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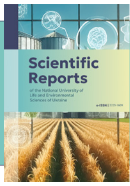

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Effectiveness of phosphite fertilisers in tomato cultivation technology

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Abstract. This study aimed to determine the effectiveness of using fertilisers containing phosphite form phosphorus in tomato cultivation under irrigated conditions in the Left-Bank Forest Steppe region of Ukraine. Field trials were conducted during 2022-2024 at the Institute of Vegetable and Melon Growing of the National Academy of Agrarian Sciences of Ukraine, on typical low-humus heavy loamy chernozem developed from loess-like loam. It was found that in tomato cultivation, it was effective

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in reducing the rate of recommended fungicides (Ridomil Gold, Luna Experience, Quadris, and the biopreparations MycoHelp and Fitocid) by 25%-50% when combined with the integrated application of the fertiliser Ecoline Phosphite (K) (10 days after transplanting – 1 L/ha; 20 days after the first application – 1.5 L/ha; 20 days after the second application – 1.5 L/ha; 20 days after the third application; 15 days after the fourth application; and 15 days after the fifth application – all at 2 L/ha). The proposed technological approaches resulted in an increase in tomato plant height by 4.3%-8.7%, the number of fruit clusters by 15.6%-20.0%, and a reduction in the development of Alternaria leaf blight to 60%-65% (compared to 82% in the control). Under this approach, crop yield increased by 4.9-8.8 t/ha, alongside an improvement in the content of soluble dry matter in the fruit (up to 3.6%-3.98%), total sugars (up to 2.49%-2.53%), and vitamin C (up to 25.48-25.82 mg/100 g). The most significant effect was observed with the application of 75% of the recommended fungicide rate in combination with Ecoline Phosphite (K), which also demonstrated strong economic performance: profit reached 311.1 thousand UAH/ha, profitability was 83.9%, and the lowest production cost was recorded at 5.69 UAH/kg

Keywords: *Solanum lycopersicum* L.; phosphorus nutrition; biometric parameters of plants; yield; biochemical composition of produce; profitability

Introduction

Investigating the effectiveness of phosphite fertilisers in tomato cultivation technology is pertinent given the necessity of enhancing crop productivity and improving fruit quality, particularly in light of increasing demands for environmental safety and economic efficiency in agricultural production. Tomatoes are a crop sensitive to mineral nutrition, with their nutrient requirement, especially phosphorus, increasing significantly during critical growth and development stages. Concurrently, traditional phosphorus fertilisers exhibit low availability to plants under unfavourable soil and climatic conditions, which limits the realisation of the crop's potential and negatively impacts fruit quality and yield. Phosphite forms of phosphorus offer several advantages, including high bioavailability, the capacity to activate physiological and biochemical processes, and the ability to increase plant resistance to diseases and stress factors. Using such fertilisers is considered a promising element in resource-saving technologies for cultivating vegetable crops, enabling a reduction in pesticide load by boosting plant immunity and decreasing the rates of chemical plant protection products applied. These issues are particularly relevant in the context of irrigated agriculture in the Left-Bank Forest-Steppe of Ukraine, where optimising tomato nutrition will contribute not only to increased yield but also to improved fruit quality indicators, enhanced economic returns from production, and the assurance of sustainable development in vegetable growing.

Global food security represents a key challenge confronting world agriculture. The necessity of feeding a steadily increasing population is compounded by significant threats to food crop yields arising from climate change. As there is no longer an abundance of available agricultural land, a 40%-50% increase in food production can only be achieved through sustainable agricultural intensification (Syromyatnikov *et al.*, 2024). Optimising nutrition systems provides the most substantial impact on boosting crop productivity, particularly for vegetable crops. According to O.V. Kuts *et al.* (2024), yield increments resulting from the application of various types of fertilisers range from 20% to 75%. The use of growth regulators also significantly influences the regulation of plant productivity levels. This is achieved through their positive effect on root architecture, which in turn enhances the conditions for plant nutrient uptake.

