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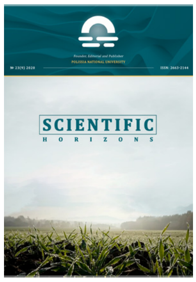

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Influence of biological products on the productivity of high oleic sunflower hybrids

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Abstract. The study's objective was to evaluate the efficacy of biological substances in enhancing the growth, development, and productivity of high-oleic sunflower hybrids, aiming to increase seed yields and improve oil quality. An investigation was carried out in the Mykolaiv region throughout 2021-2023 to assess the efficacy of seven different foliar feeding methods in producing five high-oleic sunflower hybrids. The findings indicated that the application of foliar feeding had a beneficial impact on the measured variables, such as plant height, leaf area, seed count per boll, seed yield, and oil and oleic acid concentration in seeds. In particular, the P64HE133 hybrid demonstrated the highest average yield of 3.89 t/ha, followed by Columbi with 3.69 t/ha, with no statistically significant difference between them. Foliar application of Organic-Balance helped to increase the average seed yield to 3.58 t/ha, exceeding the results of other types of spraying. The use of biological products contributed to an increase in yield by

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0.21-0.4 t/ha compared to control, as well as an increase in oil content by 0.6-2.1-5.3%. The overall impact of the combination of hybrid and foliar feeding methods on yield was the largest, amounting to 63.5%, where the impact of hybrid selection was 27.4%, foliar feeding – was 5.4%, and other factors had an impact of 3.7%. The findings suggest that the use of foliar feeding can significantly enhance productivity and enhance the quality attributes of sunflower seeds. The utilisation of these biological substances not only enhances seed production and oil content but also promotes more sustainable and robust plant development. Accordingly, the integration of such methods into agronomic practices can significantly improve crop productivity and increase the economic benefits of growing high-yielding sunflower hybrids

Keywords: fertilisation; yield; hybrids; oleic acid; biological products

INTRODUCTION

Modern agriculture is facing challenges related to climate change, preserving soil fertility, reducing the use of chemical fertilisers and pesticides, and ensuring sustainable agricultural production. The use of biopreparations containing natural microorganisms can improve plant and soil health, increase plant adaptability to stressful conditions and increase the content of oleic acid in seeds, which together will contribute to higher commercial yields of these crops.

Sunflower (*Helianthus annuus L.*) is among the four primary oilseeds of worldwide significance, alongside soybean, palm, and rapeseed (Kovalenko *et al.* 2021). The use of foliar fertilisers and growth regulators has significant potential for developing the biological capabilities of plants. As noted by Y. Domaratskiy *et al.* (2023), foliar fertilisation acts as a complementary method to root fertilisation, offering in some cases a more cost-effective and efficient solution. This method ensures that nutrients are instantly absorbed and distributed within the plants through the leaves, quickly eliminating nutritional deficiencies. The studies emphasise the importance of sunflower as one of the key oilseeds and the potential of biological products in its cultivation, some gaps have not yet been fully covered in the scientific literature. There has been limited investigation on the effects of foliar feeding on the soil microbiota and plant health. Furthermore, there is a dearth of evidence regarding the effects of these fertilisers on various sunflower cultivars, especially those that have a significant concentration of oleic acid or omega-6 carbohydrates.

High-oleic sunflower hybrids stand out among other oilseeds due to their higher oleic acid content, which exceeds 90% (Malik *et al.*, 2024). According to O. Kovalenko *et al.* (2024) and O. Yeremenko *et al.* (2023), these hybrids are characterised by increased resistance to oxidation, which reduces the risk of toxic compounds during processing, storage or use. From a nutritional point of view, the most valuable oils are those with a high content of oleic acid (up to 70%) and a low content of linoleic acid (up to 20%). Thus, modern sunflower breeding is focused on adjusting the ratio of fatty acids to create oils and fats that are highly stable and efficient. The sunflower breeding goals are focused on creating hybrids with yields of more than 5 t/ha and oil content of more than 50%, which underlines the growth of the planned development and quality requirements for this crop. Following Y.M. Hadzalo *et al.* (2023) and Y. Domaratskiy *et al.* (2022), even with the recognised potential of sunflower, environmental factors remain a significant constraint to achieving maximum yields, which currently range between 1.5 and 3 t/ha. They stressed the need for breeders to prioritise overcoming or reducing the impact of negative environmental conditions to ensure yields of 4 t/ha or higher.

