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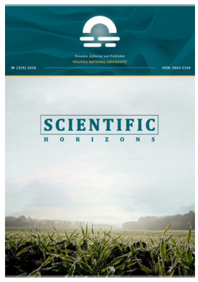

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Productivity of brown mustard plants depending on pre-sowing application of mineral fertilisers and foliar feeding

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Abstract. Brown mustard has a prominent genetic potential for seed productivity, which can be fulfilled by optimising the elements of cultivation technology, namely the nutrition system, which makes research relevant. The purpose of this study was to determine the complex effect of the combination of different variants for pre-sowing mineral feeding and foliar feeding with water-soluble fertilisers on the formation of productivity elements and biological yield of brown mustard seeds. Field, laboratory

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(for accounting for structural elements of the crop), and statistical (for mathematical processing of materials) research methods were used in the study. The study was conducted in 2020, 2021, and 2023 on the basis of the farm "KYRYCHENKO M" located in the central part of Borivskyi district of Kharkiv region. The experiment compared five variants of pre-sowing mineral feeding and five variants of foliar feeding with various combinations of water-soluble fertilisers. The largest number of seeds on the plant and the largest mass were in the variants of the combination of pre-sowing application of $N_{45}P_{45}K_{45}$ and carrying out two foliar feedings during microphases 21-23 and 50-53 with a mixture of carbamide and complex fertiliser Quantum technical – 627.3 pcs. and 1.97 g, respectively. However, these indicators did not significantly differ from the variant with a lower dose of pre-sowing fertilisers – $N_{45}P_{30}K_{30}$. Generally, according to the experiment, the highest biological yield of brown mustard seeds in an average of three years was in the variants of the combination of pre-sowing application of $N_{45}P_{45}K_{45}$ and $N_{45}P_{30}K_{30}$ with two foliar top dressings with different mixtures of fertilisers – 2.72-2.79 t/ha. Proceeding from this, the best variant in the experiment was the pre-sowing application of $N_{45}P_{30}K_{30}$ in combination with two foliar feedings during microphases 21-23 and 50-53 with a mixture of carbamide and the complex water-soluble fertiliser under study in single doses of 10 kg/ha and 2.0 l/ha, respectively. It was established that the highest biological yield of mustard seeds in all years was on the variants of pre-sowing application – $N_{45}P_{45}K_{45}$ and $N_{45}P_{30}K_{30}$. There was no significant difference between these variants by year. The findings of this study can be used by agricultural enterprises to adjust the nutrition system (pre-sowing application of complex fertilisers and foliar feeding), which will ensure a more complete fulfilment of the genetic potential of brown mustard productivity

Keywords: cultivation technology; brown mustard variety; nutrition system; mineral fertilisers; crop structure; biological seed yield; productivity; weather conditions

INTRODUCTION

The uncontrolled increase in sunflower acreage, the associated negative trends in soil degradation, and global warming are forcing us to reconsider the structure of our acreage and expand the acreage of crops that are, on the one hand, alternatives to sunflower and, on the other hand, adapted to modern climate change. Brown mustard is perhaps the best in this regard. An essential aspect of expanding the area under this crop is improving technological approaches to its cultivation. O. Zhuykov and T. Hodos (2021), along with the ability to form prominent seed yields, note the ability of mustard to tolerate prolonged droughts and hot temperatures more easily. According to A.N. Sivak and T.K. Kostyukevich (2021), these advantages are also added to by the growing demand for Ukrainian mustard abroad, especially in the EU. The average yield of mustard seeds in Ukraine is lower than in the leading EU countries, due to the insufficient fulfilment of the crop's genetic potential as a result of insufficient attention to the plant nutrition system. S.K. Verma *et al.* (2022) noted that only by optimising the nutrition system can the yield of mustard seeds be increased by 40% or more. This can be achieved by meeting the nutrient needs of plants during not only the initial stages, but the entire life cycle of plants. In this regard, S.S. Rathore *et al.* (2019) and R. Mondal *et al.* (2020) emphasise the expediency of foliar feeding, which makes it possible to promptly eliminate nutrient deficiencies and to offset the effects of abiotic and biotic stresses.

