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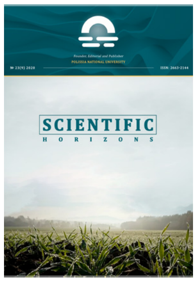

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The efficacy of chelated micronutrient fertilisers in tomato cultivation

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Abstract. The study aimed to investigate the impact of foliar fertilisation on the growth and development processes of tomato plants of different maturity groups throughout the entire growing season, as well as on overall yield levels. The research, conducted during 2018-2021 in film greenhouses at the experimental site of the State Biotechnological University, located in the south eastern part of the Left-Bank Forest-Steppe of Ukraine, examined the F1 indeterminate tomato hybrids Berberana (early maturity) and Bostina (mid-early maturity). The results demonstrated that foliar fertilisation accelerated plant development phases compared to the untreated control variant. The treated plants exhibited the most vigorous development during the budding phase, with bud formation occurring two to four days earlier than in the control group. It was observed that plants subjected to foliar fertilisation had superior biometric indicators during the mass flowering phase. The differences in primary biometric indicators during the mass flowering phase, depending on the application

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of foliar fertilisation, ranged from 3% to 18%. During the mass fruiting phase, these differences varied from 2% to 9% with a single treatment and from 5% to 17% with three treatments. Furthermore, the experiment involving three treatments demonstrated the highest monthly yield increases, exceeding the control by 12% to 21%. The findings indicated that the most effective treatment was the application of chelated micronutrient fertilisers three times, resulting in a yield increase of 17.5% (2.8 kg/m^2) for the Berberana hybrid and 14.8% (2.2 kg/m^2) for the Bostina hybrid compared to the control. These yield improvements provide producers with an opportunity for increased profit. The practical significance of this study lies in identifying the effects of foliar fertilisation on tomato yield in protected soil conditions. Additionally, the study established optimal and scientifically justified rates and application timings for complex fertilisers with chelated micronutrients. These measures ensure the maximum realisation of the crop's genetic potential

Keywords: tomato (*Solanum lycopersicum* L.); mineral fertilisers; chelated complexes; cultivation technology; foliar fertilisation; yield

INTRODUCTION

Modern agriculture faces the pressing challenge of ensuring sustainable production while reducing the reliance on chemical inputs and preserving soil fertility. As a result, there is a growing emphasis on agrotechnical and biological methods for enhancing agricultural productivity in an environmentally friendly manner. Tomato cultivation demands innovative solutions to boost overall yields. Understanding how different tomato hybrids respond to various foliar fertilisation methods and timing can unlock untapped potential for increased productivity. Such research holds both scientific and practical significance. Therefore, the relevance of this study lies in identifying the specific features of yield formation in tomatoes when water-soluble complex fertilisers with chelated micronutrients are applied. Tomatoes are one of the world's most popular vegetables. According to FAO data, global annual production of fresh tomatoes has been around 185-189 million tonnes in recent years, with an average yield of approximately 3.8 kg/m^2. Tomatoes account for about 16% of global vegetable production. In Ukraine, tomatoes represent an even larger share of total vegetable production at 2425%, although the average yield is slightly lower at around 2.9 kg/m^2.

Researchers N. Kosenko and V. Pogorielova (2020) assert that tomato yield is influenced by numerous factors, with the availability of nutrients in an accessible form within the soil being a primary determinant. Optimal yields are achieved through a combination of mineral, organic fertilisers, and foliar fertilisation. One significant challenge hindering tomato production and driving up costs is the limited availability of traditional organic and mineral fertilisers, which are crucial for enhancing crop yield and quality. A. Holodna (2021) highlights that the growing variety of fertilisers coincides with the adoption of modern agrochemical technologies in crop cultivation. This has led to increased demands for higher quality and a wider range of mineral fertilisers to maintain and restore soil fertility. M. Pylak *et al.* (2019) found that tomato plants extract substantial amounts of micronutrients from the soil, leading to depletion. To support sustainable agriculture and protect crops, it is essential to replenish soil micronutrient levels. However, under current agricultural practices and land-use systems in Ukraine, it is challenging to even maintain soil fertility, let alone improve it, without significant enhancements to state-level control mechanisms and the implementation of more effective, preferably economic, support mechanisms for soil conservation measures (Pisarenko *et al.*, 2020). Among other agronomic practices, the proper organisation of fertilisation is crucial for achieving abundant, stable, and high-quality yields of various crops cultivated in Ukraine. Foliar fertilisation provides plants with a more readily available source of nutrients compared to soil application. Combined foliar fertilisation improves plant growth, maturity, and yield, which can be attributed to the accessibility of essential nutrients and their easy absorption through leaves.

