 24 cm

Tromesečno. - Je nastavak: Review of Research work at the Faculty of Agriculture = ISSN 0354-3498. - Drugo izdanje na drugom medijumu: Journal of Agricultural Sciences (Belgrade. Online) = ISSN 2406-0968
ISSN 1450-8109 = Journal of Agricultural Sciences (Belgrade)
COBISS.SR-ID 169380871