In Ukraine, research is constantly being conducted to improve the elements of mustard agronomy, including the nutrition system. I.J. Irin *et al.* (2020) and S.J. Butenko and J. PeiPei (2022) consider the nutrition system to be the main source of improving the fulfilment of the genetic potential of plant productivity and yield of mustard seeds. The development of best possible solutions based on a harmonious combination of various types of application of the entire line of mineral nutrients required for plants, from the main application to foliar feeding, will help obtain the actual possible yield, which will be limited solely by the weather conditions of the growing season. Among producers, there is a widespread erroneous practice of introducing the so-called "statistical average" norm of mineral fertilisers, which for most oil crops is $N_{40}P_{60}$. S.V. Zherdetska (2017) notes that such a primitive approach is the reason for the underutilisation of agricultural resources and insufficient fulfilment of the genetic potential of brown mustard crops.

Specialised scientific literature provides various suggestions for the use of mineral fertilisers in mustard cultivation, which usually differ fundamentally, making it difficult for producers to decide which variant is best for them. To a large extent, the advantage of a particular fertiliser application variant is related to its cost. Therefore, given the rapid rise in the price of fertilisers in recent years, the recommendations developed earlier are often outdated and do not reflect current economic realities. N. Nehal *et al.* (2017) and S.S. Dhaliwal *et al.* (2021) substantiate the feasibility of conducting research on optimising the nutrition system through the introduction of new varieties of brown mustard, which, differing in morpho-biological type, can respond differently to the use of nutrition elements and stimulant substances.

To increase the efficiency of nitrogen use, I.A. Shevchenko *et al.* (2017) recommend applying it in parts, including the application of foliar feeding. In their opinion, this method of nitrogen application is better utilised by plants and the return on investment will be higher than with a single application. Along with determining the best doses of pre-sowing feeding, A. Shahid (2018), R. Banerjee *et al*. (2019) emphasise the significance of finding ways to increase the yield of mustard seeds through foliar feeding, noting that it is the harmonious combination of various types of feeding that will help solve the problem of low yields of mustard seeds, increase the competitiveness of its cultivation, and therefore make it more attractive for production.

A wide range of both complex and mono-element water-soluble fertilisers makes it possible to provide nutrient mixtures that are suitable for plants based on their needs in a particular period. Furthermore, along with nutrients, if necessary, one can apply stimulant, growth-regulating, or anti-stress agents. Given the leading role of optimising the plant nutrition system, including the combination of its various components, including pre-sowing fertilisation and foliar feeding of crops during the growing season, research in this area is relevant today. Therefore, the purpose of this study was to find the best possible combinations of pre-sowing mineral fertilisation and foliar feeding with water-soluble complexes that ensure the formation of higher indicators of individual plant productivity and biological yield of brown mustard seeds.

MATERIALS AND METHODS

The study was conducted in 2020, 2021, and 2023 on the basis of the farm "KYRYCHENKO M" located in the southern part of Kharkiv region. The predecessor of mustard was winter wheat. After harvesting, the field was disked in two tracks. At the end of September, the field was ploughed to a depth of 22-25 cm. Brown mustard was sown after the soil was warmed up to 5-6°C at a depth of 6-8 cm with a seed drill SZD-360 V (Ukraine) to a depth of 2-3 cm.

After sowing, the field was sprayed with Tizer herbicide at a dose of 3.0 l/ha and rolled. At the phase of 4-5 leaves, the crops were sprayed with Galera herbicide at a dose of 0.3 l/ha against annual and perennial cereal weeds. The crops were harvested with a US-made combine harvester, the Case IH Axial-Flow 6130, which ensures high-quality harvesting of small-seeded crops. The plots of the first order (factor A) in the conducted two-factor experiment were five variants of pre-sowing application of mineral fertilisers (ammonium nitrate phosphate fertiliser and ammonium nitrate): 1 – control (without fertilisers); 2 – $N_{15}P_{15}K_{15}$; 3 – $N_{30}P_{30}K_{30}$; 4 – $N_{45}P_{45}K_{45}$; 5 – $N_{45}P_{30}K_{30}$. The second-order plots were five variants of foliar feeding (Table 1).