M. Samoraj *et al.* (2024) highlight those fertilisers and biostimulants are crucial in modern agriculture, balancing the growing global demand for food with the urgent need to mitigate environmental impact, especially in regions with degraded soils and limited resources. One key approach is the use of specialised mineral fertilisers, such as chelates (organic acid salts), which exhibit high biological activity and enhance nutrient uptake by plants (Alieksieiev, 2020). D. Humennyi *et al.* (2024) note that the global trend towards using biopreparations is driving domestic vegetable growers to seek alternative fertilisation systems for crop cultivation, promoting the development of effective systems that harness the full potential of plants using biopreparations of various types. U. Karbivska *et al.* (2024) emphasise the importance of rational and systematic fertiliser use to increase crop yields and improve product quality. Further advancements in production can only be achieved through the implementation, utilisation, and continuous improvement of innovative methods and the latest cultivation technologies.

Based on this analysis, the problem addressed by this study was the evaluation of the effects of foliar fertilisation on tomato yield in protected soil conditions, particularly in spring film greenhouses, to maximise crop productivity. By establishing optimal and practical dosages and application timings for a water-soluble complex fertiliser with chelated micronutrients for tomatoes, this research contributed to realising the genetic potential of tomatoes and advancing practical vegetable cultivation.

MATERIALS AND METHODS

Experimental research was conducted from 2018 to 2021 at the experimental plot of the State Biotechnological University, located in the southeastern part of the Left-Bank Forest-Steppe region of Ukraine. The experiments were carried out in unheated spring film greenhouses. Tomato plants were cultivated in spring-summer crop rotations. The soil cover of the experimental plot and greenhouse consisted of typical chernozem on clayey carbonate loess. The Kharkiv area is characterised by variable temperatures, varying amounts of annual precipitation without a dry season, and warm summers (Beck *et al.*, 2018), making it suitable for growing tomatoes in protected ground. The average long-term sum of active temperatures is 2,669°C. Winter begins in mid-November. The average daily air temperature crosses 15°C in early April. Snowmelt usually begins in early March and ends in the first decade of April. Soil thawing to its full depth ends in the first decade of April, and warming to a depth of 20 cm to +10°C occurs at the end of the third decade of April. The summer months are characterised by high air temperatures. The average annual air temperature for the period was: June +17.9°C, July +20.2°C, and August +19°C. The maximum soil surface temperature reached +54°C. Autumn typically begins in the third decade of October. Weather conditions during the study period, according to data from the Rogan meteorological station located on the experimental field, did not significantly differ from the longterm average. The maximum deviation of temperature from the monthly average was recorded in March 2019, which was the highest during the study period and 4.6°C above the norm.

For foliar fertilisation, the Plantafol product line from Valagro, Italy, was used. Plantafol is a range of foliar fertilisers with various concentrations, characterised by high solubility and rapid, complete absorption by leaves. The product line includes formulations with different ratios of nitrogen, phosphorus, and potassium to support both the vegetative and reproductive stages of crop growth and ensure high-quality produce. In the experiment, products with N, P_2O_5, and K_2O percentages of 10.54.10; 20.20.20; and 5.15.45 were used. All products in the line contain EDTAchelated micronutrients (Cu, Fe, Mn, Zn) and can be combined with the most common pesticides. The experimental materials were the indeterminate tomato hybrids Berberana F1 (early) and Bostina F1 (mid-early). To achieve the research objectives, plants were treated with Plantafol according to the following treatments (Table 1).

Table 1*. Experimental designs*

Variant No.	Treatment	Concentration and application timing
I variant	No fertilisation (Control)	-
II variant	1 fertilising	10.54.10 at the three-leaf phase
III variant	2 fertilising	10.54.10 at the three-leaf phase + 20.20.20 at the beginning of flowering
IV variant	3 fertilising	10.54.10 at the three-leaf phase + 20.20.20 at the beginning of flowering + 5.15.45 during fruiting phase

Source: *compiled by the author based on experimental research*

To correctly interpret the results obtained from the field experiment, analysis of variance (ANOVA) was used. Logical-theoretical approaches were applied to interpret the data. During the study, the authors also used their previous findings (Yarovyi *et al.*, 2020). The research was conducted following generally accepted methodological recommendations for growing tomatoes in protected ground. Experimental research on plants, including the collection of plant material, complied with institutional, national, and international guidelines: the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The study assessed the impact of foliar fertilisation on the progression of tomato plants through developmental phases. Foliar fertilisation accelerated the progression of plants through their developmental phases compared to the untreated control variant (Table 2).