Foliar nutrition is also recommended for integrated crop protection, as it not only increases yields and improves product quality, but is also an environmentally friendly way of feeding, reducing the environmental impact associated with fertiliser applied to the soil (Lopushnyak *et al.*, 2022). This is made possible by precise dosing of nutrients directly to the plant, limiting their overuse and minimising the environmental impact (Poltoretskyi *et al.*, 2020; Tsyliuryk *et al.*, 2021). Plant growth regulators (PGRs) are a heterogeneous collection of chemical substances capable of stimulating, inhibiting, or influencing physiological and morphological processes in plants. According to S. Vdovenko *et al.* (2024), the use of PGR for controlling sunflower development has already proven to be effective in counteracting the negative impact of stressful conditions on crop productivity, as noted in the study. Although their research indicates the effectiveness of PGR in increasing crop adaptation to stressful conditions, there is room for further development of this topic. Specifically, the long-term effects of the use of PGRs on the soil microbiome and environmental safety remain insufficiently investigated (Dehtiarova, 2023). It is also worth addressing the potential development of plant resistance to PGR over time, as well as considering the impact of excessive use of PGR on non-target species, which can lead to ecological imbalances.

Therefore, this study aimed to assess the influence of biological substances on the yield and characteristics of sunflower seeds with high oleic content in the Southern Steppe environment of Ukraine. This work aimed to assess the influence of different biological chemicals on the seed development of high-oleic sunflower hybrids and to examine how these chemicals contribute to the concentration of oleic acid in the liquid extracted from the seeds.

MATERIALS AND METHODS

This study was conducted experimentally at the Educational and Research Centre of Mykolaiv National Agrarian University between 2021 and 2023. The experimental plots consist of soil characterised by southern chernozem, low-power, slightly saline, and predominantly loamy deposits found in woodlands. The pH of the soil solution was within the range of 6.8-7.2, indicating a neutral reaction. Humus concentration in the 0-30 cm layer ranged from 123 to 125 gkg^{-1} (Drobitko *et al*., 2023). The average composition of the topsoil included nitrates, which are created via the complexation of nitrates with disulfophenolic acid, resulting in the formation of trinitrophenol. Upon exposure to an alkaline environment, it produces potassium trinitrophenolate (or sodium trinitrophenolate, depending on the alkali employed) in a proportion that matches the nitrate concentration, resulting in a yellow hue. The extraction of mobile phosphorus and potassium compounds from the soil using a 1% ammonium carbonate solution with a pH of 9 at a temperature of 25 ± 20°C yields a mobile phosphorus concentration of 15-25 mg/kg^{-1}. 41-46 mg/kg^{-1}, exchangeable potassium (measured with a flame photometer). The range is 389-425 mg/kg^{-1} of soil. Located in the southern Steppe subzone of Ukraine, the experimental plot area is classified under the third agroclimatic region (Panfilova *et al*., 2019; 2023). The experimental design comprised the subsequent alternatives (Table 1):

***Table 1**. Scheme of the experiment*

Factor A – hybrids	Factor B (foliar feeding with biological products)
1. NK Ferty	1. Control (water treatment)
2. Mas 86.OL	2. Sclerocide (1 l/ha)
3. Columbi	3. Azotophyt-p (0.5 l/ha)
4. LG 5452 HO KL	4. Organic balance (0.5 l/ha)
5. P64HE133	5. Sclerocide (1 l/ha) + Helprost-Bor (1 l/ha)
	6. Azotophyt-p (0.5 l/ha) + Helprost-Bor (1 l/ha)
	7. Organic-Balance (0.5 l/ha) + Helprost-Bor (1 l/ha)

***Source:** compiled by the authors*

The plants underwent two treatments with the specific biological compounds under investigation. The first treatment occurred during the stage of 5-6 pairs of leaves, while the second treatment took place during the budding phase. Seed sowing of the examined hybrids was conducted at a soil temperature ranging from 8 to 10°C. Harvesting took place during the third decade of September in the specified years of study. The origin of hybrids is as follows: "NK Ferty" (Syngenta, France); "Mas 86.OL" (MAS Seeds, France); "Columbi" (Limagrain, France); "LG 5452 HO KL" (Limagrain, France); "P64HE133" (Pioneer, USA). The study was organised in a randomised design with four replications in each plot of 25 m^2. The planting density is 50 thousand plants/ha, with a row spacing of 70 centimetres. Generally, the appropriate fertiliser rates and agronomic procedures for sunflower production were established.

To study the growth and development of terrestrial plants, measurements and analyses were conducted using the following techniques: the height of the plants and the dimensions of the seventh leaf (its breadth and length) were evaluated immediately before the onset of pollenation. For this purpose, five typical plants marked with labels were selected from the two central rows. The leaf area was determined according to the method described by S.O. Tkachyk *et al*. (2016). Harvesting was carried out manually at full ripeness. All measurements and observations were made following the field research methodology of S.O. Tkachyk *et al.* (2016). The oil and oleic acid content of the seeds was determined using magnetic resonance techniques from Spinlock Magnetic Resonance Solutions.