Table 1. *Scheme of the variants for foliar feeding under study (factor B)*

Variant	Phases of growth and development according to the international BBCH scale	
	21-23	50-53
1 (control)	–	–
2	Carbamide (10 kg/ha) + Quantum technical (2.0 l/ha)	–
3	Carbamide (10 kg/ha) + Quantum technical (2.0 l/ha)	Carbamide (10 kg/ha) + Quantum technical (2.0 l/ha)
4	Carbamide (10 kg/ha) + Quantum technical (2.0 l/ha) + Quantum BOR Active (1.0 l/ha)	Carbamide (10 kg/ha) + Quantum technical (2.0 l/ha)
5	Carbamide (10 kg/ha) + Quantum technical (2.0 l/ha)	Carbamide (10 kg/ha) + Quantum technical (2.0 l/ha) + Quantum BOR Active (1.0 l/ha)

Source*: compiled by the authors of this study*

The experiment was set up, observations, records, and analyses were carried out according to the generally accepted methodology (Ushkarenko *et al*., 2019). Statistical processing of the findings was carried out using the Statistica 6.0 and Excel 2003 software. Highly concentrated complex chelated fertiliser Quantum Technical from the Research and Production Company Kvadrat is designed for foliar feeding and pre-sowing treatment of technical crops. It has a high content of copper (11 g/l), zinc (12 g/l), and manganese (11.3 g/l). Additionally, it contains a complex of biologically active substances, has a slightly alkaline reaction (pH – 7.5-8.5).

The mono-element fertiliser Quantum Boron Active is made based on readily available biologically active forms of boron with a content of 140 g/l (14.0%). The product also contains amino acids (1.5%), which improve the absorption of boron by plant leaves, activate metabolism, and increase plant stress resistance. The study was conducted with a new variety of brown mustard, Felicia, created at the Carpathian State Agricultural Station of the National Academy of Agrarian Sciences. The variety was included in the State Register in 2018 and is recommended for cultivation in all agro-climatic zones of Ukraine.

The research area is characterised by unstable moisture conditions and a significant temperature difference. During the years of research, the amount of precipitation during the growing season significantly deviated from the long-term average. In March and April 2020, the amount of precipitation was significantly lower than the climate norm. In May, on the contrary, the amount of precipitation was more than twice the long-term average.

Due to significant precipitation in May, as well as in the first and second decades of June, there was sufficient moisture in the second half of the 2020 mustard growing season. The air temperature in May was significantly lower than the long-term average, which complicated the growth processes of brown mustard.

In 2021, the supply of moisture to mustard plants during the growing season was sufficient. The distribution of precipitation was more balanced than in the previous year. The temperature conditions were similar to 2020. In the third decade of June, the air temperature reached 32°C, which worsened the course of growth processes at the end of the mustard growing season. The most favourable weather conditions for the growth and development of mustard plants were in 2023, which was reflected in the seed yields. In April, May, June, and the first ten days of July, there was more precipitation than the long-term average, and its distribution was even. The air temperature during the growing season met the biological needs of the crop and was virtually on par with the long-term average. On the warmest days of the summer period, it did not exceed 28.0°C. Generally, different temperature conditions and divergence in the amount of precipitation and its distribution during the spring and summer vegetation of mustard crops significantly affected the ontogeny of plants, which considerably affected their productivity. At the same time, this helped to investigate the effect of the variants of the nutrition system under study on the elements of plant productivity and biological yield of brown mustard seeds in greater depth.

Experimental studies of plants (both cultivated and wild), including the collection of plant material, were following the institutional, national, or international guidelines. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

Elements of mustard plant productivity underwent greater changes under the influence of pre-sowing mineral fertilisation. The number of pods on a plant, the number of seeds in a pod and on one plant were the largest in the variants of pre-sowing application of ammonium nitrate phosphate fertiliser in the dose of $N_{45}P_{45}K_{45}$ – 55.6 pcs., 11.0 pcs., and 614.1 pcs., respectively (Table 2). Compared to the control, the increase in performance was 11.2%, 15.8%, and 28.3%, respectively. The number of seeds per plant changed significantly, which is logical since pre-sowing fertilisation contributed to the formation of more pods and the number of seeds in them.

Table 2. *Elements of mustard plant productivity under different variants of pre-sowing application of complex fertilisers and foliar feeding (average for 2020, 2021, 2023)*