Table 2*. Impact of the treatment on the duration of interphase periods compared to the control (average for 2018-2021)*

Factor A (Hybrid)	Factor B (Treatment)	Days from sowing to			First to final harvest, days
		emergence	beginning of flowering	onset of fruiting	
Berberana	No fertilisation (Control)	5.3	60.8	130.0	89.0

Table 2. Continued

Factor A (Hybrid)	Factor B (Treatment)	Days from sowing to			First to final harvest, days
		emergence	beginning of flowering	onset of fruiting	
Berberana	1 fertilising	5.3	58.8	128.0	88.8
	2 fertilising	5.3	58.5	127.5	88.8
	3 fertilising	5.3	56.8	126.3	90.0
Bostina	No fertilisation (Control)	5.8	61.0	131.0	88.5
	1 fertilising	5.8	59.3	128.8	88.3
	2 fertilising	5.8	58.5	128.5	88.5
	3 fertilising	5.8	57.0	126.5	88.8

Source: *compiled by the author based on experimental research*

The type of hybrid had a less significant impact, with the early-maturing hybrid Berberana generally developing slightly faster, although the difference was minimal. Observations showed that plants treated with Plantafol developed most intensively during the budding phase (56-59 days from germination to the onset of flowering), with bud formation occurring two to four days earlier than in the control. The treatment also accelerated the onset of mass fruiting in all experimental variants. Plants treated with Plantafol in the three-treatment variant were the most developed, with the largest biometric parameters at the flowering phase (Table 3).

Table 3*. Impact of the treatment on plant biometric parameters at the mass flowering phase compared to the control (average for 2018-2021)*

Factor A (Hybrid)	Factor B (Treatment)	Length of central stem, cm	Plant mass, g	Number of leaves, pcs.	Leaf surface area, cm^2 per plant
Berberana	No fertilisation (Control)	111.3	1,255.0	15.8	3,367.5
	1 fertilising	115.0	1,387.5	16.5	3,680.0
	2 fertilising	125.0	1,482.5	17.3	3,837.5
	3 fertilising	126.5	1,457.5	17.5	3,800.0
Bostina	No fertilisation (Control)	110.0	1,244.0	15.5	3,170.0
	1 fertilising	116.3	1,331.3	16.3	3,365.0
	2 fertilising	120.3	1,397.5	17.5	3,550.0
	3 fertilising	126.3	1,387.5	17.5	3,592.5

Source: *compiled by the author based on experimental research*

During the study period, the greatest stem length was observed in plants subjected to a threetreatment variant, averaging 126.3-126.5 cm across hybrids, which was 14-15% higher than the control. All other treatments also exceeded the control but to a lesser extent than the threeapplication variant. Plant mass ranged from 1,244.0 to 1,482.5 g, depending on the Plantafol treatment. Berberana hybrid plants treated with two applications had the highest mass (1,842.5 g), 18% more than the control, while Bostina hybrid plants in the control group had the lowest mass (1,244.0 g). The average number of leaves per plant ranged from 15.5 for the control (Bostina) to 17.5 for the three-treatment variant in both hybrids. Leaf surface area was smallest in the control group: 3,170.0 cm^2 for Bostina hybrid and 3,367.5 cm^2 for Berberana hybrid. The maximum increase over the control was observed in Berberana hybrid plants treated with two applications, reaching 3837.5 cm^2, which is 14% more than the control. Depending on the treatment, there was a 3-18% difference in the main biometric parameters of tomato plants during the mass flowering phase. Plants treated with Plantafol three times had the highest biometric values (Table 4).