Phosphorus is one of the most vital elements required by all living organisms. In agrochemical contexts, humanity primarily utilises phosphorus in the form of phosphates (PO_4^{3-}). However, researchers such as B. Lagunas *et al.* (2019) have shown interest in the salts of phosphorous acid – phosphites (PO_3^{3}). They established that the application of phosphites offers multifaceted benefits compared to phosphates. Phosphites have been noted for their use as fertilisers, plant growth stimulants, and substances with fungicidal properties. Y. Xi *et al.* (2020) investigated that salts of phosphorous acid (phosphites) contain higher concentrations of phosphorus (52%) than traditional phosphate-based fertilisers (32%). As the most stable form of phosphorus in the environment is phosphates, phosphites undergo a gradual transformation after being applied to the soil. Soil microorganisms are capable of assimilating phosphite and transforming it into phosphates, obtaining energy and nutrients during this biological conversion.

Phosphites also exert a unique influence on plant metabolism, linked to their functional role as plant growth regulators. It is worth noting that, according to I. Panfili *et al.* (2019), plant growth stimulants are increasingly being integrated into various production systems to mitigate physiological stress and minimise undesirable environmental consequences. The authors observed that phosphite (an isostere of the phosphate anion) often acts as a potential biostimulant, as it has been shown to induce resistance to a variety of biotic and abiotic stresses, as well as enhance the yield and quality of agricultural produce.

Research by M.A. Mohammadi *et al.* (2021) indicated that phosphites are employed as a systemic fungicide to manage the prevalence of oomycetes and soil-borne diseases such as *Phytophthora*, *Pythium*, and *Plasmopara*. Generally, phosphites lead to a reduction in disease severity by promoting increased photosynthetic and enzymatic activity, decreasing the accumulation of reactive oxygen species (ROS), and modifying a large group of genes.

In this context, the present study aimed to establish the effectiveness of using fertilisers containing phosphorus in the phosphite form for tomato cultivation under irrigated conditions in the Left-Bank Forest-Steppe of Ukraine.

Materials and Methods

The research was conducted during the period 2022-2024 at the Institute of Vegetable and Melon Growing of the National Academy of Agrarian Sciences of Ukraine, located in the Left-Bank Forest-Steppe region of Ukraine. The soil of the experimental plot is classified as a typical lowhumus heavy loamy chernozem on loess-like loam. The agrochemical characteristics of the arable layer (0-25 cm) are as follows: salt extract pH – 6.1; sum of exchangeable bases – 29.0 mg-eq per 100 g of soil; hydrolytic acidity – 2.0 mg-eq per 100 g of soil; humus content – 4.0%; hydrolysable nitrogen – 109-116 mg/kg; mobile phosphorus – 183-212 mg/kg; and exchangeable potassium – 121-163 mg/kg of soil. Tomatoes of the Heizer variety were cultivated following bulb onions, utilising drip irrigation (7 applications of 50-100 m^3/ha) with a plant spacing of 70×35 cm. The research adhered to the Convention on Biological Diversity (1992).

The experimental design included the recommended tomato disease control system (a complex of fungicides and biopesticides) and combinations of reduced fungicide rates with the application of the complex fertiliser possessing fungicidal properties, Ecoline Phosphite (K):

1. No fungicides or preparations applied (absolute control)

2. Recommended fungicides (reference treatment): Ridomil Gold (2.5 kg/ha) 10 days after transplanting to the field + Luna Experience (0.75 L/ha) 20 days after the first application + Quadris (0.6 L/ha) 20 days after the second application + MycoHelp biopreparation (2 L/ha) 20-25 days after the third application + Phytocid biopreparation (2 L/ha) 15 days after the fourth application + MycoHelp (2 L/ha) 15 days after the fifth application

3. Recommended fungicides at a 25% reduced rate + Ecoline Phosphite (K): Ridomil Gold (1.88 kg/ha) + Ecoline Phosphite (K) (1 L/ha) 10 days after transplanting + Luna Experience (0.55 L/ha) + Ecoline Phosphite (K) (1.5 L/ha) 20 days after the first application + Quadris (0.45 L/ha) + Ecoline Phosphite (K) (1.5 L/ha) 20 days after the second application + Ecoline Phosphite (K) (2 L/ha) 20 days after the third application + Ecoline Phosphite (K) (2 L/ha) 15 days after the fourth application + Ecoline Phosphite (K) (2 L/ha) 15 days after the fifth application