Pre-sowing application (factor A)	Variants of fertilisers (factor B)	Quantity			Seed weight per plant, g
		pods per plant, pcs.	seeds per pod, pcs.	seeds per plant, pcs.	
Control (without fertilisers)	1	49.2	9.0	442.5	1.24
	2	50.2	9.5	478.9	1.37
	3	50.2	9.8	494.4	1.46
	4	50.4	9.7	487.6	1.43
	5	50.2	9.7	489.7	1.45
$N_{15}P_{15}K_{15}$	1	52.5	9.7	510.2	1.50
	2	53.4	10.1	540.1	1.61
	3	53.9	10.2	549.3	1.66
	4	53.9	10.1	550.0	1.67
	5	54.0	10.2	551.4	1.68
$N_{30}P_{30}K_{30}$	1	53.9	10.2	552.7	1.66
	2	54.4	10.6	578.8	1.76
	3	54.3	10.7	580.9	1.80
	4	54.4	10.6	576.1	1.79
	5	54.6	10.7	587.0	1.82
$N_{45}P_{45}K_{45}$	1	55.2	10.7	591.2	1.80
	2	55.5	11.0	611.4	1.89
	3	55.9	11.2	627.3	1.97
	4	55.7	11.1	620.6	1.95
	5	55.9	11.1	619.9	1.94
$N_{45}P_{30}K_{30}$	1	55.1	10.5	581.1	1.77
	2	55.7	10.9	609.4	1.87
	3	55.6	11.0	615.2	1.91
	4	55.6	11.1	619.0	1.92
	5	55.7	11.0	615.8	1.92

Pre-sowing application (factor A)	Variants of fertilisers (factor B)	Quantity			Seed weight per plant, g
		pods per plant, pcs.	seeds per pod, pcs.	seeds per plant, pcs.	
Average by factor A	control	50.0	9.5	478.6	1.39
	$N_{15}P_{15}K_{15}$	53.5	10.1	540.2	1.62
	$N_{30}P_{30}K_{30}$	54.3	10.6	575.1	1.77
	$N_{45}P_{45}K_{45}$	55.6	11.0	614.1	1.91
	$N_{45}P_{30}K_{30}$	55.5	10.9	608.1	1.88
Average by factor B	1	53.2	10.0	535.5	1.59
	2	53.8	10.4	563.7	1.70
	3	54.0	10.6	573.4	1.76
	4	54.0	10.5	570.7	1.75
	5	54.1	10.5	572.8	1.76
LSD_{05} of the effect A*		1.7-2.7	0.3-0.5	16.2-24.2	0.04-0.07
LSD_{05} of the effect B		1.9-2.7	0.3-0.6	17.5-26.5	0.06-0.07
LSD_{05} of partial comparisons A		2.4-3.0	0.5-0.7	19.1-27.3	0.07-0.09
LSD_{05} of partial comparisons B		2.5-3.1	0.6-0.8	19.3-27.7	0.08-0.11

Note: **LSD is the least significant difference*
Source: *compiled by the authors*

The analysis of the quantitative elements of the productivity of mustard plants did not show a significant difference between the variants of pre-sowing application of $N_{45}P_{45}K_{45}$ and $N_{45}P_{30}K_{30}$. With the same dose of nitrogen, but a lower dose of phosphorus and potassium, the number of seeds per plant decreased by only 6 pcs., which is significantly less than the LSD_{05} indicator, which over the years was 16.2-24.2 pcs. Among the variants of foliar feeding under study, the formation of the largest number of seeds per plant was ensured by the variant of two foliar feedings during microphases 21-23 and 50-53 on the international BBCH scale with a mixture of carbamide (10 kg/ha) and complex fertiliser Quantum Technical (2.0 l/ha). On average, the number of seeds in this variant was 573.4 pcs., which is 37.9 pcs. or 7.1% more than in the control. The addition of mono-elemental fertiliser Quantum Boron Active to the working mixtures did not have a positive effect on increasing the number of seeds per plant.

The formation of a greater number of seeds per plant in the variants of foliar feeding was conditioned by the greater number of seeds in the pod. The number of pods per plant did not change significantly under their influence. Under the influence of pre-sowing fertilisation, other patterns were observed, namely, they contributed to a significant increase in both the number of pods per plant and the number of seeds per pod. Therewith, their impact on these structural indicators was comparable. For instance, the number of pods and seeds in a pod increased by 10-12% in the $N_{45}P_{45}K_{45}$ applications compared to the control.