Table 4*. Impact of the treatment on plant biometric parameters at the mass fruiting phase compared to the control (average for 2018-2021)*

Factor A (Hybrid)	Factor B (Treatment)	Length of central stem, cm	Plant mass, g	Number of leaves, pcs.	Leaf surface area, cm^2 per plant	Average fruit mass, g
Berberana	No fertilisation (Control)	277.5	2,267.5	27.8	12,807.5	131.3
	1 fertilising	278.5	2,377.5	28.3	13,357.5	141.3

Table 4. Continued

Factor A (Hybrid)	Factor B (Treatment)	Length of central stem, cm	Plant mass, g	Number of leaves, pcs.	Leaf surface area, cm² per plant	Average fruit mass, g
Berberana	2 fertilising	287.5	2,502.5	28.5	13,375.0	146.3
	3 fertilising	293.8	2,615.0	29.3	13,900.0	151.3
Bostina	No fertilisation (Control)	276.3	2,245.0	27.8	11,135.0	107.5
	1 fertilising	282.5	2,288.8	28.3	12,118.8	116.3
	2 fertilising	290.0	2,287.5	28.8	12,257.5	123.8
	3 fertilising	299.3	2,412.5	29.5	12,605.0	126.3

Source: *compiled by the author based on experimental research*

For the control treatment, the average stem length for both hybrids was the shortest at 276.3277.5 cm. Plants of the Bostina hybrid treated with three applications were the tallest at 299.3 cm, 8% more than the control. Berberana hybrid plants also had the longest stems (293.8 cm) under the same treatment. Plant mass, depending on the number of treatments, ranged from 2245.0 to 2615.0 g. Berberana hybrid plants treated with three applications had the highest mass (2,615.0 g), 15% more than the control, while Bostina hybrid plants in the control group had the lowest mass (2,245.0 g). Plants of both hybrids showed a similar trend in terms of leaf number and fruit mass, depending on the number of foliar applications. The highest average leaf number (29.3-29.5 leaves/plant) was obtained with three applications, which was 5-6% higher than the control, while the lowest (27.8 leaves/plant) was observed in the control for both hybrids. The highest leaf surface area (13,900 cm²) was recorded for Berberana hybrid plants treated with three applications, which is 9% more than the control, and for Bostina hybrid (12,605 cm²) also with three applications, which is 13% more than the control. The lowest leaf surface area was observed in the control treatment. The highest average fruit mass (151.3 g) was determined for Berberana hybrid with three applications, which is 15% more than the control, and the lowest (107.5 g) for Bostina hybrid in the control. During the mass fruiting phase, a strong positive correlation was observed between the length of the main stem and the number of leaves ($r = 0.98 \pm 0.57$) (Table 5).

Table 5*. Correlation between plant biometric parameters during the mass fruiting phase (average for 2018-2021)*

Parameters	Length of central stem, cm	Plant mass, g	Number of leaves, pcs.	Leaf surface area, cm² per plant	Average mass of 1 fruit, g
Plant mass, g	-0.78 ± 0.28	x			
Number of leaves, pcs.	0.98 ± 0.57	-0.68 ± 0.33	x		
Leaf surface area, cm² per plant	-0.68 ± 0.57	0.98 ± 0.59	-0.58 ± 0.65	x	
Average mass of 1 fruit, g	-0.92 ± 0.18	0.95 ± 0.13	-0.85 ± 0.26	0.90 ± 0.20	x

Source: *compiled by the author based on experimental research*

Other biometric indicators exhibited strong and moderate inverse correlations. The study of yield dynamics by month revealed that, in July, the yield of the Berberana hybrid ranged from 6.1 kg/m² in the control variant (untreated) to 6.8 kg/m² in the three-treatment variant. For the Bostina hybrid, the yield varied from 5.6 kg/m² in the control to 6.1 kg/m² in the three-treatment variant (Fig. 1).

In August, Berberana hybrid yielded 5.2 kg/m² in the control and 6.0 kg/m² in the three-treatment variant, while Bostina hybrid yielded 5.0 kg/m² in the control and 5.4 kg/m² in the three-fertilising variant. Similarly, in September, Berberana hybrid yielded 4.4 kg/m² in the control and 5.2 kg/m² with two- and three-treatment variants, while Bostina hybrid yielded 4.1 kg/m² in the control and 4.8 kg/m² two-and three-fertilising variants. In October, the difference in yield between the experimental variants was 1-2% of the average yield. The lowest total yield was recorded in 2018: 13.3 kg/m² for Bostina hybrid in the control and 16.5 kg/m² for Berberana hybrid with three-fertilising variants. The highest total yield was recorded in 2021: 16.7 kg/m² for Bostina hybrid in the control and 20.4 kg/m² for Berberana hybrid with threefertilising variant (Table 6).