RESULTS

A three-year field trial evaluated the growth characteristics of five sunflower hybrids with a high oleic acid content. The analysis of plant height showed that the hybrid "P64HE133" had the highest average height, which was 178.93 cm. This result may indicate the high adaptability of this hybrid to growing conditions and its potential to form a productive leaf surface for efficient photosynthesis. A slightly lower average height was demonstrated by the Columbi hybrid, which is 176.79 cm, which also indicates its high phenotypic qualities and adaptability. At the same time, the NK Ferty hybrid with an average height of 175.88 cm was ranked third among the tested variants, emphasising its potential for creating optimal conditions for development. Next on the list are the hybrids "Mas 86.OL" and "LG 5452 HO KL" with average heights of 174.67 cm and 173.64 cm, respectively, demonstrating a variety of growth characteristics among high-oleic sunflower hybrids. The statistical study yielded a statistically significant difference ($P < 0.05$) between the hybrid "P64HE133" and all other variations, except for

"Columbi". Thus, the results emphasise the hierarchy of growth characteristics among the studied hybrids, indicating a significant heterogeneity in the response of plants to environmental conditions (Table 2).

***Table 2**. The impact of biological products on sunflower growth: analysis of the average plant height for the period 2021-2023, cm*

Foliar feeding with biological products (factor B)	Hybrid (factor A)					
	LG 5452 HO KL	Mas 86.OL	NK Ferty	Columbi	P64HE133	Average value
Control (water treatment)	160.54	163.76	165.54	168.95	170.98	165.55
Sclerocide	168.4	168.74	172.95	170.98	172.39	170.29
Azotophyt-p	170.6	172.61	174.55	172.61	175.32	173.54
Sclerocide + Helprost-Bor	174.76	175.26	176.71	176.98	177.71	176.28
Organic balance	177.1	177.71	178.57	178.84	179.57	178.36
Azotophyt-p + Helprost-Bor	179.73	180.29	180.75	180.75	181.39	180.98
Organic-Balance + Helprost-Bor	182.32	182.29	183.07	183.04	184.73	183.49
Average value	173.64	174.67	175.88	176.79	178.93	-

***Source:** compiled by the authors*

Within the realm of biological products, the application of the "Organic-Balance + Helprost-Bor" combination on two occasions throughout the growth season resulted in an average plant height of 183.49 cm, surpassing the achievements of other experimental variations. For instance, the combined use of "Azotophyt-p + Helprost-Bor" resulted in an average height of 180.98 cm, while the separate use of "Organic-Balance" resulted in an average height of 178.36 cm. The variants with "Sclerocide + Helprost-Bor" and "Azotophyt-p" showed 176.28 cm and 173.54 cm, respectively. The application of "Sclerocide" demonstrated a result of 170.29 cm, and the control variant without fertilisation showed the lowest average height – 165.55 cm, which demonstrates a significant ($P < 0.05$) increase in plant growth for all fertilisation options compared to the control.

Specifically, the application of "Sclerocide + Helprost-Bor" twice during the growing season resulted in a substantial rise in the average height of hybrids "NK Ferty" to 176.71 cm and "Mas 86.OL" to 175.26 cm. These results surpassed those achieved by applying the combination "Azotophyt-p" individually twice. For the "Mas 86.OL" hybrid, a similar effect was observed when the combination of "Azotophyt-p + Helprost-Bor" was used as isolated treatments twice, reaching an average height of 180.29 cm. However, when "Organic-Balance + Helprost-Bor" was applied separately twice, a slight increase in average height to 182.29 cm was found. At the same time, for all the hybrids studied, any foliar feeding contributed to an increase in plant height.

The most significant effect on plant height was the relationship between the choice of hybrids and foliar feeding regimes, which accounted for 76.5% of the total effect. In isolation, hybrid selection had a significant impact, accounting for 18.9%, while foliar fertilisation itself played a role with a 2.9% share. The other factors studied had a 1.7% effect on plant height. This highlights the importance of optimising the foliar application regime for specific sunflower hybrids to maximise their growth and development. During a detailed field study aimed at studying the morphological characteristics of high-oleic sunflower hybrids, the leaf area was assessed, which is a key factor in the process of photosynthesis and affects the overall productivity of plants. The analysis determined that hybrids "P64HE133" and "Columbi" showed the highest average leaf area among all the studied hybrids, each of which had an identical indicator (Table 3). This indicates the significant potential of these hybrids in forming an efficient photosynthetic system capable of optimising the use of sunlight.