By analogy with the number of seeds on one plant, their mass was the largest in the variants of pre-sowing application of $N_{45}P_{45}K_{45}$ and $N_{45}P_{30}K_{30}$. On average, the weight of seeds on these variants of foliar feeding was 1.91 g and 1.88 g, which is 0.52 g (37.4%) and 0.49 g (35.3%) more than in the control. The difference between the weight of seeds of one plant under the influence of foliar feeding was much smaller. As well as the number of seeds per plant, the weight of seeds per plant was highest in the variant with two foliar applications of a mixture of carbamide and Quantum Technical fertiliser. In this variant, it was 1.76 g, which is 0.17 g (10.7%) more than in the control. The addition of Quantum Boron Active fertiliser (fourth and fifth variants of factor B) to the working mixtures did not increase the weight of seeds per plant. Generally, according to the experiment, the largest mass of seeds of one plant was in the variant of pre-sowing application of $N_{45}P_{45}K_{45}$ and carrying out two foliar fertilising with a mixture of carbamide and Quantum Technical fertilisers – 1.97 g. However, according to the statistical analysis, it did not significantly differ from the variant with a lower dose of pre-sowing fertilisers – $N_{45}P_{30}K_{30}$ in combination with the same variant of foliar feeding. The factors under study caused significant changes in the biological yield of mustard seeds, and their influence on this indicator was higher than on the analysed elements of plant productivity, due to the positive effect of pre-sowing fertilisation and foliar feeding on the preservation of more plants to the full ripeness phase.

Factor A had a much greater influence on the change in the biological yield of mustard seeds. The highest biological yield of seeds on average by year and variant of foliar feeding was in the variant of pre-sowing application of $N_{45}P_{45}K_{45}$ – 2.71 t/ha, which is 0.86 t/ha or 46.5% more than in the control (Table 3). Therewith, it did not significantly differ from the variant of pre-sowing application of $N_{45}P_{30}K_{30}$. The difference between these variants was only 0.05 t/ha, and according to the statistical analysis using the ranking of the results, the biological yield of seeds on these variants was within the same rank group. The effect of foliar feeding on the biological yield of seeds was much less. The largest difference between the indicators under their influence was 0.27 t/ha or 12.3%. All variants of foliar feeding provided a significant increase in the biological yield of seeds compared to the control. Furthermore, high efficiency of feeding during microphases 50-53 was proved, since the biological yield in variants with two instances of foliar feeding was higher compared to the variant where only one feeding was carried out during microphases 21-23.

Table 3. *Biological yield of mustard seeds depending on pre-sowing application of complex fertilisers and foliar feeding, t/ha (average for 2020, 2021, 2023)*

Pre-sowing application (factor A)	Foliar fertilisation (factor B)	Biological yield, t/ha		+/- to control factor A	+/- to control factor B
		indicator	RG*		
Control (without fertilisers)	1	1.61	I	–	–
	2	1.80	II	–	+0.19
	3	1.95	III	–	+0.34
	4	1.93	II	–	+0.32
	5	1.96	III	–	+0.35
$N_{15}P_{15}K_{15}$	1	2.01	I	+0.40	–
	2	2.20	II	+0.40	+0.19
	3	2.29	III	+0.34	+0.28
	4	2.30	III	+0.37	+0.29
	5	2.31	III	+0.35	+0.30
$N_{30}P_{30}K_{30}$	1	2.30	I	+0.69	–
	2	2.46	II	+0.66	+0.16
	3	2.52	III	+0.57	+0.22
	4	2.51	III	+0.58	+0.21
	5	2.54	III	+0.58	+0.24
$N_{45}P_{45}K_{45}$	1	2.53	I	+0.92	–
	2	2.68	I	+0.88	+0.15
	3	2.79	II	+0.84	+0.26
	4	2.77	II	+0.84	+0.24
	5	2.76	II	+0.80	+0.23
$N_{45}P_{30}K_{30}$	1	2.49	I	+0.88	–
	2	2.64	I	+0.84	+0.15
	3	2.73	II	+0.78	+0.24
	4	2.73	II	+0.80	+0.24
	5	2.73	II	+0.77	+0.24
Average by factor A	control	1.85	I	–	–
	$N_{15}P_{15}K_{15}$	2.22	II	+0.37	–
	$N_{30}P_{30}K_{30}$	2.47	III	+0.62	–
	$N_{45}P_{45}K_{45}$	2.71	IV	+0.86	–
	$N_{45}P_{30}K_{30}$	2.66	IV	+0.81	–
Average by factor B	1	2.19	I	–	–
	2	2.36	II	–	+0.17
	3	2.45	III	–	+0.26
	4	2.45	III	–	+0.26
	5	2.46	III	–	+0.27