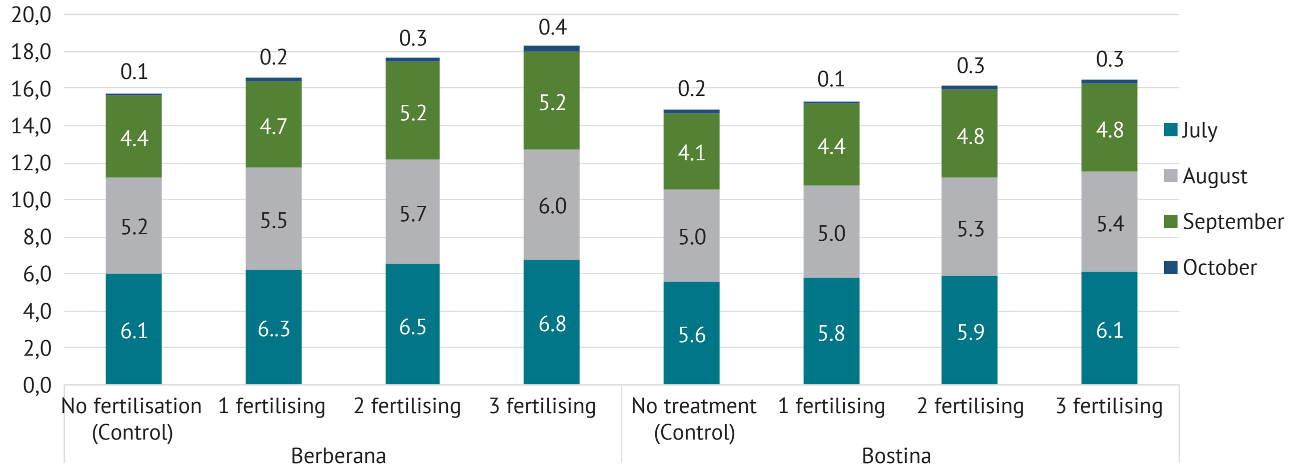

***Figure 1**. Dynamics of fruit yield formation by month under different treatments compared with the control, kg/m^2 (average for 2018-2021)*

***Source:** compiled by the author based on experimental research*

***Table 6**. Total yield formation under different treatments compared with the control (2018-2021)*

Factor A (Hybrid)	Factor B (Treatment)	Yield, kg/m^2				on average	± compared to control	
		2018	2019	2020	2021		kg	%
Berberana	No fertilisation (Control)	14.5	15.2	14.9	18.1	15.7	-	-
	1 fertilising	15.2	16.3	15.9	19.0	16.6	0.9	5.9
	2 fertilising	15.9	17.1	18.2	19.5	17.7	2.0	12.8
	3 fertilising	16.5	18.3	18.2	20.4	18.4	2.7	17.1
Bostina	No fertilisation (Control)	13.3	15.1	14.2	16.7	14.8	-	-
	1 fertilising	14.0	15.6	14.3	17.4	15.3	0.5	3.3
	2 fertilising	14.4	15.9	16.6	17.7	16.2	1.3	8.9
	3 fertilising	14.8	16.8	16.4	18.0	16.5	1.7	11.3

***Source:** compiled by the author based on experimental research*

Depending on the treatments applied using the Plantafol preparation, the total yield increased for the Berberana hybrid from 15.7 kg/m^2 in the control to 18.4 kg/m^2 in the three-fertilising variant, and for the Bostina hybrid from 14.8 kg/m^2 in the control to 16.5 kg/m^2 under the same variant. To evaluate the results of the field experiment, correct use and interpretation of the obtained data is necessary. Although there are no significant differences between the results of using different statistical analysis methods, depending on the experimental data, each has its advantages and disadvantages. For the analysis of data obtained in the field experiment, ANOVA is a suitable method for correctly assessing the impact of experimental factors on tomato yield (Table 7).

***Table 7**. Results of analysis of variance of data by factors of the field experiment*

Variance	*SS*	*df*	*MS*	*F*	*p-value*	*Critical F-value*	
						0.95	*0.99*
Factor A (Hybrid)	7.60	1	7.60	4.70	0.04	4.26	7.82
Factor B (Treatment)	45.31	3	15.10	9.34	0.00028	3.01	4.72
Interaction of AB factors	1.06	3	0.35	0.22	0.88	3.01	4.72
Model error	38.79	24	1.62	x	x	x	x
Total	92.76	31	x	x	x	x	x