***Table 3**. Leaf area of sunflower hybrids in the flowering phase depending on biological products, m2 (average for 2021-2023)*

Foliar feeding with biological products (factor B)	Hybrid (factor A)					
	LG 5452 HO KL	Mas 86.OL	NK Ferty	Columbi	P64HE133	Average value
Control (water treatment)	0.585	0.592	0.6	0.609	0.617	0.601
Sclerocide	0.628	0.642	0.65	0.66	0.673	0.651
Azotophyt-p	0.661	0.665	0.675	0.687	0.7	0.678
Sclerocide + Helprost-Bor	0.7	0.71	0.715	0.72	0.725	0.714
Organic balance	0.725	0.73	0.735	0.74	0.745	0.735
Azotophyt-p + Helprost-Bor	0.75	0.755	0.76	0.765	0.77	0.76
Organic-Balance + Helprost-Bor	0.775	0.78	0.785	0.79	0.795	0.785
Average value	0.689	0.711	0.717	0.741	0.756	-

***Source:** compiled by the authors*

Compared to "P64HE133" and "Columbi", hybrids "NK Ferty" and "Mas 86.OL" showed slightly lower average leaf area for each of them. These results indicate that these hybrids also have good adaptability to external conditions and can effectively develop leaf areas to meet the plant's photosynthetic needs. The lowest average leaf area was found in the hybrid "LG 5452 HO KL". Even though this value is only slightly inferior to other hybrids, statistical analysis confirmed that all hybrids had a statistically significant advantage over "LG 5452 HO KL" in this parameter ($P < 0.05$). This finding emphasises the significance of genetic elements and the influence of agricultural methods on the formation of the leaf surface, which is directly linked to the plant's ability to undertake photosynthesis and hence its production.

Thus, the analysis of leaf area identified the variability between the studied hybrids and emphasised the importance of this parameter in determining photosynthetic efficiency and overall adaptation of plants to growing conditions. The analysis of the impact of foliar feeding on the leaf surface development of sunflowers revealed that the combination of long-term "Organic-Balance" and "Helprost-Bor", together with a separate two-time application of "Azotophyt-p" and "Helprost-Bor", resulted in the attainment of the highest average leaf area. "Organic-Balance" and "Sclerocide + Helprost-Bor" fertilisers provided the average leaf area, indicating a decrease in efficiency with a decrease in fertiliser intensity. The application variant "Azotophyt-p" and the separate application "Sclerocide" showed an even smaller average area of 0.678 m^2 and 0.651 m^2 respectively. The control variant, without any fertilisation, showed the lowest average leaf area, emphasising the importance of foliar fertilisation for leaf surface development.

Among the analysed hybrids, "P64HE133" showed that a two-time application of "Azotophyt-p" resulted in an increase in the average leaf area to 0.678 m^2, which was higher than with long-term use of the biological product "Sclerocide". A similar trend was observed with the two-time application of "Organic-Balance + Helprost-Bor" compared to the long-term use of "Azotophyt-p + Helprost-Bor". Interestingly, for Mas 86.OL, the use of "Organic-Balance" alone resulted in a slightly higher average leaf area compared to the long-term use of "Sclerocide + Helprost-Bor". Hybrids and the use of foliar fertilisers had the greatest impact on leaf area, accounting for 50.1%. The next most important factor was the use of foliar fertilisers, which contributed 33.2% to the increase, while hybrids themselves contributed 11.4%. Other factors accounted for 5.3% of the impact. The "P64HE133" hybrid showed the highest average number of kernels per basket, followed by "Columbi", "NK Ferty", "Mas 86.OL", and "LG 5452 HO KL" with 1048.1 kernels. At the same time, "P64HE133" was distinguished by a significantly higher average number of grains compared to other hybrids, and all hybrids showed a statistically significant ($P < 0.05$) excess over "LG 5452 HO KL".

The highest average number of grains per basket among the hybrids was recorded with the double use of "Organic-Balance + Helprost-Bor", amounting to 1224.4 pieces. "Azotophyt-p + Helprost-Bor", "Organic-Balance", "Sclerocide + Helprost-Bor", "Azotophyt-p" and "Sclerocide" were next, while the control group had the lowest number of 1128 units. The application of each foliar fertiliser led to a statistically significant ($P < 0.05$) rise in the mean grain count when compared to the control group. The difference between the highest result with "Organic-Balance + Helprost-Bor" and the results with "Azotophyt-p + Helprost-Bor" or "Organic-Balance" was not statistically significant, unlike the results for the other hybrids (Table 4).