Note: **RG – rank groups*
Source: *compiled by the authors*

There was virtually no difference between the variants for carrying out two instances of foliar feeding with different mixtures of water-soluble fertilisers, which indicates that it is inexpedient to incur additional costs for the purchase and application of the mono-elemental fertiliser Quantum Boron Active. Generally, according to the experiment, the highest biological yield of brown mustard seeds in an average of three years (2.72-2.79 t/ha) was formed in the variants of the combination of pre-sowing application of $N_{45}P_{45}K_{45}$ and $N_{45}P_{30}K_{30}$ with two instances of foliar feeding with different mixtures of fertilisers. Proceeding from this, the variant of pre-sowing application of $N_{45}P_{30}K_{30}$ in combination with two instances of foliar feeding is best in the experiment. Increasing the dose of pre-sowing mineral fertilisers, as well as including the mono-elemental fertiliser Quantum Boron Active in tank mixtures, did not provide a significant increase in the biological yield of seeds, while growing costs increased significantly. The biological yield of mustard seeds underwent significant changes under the influence of weather conditions. Favourable temperature conditions, sufficient precipitation, and their uniform distribution during the vegetation of mustard plants in 2023 contributed to a higher biological yield of seeds. Specifically, on average, the biological yield of mustard seeds in 2020, 2021, and 2023 was 1.99 t/ha, 2.43 t/ha, and 2.71 t/ha, respectively (Table 4).

Table 4. *Biological yield of brown mustard seeds under different variants of pre-sowing application of complex fertilisers and foliar feeding, t/ha*

Pre-sowing application (factor A)	Foliar fertilisation (factor B)	Year					
		2020		2021		2023	
		BY*	RG**	BY	RG	BY	RG
Control (without fertilisers)	1	1.36	I	1.65	I	1.81	I
	2	1.48	II	1.90	II	2.03	II
	3	1.60	III	2.06	III	2.20	III
	4	1.60	III	1.99	II	2.19	III
	5	1.59	III	2.05	III	2.24	III
$N_{15}P_{15}K_{15}$	1	1.71	I	2.04	I	2.29	I
	2	1.82	I	2.23	II	2.56	II
	3	1.91	II	2.34	III	2.61	II
	4	1.90	II	2.30	II	2.70	III
	5	1.92	II	2.38	III	2.63	II
$N_{30}P_{30}K_{30}$	1	1.92	I	2.36	I	2.61	I
	2	2.09	II	2.53	II	2.76	II
	3	2.13	II	2.54	II	2.89	III
	4	2.13	II	2.55	II	2.84	III
	5	2.14	II	2.55	II	2.93	III
$N_{45}P_{45}K_{45}$	1	2.17	I	2.56	I	2.86	I
	2	2.28	I	2.69	I	3.06	II
	3	2.33	II	2.82	II	3.23	III
	4	2.36	II	2.82	II	3.13	II
	5	2.33	II	2.76	II	3.17	III
$N_{45}P_{30}K_{30}$	1	2.14	I	2.56	I	2.76	I
	2	2.24	I	2.75	II	2.93	II
	3	2.25	I	2.75	II	3.15	III
	4	2.23	I	2.76	II	3.20	III
	5	2.30	II	2.74	II	3.14	III
Average by factor *A*	control	1.53	I	1.93	I	2.09	I
	$N_{15}P_{15}K_{15}$	1.85	II	2.26	II	2.56	II
	$N_{30}P_{30}K_{30}$	2.08	III	2.51	III	2.81	III
	$N_{45}P_{45}K_{45}$	2.29	IV	2.73	IV	3.09	IV
	$N_{45}P_{30}K_{30}$	2.23	IV	2.71	IV	3.04	IV
Average by factor B	1	1.86	I	2.23	I	2.47	I
	2	1.98	II	2.42	II	2.67	II
	3	2.04	II	2.50	II	2.82	III
	4	2.04	II	2.48	II	2.81	III
	5	2.06	II	2.50	II	2.82	III
Mean		1.99		2.43		2.71	
LSD_{05} of the main effect A		0.07		0.08		0.09	
LSD_{05} of the main effect B		0.09		0.08		0.11	
LSD_{05} of the partial comparisons of the effect of A		0.11		0.12		0.14	
LSD_{05} of the partial comparisons of the effect of B		0.13		0.13		0.16	

Notes: ** BY – biological yield, t/ha; **RG – rank group*
Source*: compiled by the authors*

In all years, the biological yield of mustard seeds was more affected by the influence of pre-sowing fertilisation. Their impact was slightly higher in the less favourable weather conditions of 2020. Specifically, this year's pre-sowing application of mineral fertilisers ensured a maximum increase in the biological yield of mustard seeds by 48%, compared to 41.5% and 47.8% in 2021 and 2023, respectively. Thus, weather conditions made certain adjustments to the effectiveness of pre-sowing fertilisation, while the general pattern of effectiveness of the compared variants was maintained. The highest biological yield of mustard seeds in all years was in the fourth and fifth variants of pre-sowing application of mineral fertilisers – $N_{45}P_{45}K_{45}$ and $N_{45}P_{30}K_{30}$. There was no significant difference established between these variants by year.