***Source:** compiled by the author based on experimental research*

The actual Fisher criterion for F_A is 7.60, which exceeds the theoretical criterion at the 0.95 probability level. This indicates that the variability of the hybrid has a statistically significant effect on tomato yield at this significance level. For Factor A, the null hypothesis of no effect of the factor levels is rejected – demonstrating that the use of tomato hybrids from different maturity groups significantly influences yield. The actual Fisher criterion for F_B is 15.10. The null hypothesis of no effect of the factor levels for Factor B is also rejected, confirming that the number of fertiliser applications has a statistically significant impact on tomato yield. However, since the actual Fisher criterion for F_{AB} is 0.22, which is lower than the theoretical value, the interaction of these factors does not have a statistically significant effect on yield in the field experiment. The least significant difference was calculated at various significance levels (0.01 and 0.05) for the experimental factors to further characterise the field experiment (Table 8).

***Table 8**. Results of analysis of variance by factors of the field experiment*

Experimental factor		**Mean, kg/m²**	**Difference by factor**		**Sx%**	**T%**
		A	**B**			
A (Hybrid)	Berberana	17.1	-	x	5.5	94.5
	Bostina	15.7	***1.4***	x		
B (Treatment)	No fertilisation (Control)	15.3	x	-		
	1 fertilising	16.0	x	0.7		
	2 fertilising	16.9	x	***1.7***		
	3 fertilising	17.4	x	***2.2***		
$LSD_{0.95}$ by factor			**1.3**	**0.9**		
$LSD_{0.99}$ by factor			**1.8**	**1.3**		

Source: *compiled by the author based on experimental research*

The difference in mean sample values cannot be attributed solely to randomness. Using tomato hybrids from different maturity groups in the experiment resulted in a yield increase at a reliable probability level of 0.05 against the background of foliar fertilisation. Moreover, a significant increase in total yield was observed at both levels of reliable probability with tomato hybrids of varying maturity. This increase was achieved through the application of Plantafol 10.54.10 at the three-leaf phase, Plantafol 20.20.20 at the beginning of the flowering phase, and Plantafol 5.15.45 during the fruiting phase under the three-treatment variant.

Traditional chemical fertilisers have low plant availability, leading to soil degradation and environmental pollution. As a result, as noted by F. Areche *et al.* (2023), there has been a growing demand for safer and more environmentally friendly fertiliser application formulas. Scientific research by J. Chipomho *et al.* (2018) has shown that the use of foliar fertilisers that improve the bioavailability of various types of fertilisers and minerals and stimulate plants to grow faster and improve nutrient uptake has a positive overall impact on plant development. Researchers N. Gruda *et al.* (2024) and H. Dasgan *et al.* (2024) have demonstrated that, due to their greater efficiency, foliar application of mineral fertilisers with amino chelates can be a sustainable approach to plant nutrition management, especially in drought conditions. Recent studies have revealed the critical role and complex functions of micronutrients in optimising vegetable production. Research by J. Gui *et al.* (2022) and Z. Jia *et al.* (2022) has expanded the understanding of the profound effects of micronutrients such as Fe, Zn, and Cu on plant nutrient use, growth, and development. An element like Mn also plays an important role. In studies by A. Nazir *et al.* (2024) and M. ElMogy and H. Abd El-Gawad (2023), it is noted th at the practice of applying micronutrients is vital for processes such as photosynthesis and carbohydrate metabolism, emphasising its effectiveness in increasing overall vegetable yields and improving fruit quality during post-harvest storage. These results indicate the potential of foliar application of mineral fertilisers with amino chelates as an effective means of increasing tomato yield and correlate with the original study.

In a study by G. Disciglio *et al.* (2024), the effects of biostimulants (containing auxins, cytokinins, and micronutrients such as Zn, Mg, and Mn) applied three times during the growing season (during transplanting, before flowering, and during fruit enlargement) on spring-grown tomatoes were investigated. Significantly higher marketable yields were observed in both experimental fields with foliar fertilisation, increasing by 6.8-16.1% (an average of 10.312.1 kg/m²) compared to the control (no treatment). The results obtained in this study align with their findings.