***Table 4**. Number of seeds in a basket of sunflower hybrids depending on biological products, pcs. (average for 2021-2023)*

Foliar feeding with biological products (factor B)	Hybrid (factor A)					
	LG 5452 HO KL	Mas 86.OL	NK Ferty	Columbi	P64HE133	Average value
Control (water treatment)	1,001	1,036	1,110	1,232	1,261	1,128
Sclerocide	1,041	1,050	1,121	1,242	1,289	1,148.6
Azotophyt-p	1,043	1,058	1,158	1,265	1,294	1,163.6
Sclerocide + Helprost-Bor	1,051	1,070	1,177	1,281	1,295	1,174.8
Organic balance	1,054	1,077	1,216	1,294	1,320	1,192.2
Azotophyt-p + Helprost-Bor	1,058	1,089	1,232	1,295	1,330	1,200.8
Organic-Balance + Helprost-Bor	1,089	1,121	1,242	1,324	1,346	1,224.4
Average value	1,048.1	1,066.6	1,182.3	1,276.1	1,305	-

***Source:** compiled by the authors*

Essentially, the application of biological products twice led to a marginal rise in the seed count per basket in comparison to the extended treatment. However, for the "NK Ferty" hybrid, long-term use of fertiliser has proved particularly effective. When using the "Sclerocide" combination, the number of seeds per head slightly decreased compared to the two-time use of "Azotophyt-p". A similar trend was observed for the "LG 5452 HO KL" hybrid, where "Sclerocide" yielded 1041 seeds, while the use of "Azotophyt-p" alone yielded 1043 seeds. Moreover, in the case of "LG 5452 HO KL", the use of "Azotophyt-p + Helprost-Bor" resulted in a decrease in the number of seeds per head compared to the use of "Organic-Balance + Helprost-Bor". For the hybrid "Mas 86.OL", the long-term application of "Organic-Balance" also showed a slight decrease in the number of seeds compared to the two-time application of "Azotophyt-p + Helprost-Bor".

Despite this, each use of biological products showed better results on average on each hybrid than the control. The combined effect of hybrids and foliar treatments was most effective (56.4%) in increasing the number of seeds per head. Hybrids came in second with 39.5%, followed by foliar fertilisers (1.1%) and other factors (3%). Seed yield is considered a key indicator for assessing the economic benefits of using modern hybrids. In this context, the "P64HE133" hybrid had the highest average seed yield, reaching 3.82 t/ha. In the last season, agricultural research showed that among the various hybrids tested at the test site, such as "Columbi", "NK Ferty", "Mas 86.OL" and "LG 5452 HO KL" stand out in terms of seed yield. In particular, "Columbi" showed a result of 3.72 t/ha, "NK Ferty" – 3.56 t/ha, "Mas 86.OL" – 3.29 t/ha, and "LG 5452 HO KL" – 3.11 t/ha.

Interestingly, the increase in yields in these studies may be due not only to the genetic characteristics of the hybrids themselves but also to the use of modern biological products that contribute to better plant development, increased stress resistance and protection against pests and diseases. This underscores the importance of an integrated approach to agricultural production that combines high-quality seed with advanced agricultural technologies. Among the different methods of using biological products, the use of double fertilisation "Organic-Balance + Helprost-Bor" demonstrated significantly better average seed yields compared to other methods. Notably, the average yields between the different methods of foliar feeding and the control group differed significantly (Table 5).

***Table 5**. Influence of biological products on seed yield of sunflower hybrids, t/ha (average for 2021-2023)*

Foliar feeding with biological products (factor B)	Hybrid (factor A)					
	LG 5452 HO KL	Mas 86.OL	NK Ferty	Columbi	P64HE133	Average value
Control (water treatment)	2.98	3.01	3.17	3.4	3.56	3.23
Sclerocide	2.97	3.11	3.36	3.56	3.87	3.37
Azotophyt-p	3.14	3.31	3.35	3.74	3.82	3.48
Sclerocide + Helprost-Bor	3.37	3.47	3.5	3.68	3.69	3.54
Organic balance	3.06	3.22	3.49	3.81	3.83	3.48
Azotophyt-p + Helprost-Bor	3.08	3.5	3.54	3.91	3.95	3.8
Organic-Balance + Helprost-Bor	3.19	3.41	3.5	3.93	4.04	3.93
Average value	3.11	3.29	3.56	3.72	3.82	-

***Source:** compiled by the authors*

Usually, seed yields with three times foliar spraying exceeded the results of two times application of similar fertilisers and PGR. This demonstrates the effectiveness of more intensive nutrient application methods in increasing the productivity of most hybrids. However, some exceptions to this rule have been recorded, especially for specific hybrids that show differences in response to cultivation. Specifically, the hybrid "NK Ferty" showed a slightly reduced seed yield when sprayed twice with the "Sclerocide" combination, compared to a single application of "Azotophyt-p". This may indicate that for some hybrids, increasing the number of sprays does not always lead to better results, possibly due to the achievement of optimal nutrition levels or due to the specific needs of the hybrid itself. Moreover, the hybrid "Mas 86.OL" showed a lower seed yield when "Sclerocide + Helprost-Bor" was applied twice compared to the two-time application of "Organic-Balance". This confirms the idea that not all hybrids are more productive with more intensive fertilisation regimes, and in some cases, less intensive but well-targeted fertilisation can be more beneficial. As such, although the general trend shows the benefits of double foliar spraying to increase seed yields in most cases, some exceptions require an individualised approach to each hybrid. It is necessary to address the specific needs of each hybrid and the possibility of reaching yield requirements, which may make further investments in additional sprays less effective.

