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).

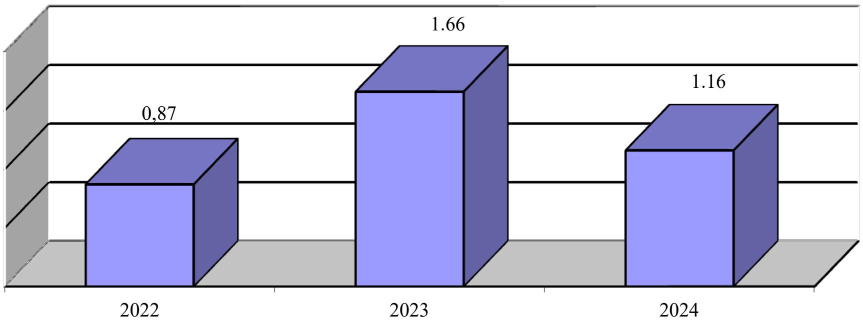


Figure 1. Humidity level (2021–2023).

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.

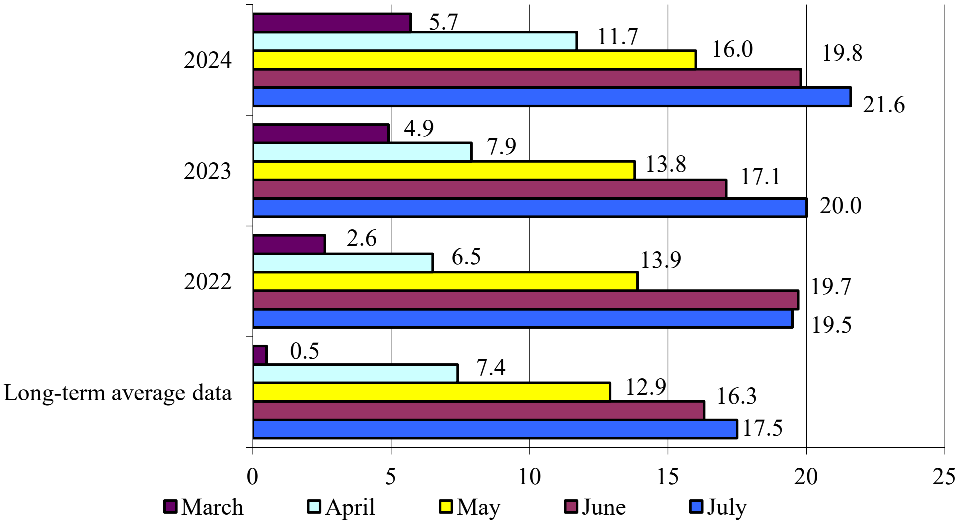


Figure 2. Average daily air temperature during the growing season (2022–2024), °C.

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).

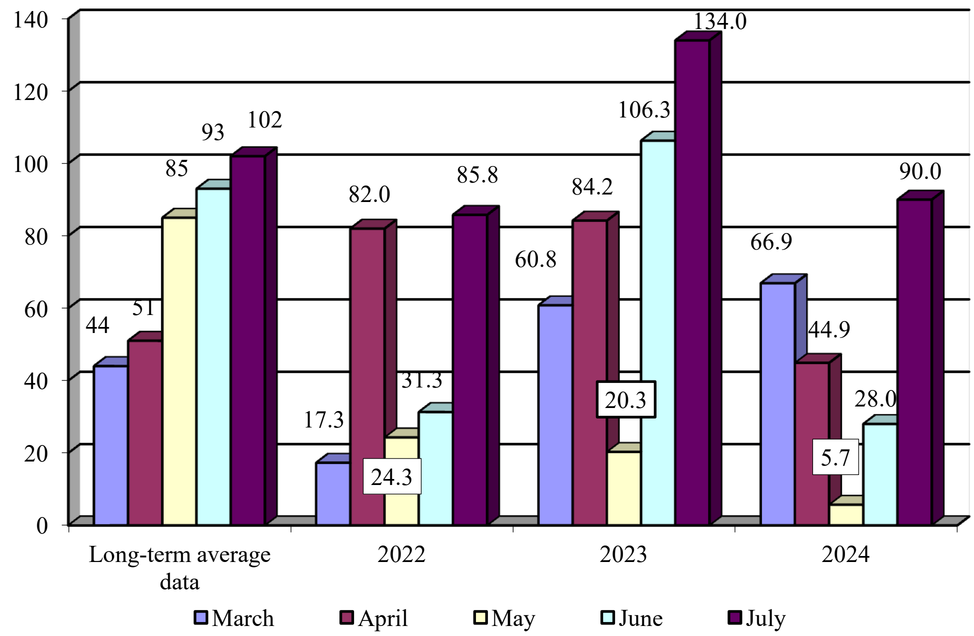


Figure 3. Precipitation during the growing season (2022–2024), mm.