In an experiment conducted by Bulgarian scientists G. Patamanska *et al.* (2021) in a film greenhouse, a two-factor trial was carried out with the Big Beef F1 greenhouse tomato hybrid. The experimental factors in the study were irrigation and foliar fertilisation with mineral fertilisers. Foliar fertilisation was studied by spraying tomato leaves with a complex mineral NPK fertiliser at three different concentrations. The results of the experiment determined that the maximum total tomato yield was obtained with the highest fertiliser rate under both full and deficit irrigation conditions –

at 12.8 and 9.07 kg/m^2, respectively, which is 43.9% and 29.3% higher than the control (no treatment). This is also confirmed by the research of J. Olivarez-Rodríguez *et al.* (2021), who studied foliar fertilisation of tomatoes with nanoparticles (NPs) consisting of ZnO, Fe_2O_3, and CuO, applied individually and in combination: Zn, Fe, Cu, Zn+Cu, Zn+Fe, Cu+Fe, Zn+Cu+Fe, and a control without application, for a total of eight treatments. It was found that when plants were treated with combinations of Zn+Cu, Zn+Fe, and Cu+Fe, the yield increased by 24.5-34.3% compared to control plants, recording a value of 2.15-2.32 kg/plant. The highest productivity was shown by plants treated with a complex of Zn+Cu+Fe, at a level of 2.88 kg/plant, which was 66% higher than the yield of untreated plants. Three variants of foliar treatment with the use of preparations and a separate control were studied by authors L. Vultaggio *et al.* (2022). Treatments were organised in a randomised complete block design with three replicates per treatment, totalling 12 experimental units. In this study, plant biostimulants containing phytohormones and two preparations containing NPK and micronutrients K, Ca, Mg, Fe, Mn, B, Zn, and Cu in different concentrations were used. Foliar fertilisation improved the early yield of fresh tomatoes by 14.130.0% compared to untreated plants, without a significant difference between treatments with biostimulants. These data confirm the results of the current study, which also recorded an increase in tomato yield of 14.8-17.5% due to foliar fertilisation.

M. Nighat *et al.* (2018) demonstrated the effectiveness of foliar fertilisation with micronutrients in tomato plants. Foliar application of micronutrients was conducted 15 days after transplanting and repeated at 15-day intervals. A total of three foliar sprays were applied during the growing season. Significant differences were observed between treatments in terms of leaf count, number of branches, and root length per plant. The maximum number of leaves (76.35), branches (10.27), and root length (37.16 cm) per plant was observed with the maximum concentration of micronutrients and three applications, and the highest yield (4.5 kg/m^2) was also recorded. The minimum number of leaves (54.05), branches (4.13), and root length (28.16 cm) per plant was observed under natural conditions in the control. These results support current findings that foliar fertilisation has a significant impact on overall plant development and yield. A similar trend was observed in the research of B. Essa *et al.* (2024), where cherry tomatoes showed a positive response to foliar application. The study examined four genotypes of cultivated cherry tomatoes treated with salicylic acid and methyl jasmonate. Treatment of plants with an aqueous solution of methyl jasmonate proved to be the most effective in increasing yield, providing a yield of 3.02-6.74 kg/m^2, which is 8.6-25.7% higher than the untreated variant.

The study by O. Kuts *et al.* (2023) revealed that the use of mineral fertilisers and fertilisation systems incorporating microbial preparations for foliar application of tomato variety Chaika resulted in a significant increase in the number of clusters per plant. This increase ranged from 10.6% to 77.5% at the beginning of flowering and 17.0% to 52.8% at the full fruiting phase. Additionally, on average over the years of the study, applying fertilisers and foliar application three times contributed to a 50.8-142.0% increase in tomato seed yield. W. Lakshari *et al.* (2023) conducted a similar experiment in Sri Lanka. Foliar treatments were applied at the growing, flowering, and fruiting phases using chitosan at three different concentrations (70, 80, and 120 ppm). Foliar fertilisation positively influenced vegetative growth, leaf area, plant height, chlorophyll index, and dry matter. Moreover, it increased the total soluble solids, fruit weight, and diameter. The researchers concluded that foliar application at the maximum concentration of the preparation yielded the highest crop (almost 2.7 times higher than other variants) and better fruit quality.

Overall, most practical studies also indicate that the application of micronutrients in foliar fertilisation is beneficial not only for shoot and root growth but also acts as a catalyst for nutrient absorption processes, thus contributing to increased yields of vegetable crops. In conclusion, the results of determining the impact of foliar fertilisation on tomato yield under protected ground conditions demonstrate the effectiveness of foliar fertilisation with water-soluble complex micronutrients and contribute to the enrichment and deepening of agronomic science.