4. Recommended fungicides at a 50% reduced rate + Ecoline Phosphite (K): Ridomil Gold (1.25 kg/ha) + Ecoline Phosphite (K) (1 L/ha) 10 days after transplanting + Luna Experience (0.38 L/ha) + Ecoline Phosphite (K) (1.5 L/ha) 20 days after the first application + Quadris (0.3 L/ha) + Ecoline Phosphite (K) (1.5 L/ha) 20 days after the second application + Ecoline Phosphite (K) (2 L/ha) 20 days after the third application + Ecoline Phosphite (K) (2 L/ha) 15 days after the fourth application + Ecoline Phosphite (K) (2 L/ha) 15 days after the fifth application.

The research was conducted according to the methodology for experimental work in vegetable growing (Bondarenko & Yakovenko, 2001). The accounting plot area was 21.0 m^2, with four replications. In the experiment, biometric parameters of tomato plants (plant height and number of trusses per plant) were recorded dynamically. Assessments of plant damage by Alternaria leaf blight were determined using a 5-point scale dynamically (in the second ten-day period of July and the third ten-day period of August). The scale was defined as follows: 0 – no damage; 1 – yellowing of 1-2 leaves; 2 – yellowing of 3-4 leaves; 3 – yellowing of half the plant; 4 – yellowing of the entire plant, which blackens and dries out. The prevalence of the disease was calculated using the formula:

$$P = \frac{a}{k} \cdot 100\%, \tag{1}$$

where P is the disease prevalence, %; a is the number of affected plants, units; k is the total number of assessed plants, units. The degree of disease development intensity was calculated using the formula:

$$C = \frac{\sum a \cdot b}{n \cdot k} \cdot 100\%, \tag{2}$$

where C is the degree (intensity) of disease development; a is the number of affected plants for each score, units; b is the damage score; n is the highest score on the assessment scale; k is the total number of assessed plants, units.

Total yield and marketable yield, along with marketability, were also determined. Biochemical parameters of the tomato fruits assessed included: total soluble solids content – refractometrically according to DSTU 7804:2015 (2016); total sugars content – according to DSTU 4954:2008 (2009); ascorbic acid (Vitamin C) content – according to DSTU 7803:2015 (2016); and acidity – titrimetrically according to DSTU ISO 6632-2001 (2002). Statistical analysis of the research results was performed using analysis of variance, with years treated as replicates.

Results

It was noted that both the use of the complex of recommended fungicides and the combination of reduced fungicide rates with the application of Ecoline Phosphite (K) fertiliser increased tomato plant height (Fig. 1). When reducing the fungicide rate and adding Ecoline Phosphite (K), this parameter did not change significantly. In these variants, tomato plant height in the third ten-day period of July increased by 6.8%-8.7%, and in the first ten-day period of September, by 4.3%-7.4%.

A positive effect of fungicides and Ecoline Phosphite (K) fertiliser on the formation of trusses on tomato plants, which is a component of crop yield, was also established (Fig. 2). By the end of the growing season, the number of trusses increased from 4.5 units/plant in the control to 5.25.4 units/plant with the application of fungicides and Ecoline Phosphite (K) fertiliser. A synergistic effect was observed when using the 50% fungicide rate in combination with Ecoline Phosphite (K) fertiliser.

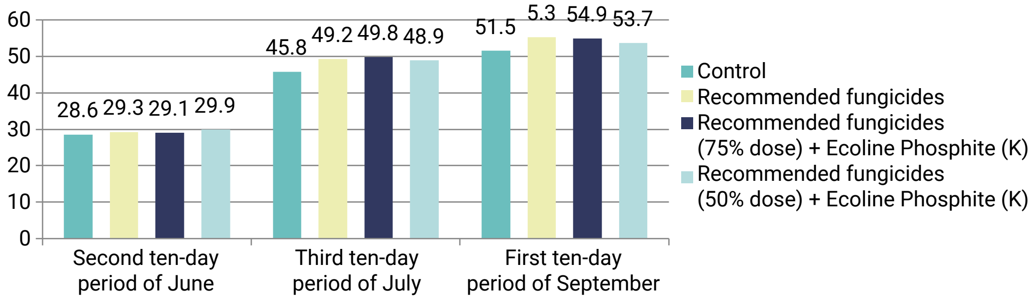

Figure 1. *Effect of fungicides and Ecoline Phosphite (K) fertiliser on tomato plant height, cm (average for 2022-2024)*