In contrast to pre-sowing mineral feeding, the effect of foliar feeding on changes in the biological yield of mustard seeds varied over the years. In less favourable weather conditions of the 2020 and 2021 growing seasons, all variants of foliar feeding contributed to a significant increase in the biological yield of seeds compared to the control variant, with no difference between them. That is, the second foliar feeding during 50-53 microphases with different mixtures of water-soluble fertilisers did not increase the biological yield of seeds compared to the variant of a single foliar feeding during microphases 21-23. Under more favourable conditions in 2023, the second foliar application provided a significant increase in the biological yield of seeds. According to the authors, this is logical, as this year's weather conditions "enabled" plants to fulfil their potential to a greater extent, and in such conditions the role of optimising the plant nutrition system is increasing, which is why the additional introduction of a complex of micro- and macroelements at the beginning of budding (microphases 50-53) enables plants to fulfil their potential significantly better.

The findings of the conducted study show that the productivity of brown mustard plants and their biological seed yield largely depend on the nutrition system. Among the components of the plant nutrition system, the key factor was the pre-sowing application of mineral fertilisers. While noting the crucial role of the main, pre-sowing, and seedbed fertiliser application in mustard cultivation, the opinions of scientists differ significantly on the issue of fertiliser application rates. This is logical, because the fertiliser application rate is adjusted by a range of factors, the main one being the agro-climatic potential of the growing area. In this regard, M.I. Blaschuk and N.M. Tetereshenk o (2017) recommend determining the doses of their application based on the planned yield, soil fertility, and predecessor. Depending on these components, they outline the range of application rates of mineral fertilisers from $N_{40}P_{40}K_{40}$ to $N_{80}P_{60}K_{80}$. Therewith, there are recommendations that go beyond this range. Most fertiliser application rate recommendations fall within this range, but there are recommendations that go beyond it. Specifically, the pre-sowing application of $N_{45}P_{30}K_{30}$ was the best variant in the experiment. Therefore, the dose of phosphorus and potassium was outside this range. An analogous recommendation is provided by A.V. Melnyk *et al.* (2019), who prefer pre-sowing application of $N_{30}P_{30}K_{30}$ when growing brown mustard of Prima and Retro varieties. Therewith, there is a rationale for pre-sowing fertilisation that, on the contrary, exceeds this range. Specifically, in the experiments conducted by A. Sarkar *et al.* (2021) on the Ganges soils of West Bengal, the highest increases in mustard seed yields were formed against the background of pre-sowing N_{100}. While investigating different doses of pre-sowing fertiliser in Indonesia, B. Utomo (2022) found that the highest indicators of plant productivity and yield of brown mustard seeds are formed with doses of fertilisers $N_{115}P_{115}K_{115}$.

No less controversial are the issues of foliar feeding. Varying opinions are expressed regarding the phases of application, types of fertilisers, and their combinations. K. Rana *et al.* (2020) note the higher efficiency of foliar feeding on high backgrounds. The findings of the present study do not agree with this opinion, as the effectiveness of foliar feeding was highest in the variants where no fertiliser was applied. V.F. Sayko and V.S. Vishnevsky (2015) note the high efficiency of foliar feeding during the budding phase, explaining this by decreasing the reduction of the inherent generative components. These data are generally consistent with the findings of the present study, since according to the average three-year data, the second foliar application with a mixture of the fertilisers under study provided a considerable increase in the biological yield of seeds, but various patterns were observed in terms of years. Specifically, in the less favourable weather conditions of 2020 and 2021, the second fertilisation (at the beginning of budding) did not significantly increase seed yields. Therefore, the effectiveness of foliar feeding depends on the weather conditions of the year.

Generally, all researchers note the significance of such components of the nutrition system as pre-sowing fertilisation and foliar feeding. Therewith, there is a wide range of proposals for pre-sowing doses, phases, and tank mixtures for foliar application, which is due to the different growth and development conditions of mustard plants. Therefore, these issues require further investigation, especially as the market for pre-sowing and foliar fertilisers is constantly being updated with new, more effective products.