The application of any form of foliar treatment on each hybrid resulted in an enhancement in seed yield when compared to the control group that did not receive any further fertilisation. The combined effect of hybrid characteristics and foliar nutrition proved to be the most powerful factor affecting yield, accounting for 64.5% of the total impact. The hybrids themselves contributed 27.3% of the impact, while biological products had 6.9%. Other aspects accounted for only 1.3% of the impact on the final yield. The key indicator for assessing the quality of oilseeds is their oil content. In this respect, the "P64HE133" hybrid showed the highest average level of 51.3%. The oil content of other hybrids decreased in the following order: "Columbi", "NK Ferty", "Mas 86.OL", "LG 5452 HO KL". The use of biopreparations increased the oil content by 0.9-1.8% (Fig. 1).

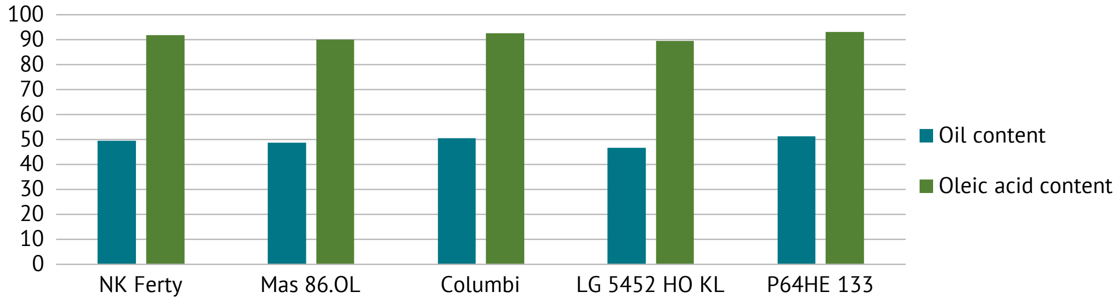

***Figure 1**. Oil and oleic acid content in sunflower hybrid seeds, %*
(average for 2021-2023 and by the factor of foliar feeding of crops with biological products)
***Source:** compiled by the authors*

In conducting a thorough examination of the qualitative attributes of seeds from several sunflower hybrids, particular emphasis was given to the oleic acid concentration, a crucial constituent that governs the nutritional and industrial worth of oil. In particular, the hybrid "P64HE133" had the highest average oleic acid content among all the hybrids studied, reaching 93.1%. This high figure underlines the potential of the "P64HE133" hybrid not only in terms of yield but also in terms of the quality of the products obtained. Compared to "P64HE133", the other hybrids showed lower average values of oleic acid content, but they also showed significant variability in this component, depending on growing conditions and applied agricultural technologies. Notably, the use of foliar fertilisers can increase the content of oleic acid in seeds by 2.1-5.3%, which underlines the importance of agrochemical measures to improve the quality of agricultural products.

It is worth noting that the content of oleic acid in each of the studied hybrids exceeded the total oil content, which indicates a high level of saturation with this valuable component. This high oleic acid content makes these hybrids particularly attractive to produce high-quality oils suitable for use in the food industry and for other purposes, such as biofuel production.

DISCUSSION

The investigation's results indicated a significant correlation between the use of biological products and the yield of sunflowers. Furthermore, it was imperative to emphasise the contingent nature of the indications on the sunflower hybrid. Nevertheless, to enhance the credibility and pertinence of the analysis, it is essential to analyse these indicators about comparable studies conducted by other authors.

In the context of agronomic research, analysis of the impact of biological products on the physiological characteristics of plants is prioritised. Specifically, one of the areas of research is the effects of mycorrhizal preparations that facilitate symbiosis between plant roots and fungi, thereby increasing their ability to assimilate nutrients and resistance to stressful conditions. One of these drugs is MycoFriend, which was studied by G. Sousa *et al.* (2021), M. Gandariasbeitia *et al.* (2022), and S. Hafez *et al.* (2021), to determine its potential for increasing sunflower (*Helianthus annuus L.*) yield. The application of MycoFriend in the row before sowing resulted in a 1.9-2.5 cm increase in plant height compared to the control group that did not utilise the biological product. At full maturity, the plants in the treated plots had an average height of 170.3-174.5 cm. These results correlate with the original study, which also recorded an improvement in plant growth using mycorrhizal preparations, although, in the original study, plant height was slightly higher. This may indicate the variability of plant responses to mycorrhizal preparations depending on specific growing conditions, soil properties and climatic factors. Thus, research confirms the potential of biological products as a means of optimising crop growth and development, offering an effective tool for increasing productivity in conditions where traditional agrochemical intervention may be limited or undesirable.