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:

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

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:

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

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 $ha^{-1}$).

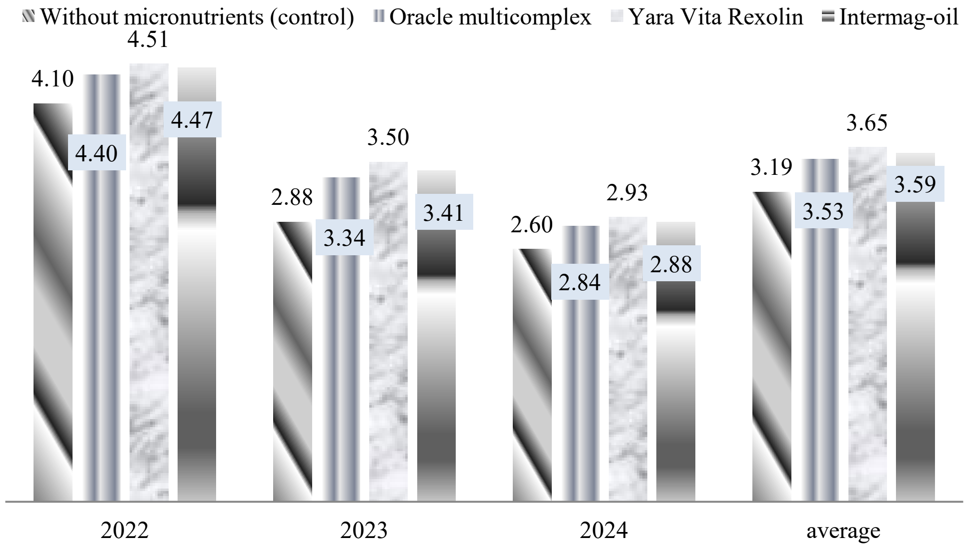


Figure 6. Seed yield of the Zhuravka oilseed radish variety depending on foliar application of micronutrients (2022–2024), t $ha^{-1}$.

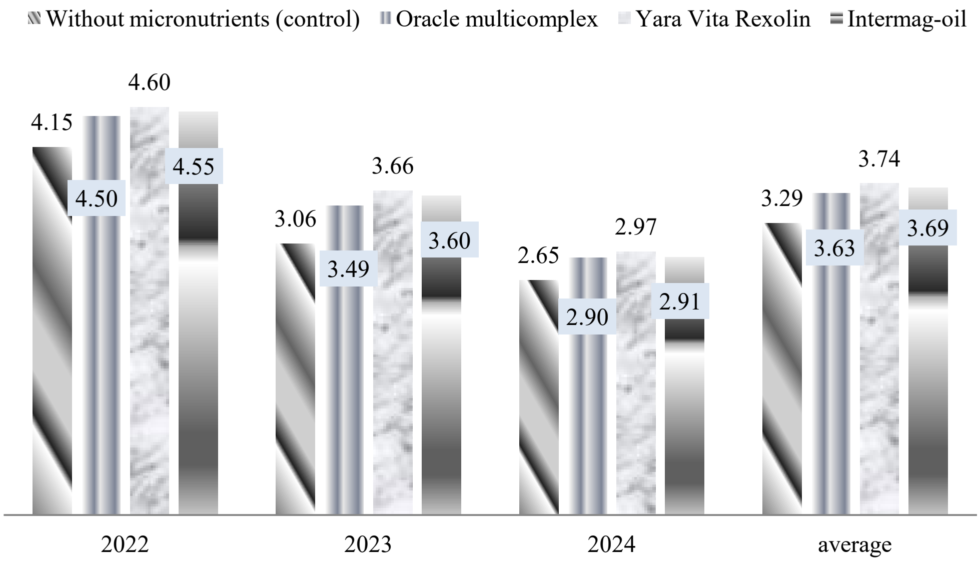


Figure 7. Seed yield of the Fakel oilseed radish variety depending on foliar application of micronutrients (2022–2024), t $ha^{-1}$.

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.