Source: developed by the authors

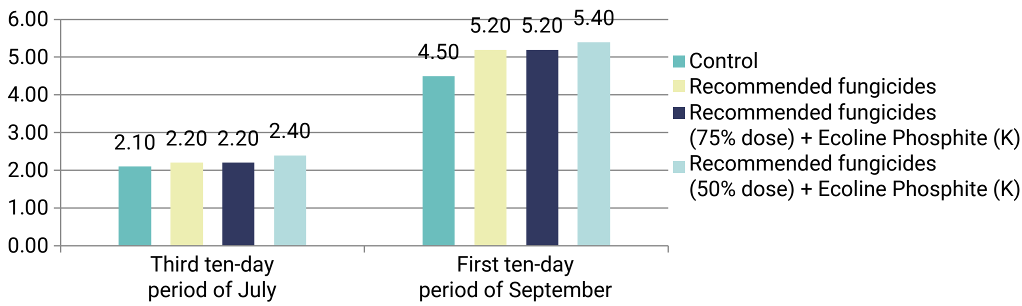

Figure 2. *Effect of fungicides and Ecoline Phosphite (K) fertiliser on the number of tomato plant trusses, units/plant (average for 2022-2024)*

Source: developed by the authors

During the years of the study, Alternaria leaf blight (*Alternaria solani*) predominantly affected tomato plantings annually, while in 2023, late blight (*Phytophthora infestans*) developed in small foci, though this disease did not significantly impact plant development. Regarding the effect on Alternaria leaf blight development, the additional use of Ecoline Phosphite (K) fertiliser proved effective when the rate of recommended fungicides was reduced by 25%-50% (Table 1).

Table 1. *Effect of fungicides and Ecoline Phosphite (K) fertiliser on the prevalence and development of tomato Alternaria leaf blight, % (average for 2022-2024)*

Variants	Second ten-day period of July		Third ten-day period of August	
	Spread	Development	Spread	Development
1. Control	100	9.6	100	82
2. Recommended fungicides	100	8.1	100	70
3. Recommended fungicides (75% dose) + Ecoline Phosphite (K)	100	7.8	100	65
4. Recommended fungicides (50% dose) + Ecoline Phosphite (K)	100	8.0	100	60

Source: developed by the authors

During the period of mass tomato fruiting, reducing the rate of recommended fungicides by 25% in combination with the use of Ecoline Phosphite (K) ensured a reduction in the degree of disease development to a level of 65%, and with a 50% reduction in the fungicide rate, it decreased to as low as 60%. Thus, the use of fertiliser containing phosphorus in the phosphite form acts as a substance with fungicidal properties, as well as an additional measure for optimising plant nutrition, which contributes to a better effect on tomato plants and a reduction in the degree of Alternaria leaf blight development.

Even though all tested variants resulted in a tomato yield increase of 4.5-9 t/ha, or 7.9%15.9%, the maximum impact on crop yield level was observed when combining fungicides at a 75% rate with the application of Ecoline Phosphite (K) fertiliser (Table 2). This variant also demonstrated the maximum level of marketable produce (96%).

Table 2. *Change in tomato yield using fungicides and Ecoline Phosphite (K) fertiliser (average for 2022-2024)*

Variants	Total yield, t/ha	Increase		Marketability, %
		t/ha	%	
1. Control	56.26	–	–	91.6
2. Recommended fungicides	60.72	4.48	7.9	93.7
3. Recommended fungicides (75% dose) + Ecoline Phosphite (K)	65.21	8.95	15.9	96.0
4. Recommended fungicides (50% dose) + Ecoline Phosphite (K)	61.19	4.93	8.8	94.0
$LSD_{0.95}$		5.37		

Source: developed by the authors

The variant combining fungicides at a 75% rate with Ecoline Phosphite (K) fertiliser also provided the maximum positive impact on the biochemical composition of the tomato produce (Table 3). Under this technological measure, a significant increase in total soluble solids to a level of 3.98% and total sugars to a level of 2.53% was noted. There was also a positive trend regarding the increase in vitamin C content in the fruits to a level of 25.48 mg/100 g. Reducing the fungicide rate by 50% in combination with the application of Ecoline Phosphite (K) fertiliser was also effective; this significantly increased the total sugar content in the fruits to 2.49% and showed a positive trend for the increase in vitamin C content in the fruits to a level of 25.82 mg/100 g.