CONCLUSIONS

The findings of the conducted study strongly suggest the following conclusions: indicators of the elements of productivity of brown mustard plants of the Felicia variety were the highest in the variants of pre-sowing application of $N_{45}P_{30}K_{30}$ and $N_{45}P_{45}K_{45}$ in combination with two instances of foliar feeding during microphases 21-23 and 50-53 according to the international scale with a mixture of carbamide and complex fertiliser Quantum Technical in a single dose of 10 kg/ha and 2.0 l/ha, respectively. The addition of mono-element water-soluble fertiliser Quantum Boron Active to the working solution during foliar application did not increase either plant productivity elements or biological yield of mustard seeds.

The highest biological yield of mustard seeds in the experiment – 2.79 t/ha, was formed in the variant of the combination of pre-sowing application of $N_{45}P_{45}K_{45}$ and carrying out two instances of foliar dressing with a mixture of carbamide (10 kg/ha) and complex water-soluble fertiliser Quantum Technical (2.0 l/ha). Therewith, when reducing the dose of fertilisers in pre-sowing application to $N_{45}P_{30}K_{30}$ in combination with the same variant of foliar feeding, the biological yield of seeds did not decrease significantly, which strongly suggests the impracticality of increasing the dose of pre-sowing application of phosphorus and potassium from 30 kg/ha to 45 kg/ha in the active substance. Considering the wide range of fertilisers and their constant replenishment, different requirements and specifics of varieties, as well as significant fluctuations in fertiliser prices, it is advisable to continue research into optimising the nutritional regime of brown mustard, as a more in-depth study of this issue will help to increase its yield and competitiveness, and thus expand the area under cultivation.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Продуктивність рослин гірчиці сизої залежно від передпосівного внесення мінеральних добрив і позакореневих підживлень

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Анотація. Гірчиця сиза має високий генетичний потенціал насіннєвої продуктивності, реалізували який можна шляхом оптимізації елементів технології вирощування, зокрема системи живлення, що обумовлює актуальність досліджень. Мета досліджень полягала у визначенні комплексного впливу поєднання різних варіантів передпосівного внесення мінеральних добрив і позакореневих підживлень водорозчинними добривами на формування елементів продуктивності та біологічну врожайність насіння гірчиці сизої. Під час досліджень використовували польовий, лабораторний (для обліку структурних елементів урожаю) та статистичний (для математичної обробки матеріалів) методи досліджень. Дослідження проводили в 2020, 2021 і 2023 рр. на базі фермерського господарства «КИРИЧЕНКО М» розташованого в центральній частині Борівського району Харківської області. У досліді порівнювали п'ять варіантів передпосівного внесення мінеральних добрив і п'ять варіантів позакореневих підживлень різними сполученнями водорозчинних добрив. Найбільша кількість насінин на рослині і найбільша їх маса була у варіантах поєднання передпосівного внесення $N_{45}P_{45}K_{45}$ і проведення двох позакореневих підживлень під час мікрофаз 21-23 і 50-53 сумішшю карбаміду і комплексного добрива Квантум технічні – 627,3 шт. і 1,97 г відповідно. Проте, ці показники істотно не відрізнялися від варіанту з меншою дозою передпосівного внесення добрив – $N_{45}P_{30}K_{30}$. У цілому по досліду найвища біологічна врожайність насіння гірчиці сизої в середньому за три роки була у варіантах поєднання передпосівного внесення $N_{45}P_{45}K_{45}$ і $N_{45}P_{30}K_{30}$ з двома позакореневими підживленнями різними сумішами добрив – 2,72-2,79 т/га. Виходячи з цього, оптимальним у досліді є варіант передпосівного внесення $N_{45}P_{30}K_{30}$ у поєднанні з проведенням двох позакореневих підживлень під час мікрофаз 21-23 і 50-53 сумішшю сечовини і досліджуваного комплексного водорозчинного добрива в разових дозах 10 кг/га і 2,0 л/га відповідно. Встановлено, що найвища біологічна врожайність насіння гірчиці в усі роки була на варіантах передпосівного внесення – $N_{45}P_{45}K_{45}$ і $N_{45}P_{30}K_{30}$. При цьому істотної різниці між цими варіантами по роках не було. Результати досліджень можуть бути використані аграрними підприємствами для корегування системи живлення (передпосівного внесення комплексних добрив і позакореневих підживлень), що забезпечить більш повну реалізацію генетичного потенціалу продуктивності гірчиці сизої

Ключові слова: технологія вирощування; сорт гірчиці сизої; система живлення; мінеральні добрива; структура врожаю; біологічна врожайність насіння; продуктивність; погодні умови