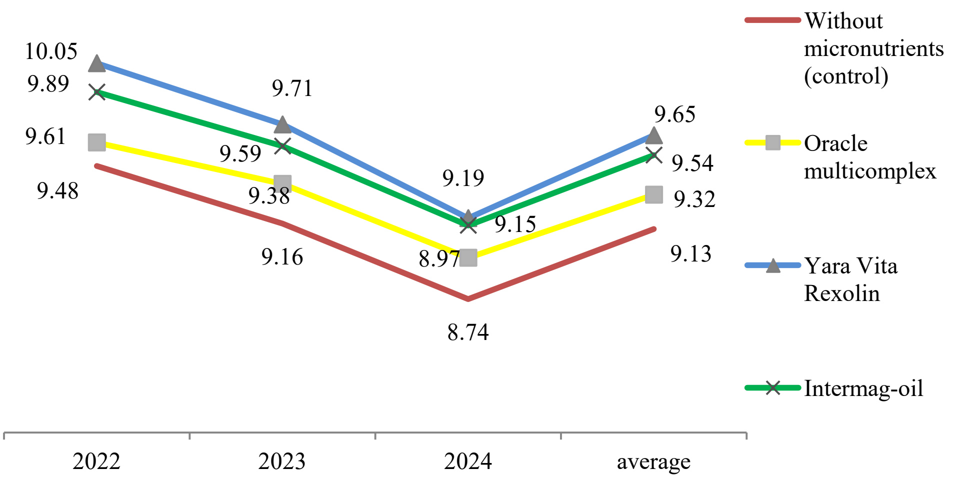


Figure 8. Thousand-seed weight of the Zhuravka oilseed radish variety depending on foliar application of micronutrients (2022–2024), g.

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$^{-1}$).

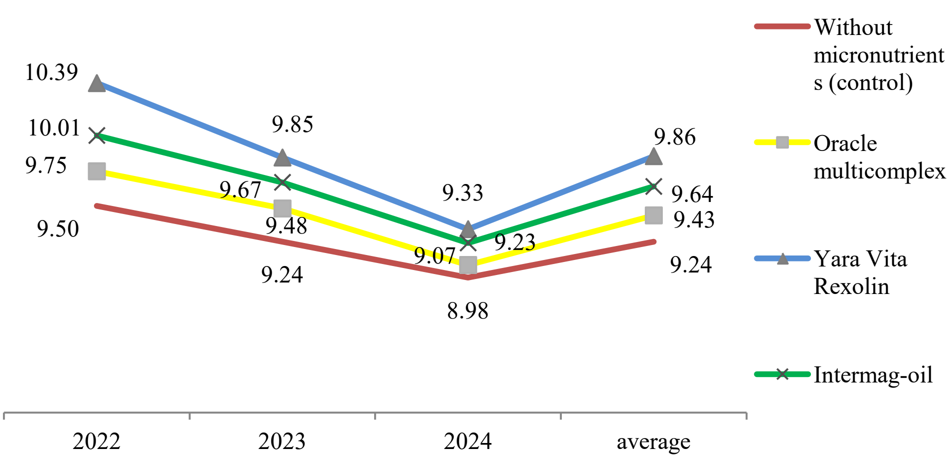


Figure 9. Thousand-seed weight of the Fakel oilseed radish variety depending on foliar application of micronutrients (2022–2024), g.

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).

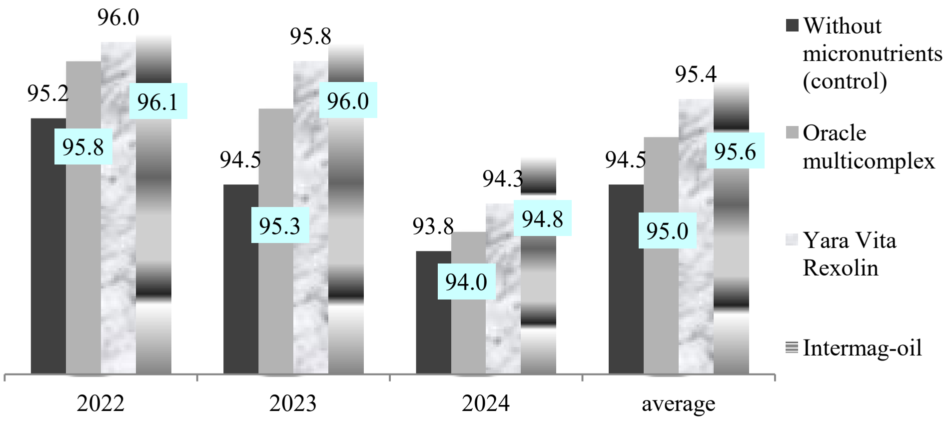


Figure 10. Laboratory germination of oil radish seed varieties depending on foliar micronutrient fertilization (average for varieties, 2022–2024), %.

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