CONCLUSIONS

The research established that foliar fertilisation with Plantafol was highly effective when cultivating the tomato hybrid. The study of plant biometric parameters showed a positive impact of foliar fertilisation on plant growth and development throughout the entire vegetative period. Plants treated with Plantafol exhibited the most intensive development during the budding phase, leading to a faster growth rate compared to the control. During the mass flowering phase, the studied hybrids under the foliar fertilisation treatment had the most developed plants, on average 3-18% more than the control. In the mass fruiting phase, the highest biometric indicators among those studied were recorded for the treatment with three foliar applications.

The application of foliar fertilisation resulted in increased tomato yields. The dynamics of monthly yield formation across treatment variants revealed the highest monthly yield levels for both hybrids in the treatment with three foliar applications, exceeding the untreated control by 12-21%. The most effective treatment was the variant with three applications, which led to yield increases of 17.5% (by 2.8 kg/m^2) for the Berberana hybrid and 14.8% (by 2.2 kg/m^2) for the Bostina hybrid compared to the control.

The calculation of the least significant difference for both experimental factors at a 95% confidence level confirmed the significance of these results. For Factor A – the cultivation of indeterminate tomato hybrids of different maturity groups (F1 hybrid Berberana, early, and F1 hybrid Bostina, mid-early) – 1.4 kg/m^2 ($LSD_{0.95}$ = 1.4). For Factor B – foliar fertilisation with Plantafol – 1.7 kg/m^2 ($LSD_{0.95}$ = 0.9) for the two-application treatment (Plantafol 10.54.10 during the three-leaf phase and Plantafol 20.20.20 at the beginning of flowering) and 2.2 kg/m^2 ($LSD_{0.95}$ = 0.9) for the threeapplication treatment (Plantafol 10.54.10 during the three-leaf phase, Plantafol 20.20.20 at the beginning of flowering, and Plantafol 5.15.45 during the fruiting phase). By influencing the processes of yield structure formation through foliar fertilisation, it is possible to affect the crop yield of tomatoes. This provides an opportunity for producers to increase their profits. The results of the study indicate the need for further research aimed at studying the specific effects of different complexing agents on plant development and evaluating the agrochemical effect of applying such fertilisers through foliar fertilisation, as well as selecting the optimal fertiliser composition for further use in the full cycle of tomato cultivation.

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CONFLICT OF INTEREST

None.

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Ефективність застосування хелатних мікродобрив при вирощуванні помідора

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Анотація. Метою дослідження було дослідження впливу позакореневих підживлень на процеси проходження росту та розвитку рослин помідора різної групи стиглості протягом всього вегетативного періоду та рівень загальної врожайності. У досліді проведеному у 2018-2021 роках у плівкових теплицях на дослідній ділянці Державного біотехнологічного університету у південно-східній частині Лівобережного Лісостепу України вивчали індетермінантні гібриди F1 помідора Берберана (ранній) та Бостіна (середньранній). Встановлено, що застосування позакореневих підживлень порівняно з контрольним варіантом без обробки пришвидшувало проходження рослинами фаз розвитку. Розвиток оброблених препаратом рослин був найбільш інтенсивним у фазу бутонізації, на дві-чотири доби раніше за контроль відбувалось формування бутонів на рослині. Відзначено, що перевищення біометричних показників у фазу масового цвітіння мали рослини, які отримували позакореневі підживлення. Різниця між основними біометричними показниками, в залежності від проведених позакореневих підживлень, у фазу масового цвітіння відзначена на рівні 3-18 %, у фазу масового плодоношення від 2-9 % за варіантом з одним до 5-17 % за варіантом з трьома обробками. Також у досліді з трьома обробками рослин визначено максимальний врожайності за місяцями – на 12-21 % більше контролю. За результатами досліджень визначено, що найкращим виявився варіант досліду з трьома обробками хелатними мікродобривами, за яким отримано підвищення врожайності для гібриду Берберана на 17,5 % (на 2,8 кг/м^2) порівняно з контролем та для гібриду Бостіна на 14,8 % (на 2,2 кг/м^2) порівняно з контролем, завдяки чому виробники матимуть можливість отримувати додатковий прибуток. Таким чином, практична цінність даного дослідження полягала у виявленні впливу позакореневих підживлень на врожайність помідора в умовах захищеного ґрунту та визначення оптимальних та практично обґрунтованих доз та строків застосування комплексного добрива з мікроелементами у хелатній формі, що забезпечить максимальну реалізацію генетичного потенціалу культури

Ключові слова: помідор (*solánum lycopérsicum* L.); мінеральні добрива; хелатні комплекси; технологія вирощування; позакореневі підживлення; урожайність