In agronomic studies by S. Li *et al.* (2023) and J. Li *et al.* (2022), the impact of the BTU biocomplex, which includes natural nitrogen-fixing, fungicidal and other beneficial bacteria, as well as biologically active products of their vital activity, on different types of crops in different agroclimatic conditions, was studied. The results indicated that the use of this product enhances the efficacy of seed germination, enhances the regularity of seedlings, decreases plant infection with various diseases without causing addiction, and boosts yields by 10-30%. These results confirm the high efficiency of the BTU biocomplex and its prospects for application in agronomy, especially in Ukraine, seeking sustainable methods to increase the productivity of agricultural systems.

Contemporary academic research in the subject of agronomy is increasingly focussing on investigating the influence of biological products on the morphological and physiological traits of plants. One of the main areas is the analysis of the ability of these products to improve growth parameters, such as the number of leaves per plant, which can significantly affect the overall productivity of plants by increasing photosynthetic activity.

A study conducted by B. Han *et al*. (2021), A. Oliveira *et al*. (2022) and D. Nguyen *et al*. (2021) conducted the effect of Biopolin on sunflower plants, in particular, on changes in the number of leaves. An observed variation in the leaf count per plant, ranging from 17.8 to 27.1 pieces, was attributed to the administration of Biopolin. All hybrids examined showed a substantial rise in leaf count, with a difference ranging from 4.4 to 8.8 leaves compared to the control plots without the preparation. These data should be compared with the results of the original study, which focused on measuring leaf area rather than directly on the number of leaves. Initial observations revealed a rise in leaf area, suggesting a beneficial impact of mycorrhizal preparations on the growth of leaf mass. However, by assessing the number of leaves, a more detailed picture can be obtained of changes in the growth characteristics of the plant, indicating a potential improvement in not only the quantitative but also the qualitative parameters of photosynthesis.

Studies have shown moderate correlations between yield and oil quality, which demonstrates that changes in the growing season due to heat stress do not directly affect oil quality. Heat stress can affect the oil content by reducing the number of seeds and increasing the sterile zone on the sunflower heads. In particular, a drop in seed count can lead to a decrease in oil content, while an increase in sterile area can contribute to an increase in oil content (Shahini *et al*., 2023). Under conditions of heat stress, variations in the concentration of oleic acid are observed, which becomes more sensitive to high temperatures. Under normal temperature conditions, oil content is positively correlated with an oleic acid content, which is in line with previous results of H. Amimy *et al*. (2023), but under heat stress this relationship becomes negative. Reducing the oil content at high temperatures does not necessarily increase the oleic acid concentration. Along with the increase in oleic acid caused by genetic and environmental factors, there may be a decrease in the concentration of palmitic acid, as confirmed by the study by P. Lemos *et al*. (2022). These discoveries are important for Ukraine, one of the world's leading sunflower producers. An assessment of the influence of heat stress on the quality and yields of oil can be utilised to formulate climate change adaptation measures that will guarantee the sustainability of production in the presence of global warming and climate fluctuations.

Considerable focus is given in agriculture to the influence of biological products on crop productivity (Tanchyk *et al*., 2024). These are based on biological products that show great promise in increasing sunflower yields. P. Evon *et al*. (2023) and N. Alzamel *et al*. (2022), who studied the ES Balistic hybrid, noted that the use of Polymyxobacterin increased yields compared to control plots where the biological product was not used. Under control conditions, the average yield was 2.62 t/ha. However, after the application of the biological product, an increase in this indicator was recorded, which confirms its effectiveness. Also noted are the results of J. Anandappa *et al*. (2023), M. Al-Zaidy and I. Al-Hilfy (2023) and B. Adeleke *et al*. (2022), who analysed the "SY Experto" hybrid and acquired similar trends. In the control plots, the yield of this hybrid was slightly higher and amounted to 2.7 t/ha. The use of biological products also increased yields, but, as in the first case, slightly higher results were reported in the original study, which could be due to differences in weather conditions, soil, or other agronomic parameters between the studies. These results indicate the potential of biological products as an effective means of increasing sunflower productivity, providing a rationale for further research and the potential integration of this biological product into modern agronomic practices.

The growing season is a critical factor that affects harvest time and quality, and the ability of biological products to modulate this period can have significant agronomic implications. A. Ghendov-Moșanu *et al*. (2023), R. Puttha *et al*. (2023) and K. Asish *et al*. (2023) examined the length of the growth season for two sunflower hybrids, namely the medium-early hybrid "P64LE121" and the medium-ripening hybrid "P64LE99". Following the study results, the vegetation period of the medium-early hybrid ranged from 102 to 113 days, while that of the medium-ripening hybrid lasted from 108 to 116 days. Particular attention was devoted to the effect of the biological product FitBest applied to the row before sowing. This application of the product demonstrated the ability to extend the growing season of both hybrids to a maximum duration of 113-116 days. This increase may be due to improved growth conditions, such as increased nutrient availability or improved water nutrition. Significantly, the aforementioned study did not include the duration of the growing season as a crucial factor. Instead, the focus was directed towards other agronomic aspects such as the yield of crops and the overall quality of seeds. Failure to address the length of the growing season in previous studies may indicate an underestimation of its impact on the final result of crop production.

CONCLUSIONS

The study findings showed that the biological products proved efficacy in enhancing several important parameters of sunflower agriculture, such as plant height, leaf area, seed count in baskets, seed yield, and seed quality, including oil and oleic acid content. Particularly striking results were obtained for the "P64HE133" and "Columbi" hybrids, which showed the highest average yield with the highest oil content.

The application of "Organic-Balance + Helprost-Bor" twice, as well as the double use of "Azotophyt-p +

Helprost-Bor", proved to be effective, providing high average seed yields for all hybrids in general – 3.8 t/ha and 3.93 t/ha respectively, which is significantly higher than the control group. Importantly, the biological products enhanced seed production by 0.21-0.4 metric tonnes per hectare compared to the control group and increased oil content by 0.9-1.8%. This highlights the importance of foliar feeding as a strategy to optimise sunflower production performance. Additionally, the average oleic acid content in the seeds, which is critical for oil quality, was increased by 2.1-5.3% due to foliar nutrition. In general, the combined effect of hybrid and biological product selection had the largest share in improving seed yields (63.5%), followed by the contributions of the hybrid itself (27.4%) and biological products (15.3%). In conclusion, to achieve optimal yields (between 3.37 and 3.93 t/ha) and seed quality, it is recommended to use targeted biological products, in particular, the combination of "Organic-Balance + Helprost-Bor" or "Azotophyt-p + Helprost-Bor" twice on the hybrids "P64HE133" and "Columbi".

Further research should address the genetic interaction between high oleic sunflower hybrids and biological products, which may reveal which genetic markers influence the increased response to biological products. This could be used to develop targeted breeding strategies to improve plant response to biological fertilisation.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Вплив біопрепаратів на продуктивність високоолеїнових гібридів соняшнику

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Анотація. Дослідження було спрямоване на вивчення ефективності застосування біопрепаратів на ріст, розвиток та продуктивність високоолеїнових гібридів соняшнику з метою підвищення урожайності насіння та покращення якості олії. Протягом 2021-2023 років в Миколаївській області було проведено експеримент, спрямований на вивчення ефективності семи варіантів позакореневого підживлення на продуктивність п'яти високоолеїнових гібридів соняшнику. Результати показали, що позакореневе підживлення мало позитивний вплив на визначені параметри, включаючи висоту рослин, площу листка, кількість насінин у кошику, урожайність насіння, вміст олії та олеїнової кислоти в насінні. Зокрема, гібрид "P64HE133" продемонстрував найвищу середню урожайність 3,89 т/га, наступним був "Коломбі" з показником 3,69 т/га, при цьому між ними не було виявлено статистично значущої різниці. Позакореневе підживлення "Органік-баланс" сприяло підвищенню середньої урожайності насіння до 3,58 т/га, перевищуючи результати від інших видів обприскувань. Застосування біопрепаратів сприяло збільшенню урожайності на 0,21-0,4 т/га порівняно з контролем, а також збільшенню вмісту олії на 0,6-2,1-5,3%. Загальний вплив комбінації гібриду та способів позакореневого підживлення на урожайність був найбільшим, склавши 63,5%, де вплив вибору гібрида становив 27,4%, позакореневого підживлення – 5,4%, а інші чинники мали вплив 3,7%. Результати вказують на те, що позакореневе підживлення може ефективно підвищити урожайність та покращити якісні характеристики насіння соняшнику. Застосування цих біопрепаратів не лише збільшує кількість насіння та вміст олії в них, але й сприяє більш стійкому та здоровому росту рослин. Відповідно, інтеграція таких методів у агротехнічні практики може значно покращити продуктивність сільськогосподарських культур і збільшити економічну вигоду від вирощування високоврожайних гібридів соняшнику

Ключові слова: підживлення; урожайність; гібриди; олеїнова кислота; біопрепарати