Table 3. *Effect of fungicides and Ecoline Phosphite (K) fertiliser on the biochemical composition of tomato fruits (average for 2022-2024)*

Variants	Content in fruits, %			
	Soluble dry matter	Total sugar	Vitamin C, mg/100g	Acidity
1. Control	3.46	2.11	25.11	0.46
2. Recommended fungicides	3.61	2.43	24.67	0.45
3. Recommended fungicides (75% dose) + Ecoline Phosphite (K)	3.98	2.53	25.48	0.46
4. Recommended fungicides (50% dose) + Ecoline Phosphite (K)	3.60	2.49	25.82	0.46
$LSD_{0.95}$	0.30	0.22	1.88	0.04

Source: developed by the authors

The use of Ecoline Phosphite (K) fertiliser proved to be an economically advantageous technological measure (Table 4). Understandably, this technological approach increases costs due to the price of the fertiliser and the cost of harvesting the additional yield, but it reduces expenditure on recommended fungicides. Consequently, the total costs increase to a much lesser extent (by 19.6-30.5 thousand UAH/ha) than the additional profit generated by using Ecoline Phosphite (K) fertiliser with a reduced fungicide rate (by 72.3-136.3 thousand UAH/ha).

Table 4. *Economic efficiency of using Ecoline Phosphite (K) fertiliser for tomato cultivation (average for 2022-2023)*

Variants	Economic indicators				
	Marketable yield, t/ha	Total costs, thousand UAH/ha	Profit, thousand UAH/ha	Production cost, UAH/kg	Production profitability, %
1. Control	51.53	340.5	174.8	6.61	51.3
2. Recommended fungicides	60.72	360.1	247.1	5.93	68.6
3. Recommended fungicides (75% dose) + Ecoline Phosphite (K)	65.21	371.0	311.1	5.69	83.9
4. Recommended fungicides (50% dose) + Ecoline Phosphite (K)	61.19	360.6	251.3	5.89	69.7

Source: developed by the authors based on Minfin (n.d.)

This technological measure is particularly beneficial when the fungicide rate is reduced by 25%, leading to a high level of profitability (83.9%) and a reduction in production cost from 5.93 UAH/kg with the full fungicide rate to 5.63 UAH/kg.

Discussion

The use of phosphite fertilisers (Ecoline Phosphite (K)) primarily had a positive impact on the growth of certain biometric parameters of tomato plants, such as plant height and the number of trusses per plant. Higher rates of vegetative growth positively influence future plant productivity by increasing the photosynthetic apparatus and also facilitating faster recovery of leaves damaged by diseases (primarily Alternaria leaf blight).

Research indicating certain fungicidal properties of phosphite fertilisers (Ecoline Phosphite (K) providing a reduction in disease development to 65%, and with reduced rates to 50%-60%) is also supported by the scientific studies of other researchers. Similar results were obtained in studies by I. Fagundes-Nacarath *et al.* (2018) and L.C. Costa *et al.* (2020), where the use of phosphite fertilisers in bean cultivation reduced the negative consequences of *Sclerotinia sclerotiorum* development by decreasing photochemical dysfunctions. However, the action of phosphites on phytopathogens involves both direct and indirect effects. In the first instance, according to M.G. Yáñez-Juárez *et al.* (2018), phosphite ions, upon contact with pathogens, affect their growth and reproduction by influencing the expression of genes encoding compounds essential for various cell structures. Research by R. Garcia-Velasco *et al.* (2020) indicates that the application of phosphites inhibits the oxidative phosphorylation of oomycete metabolism, halts mycelial growth processes, and increases the activity of the pentose phosphate pathway, which significantly reduces enzyme activity.

In the research of O. Silva *et al.* (2013), phosphite was considered a biostimulant of systemic acquired resistance. Upon entering the plant cell, it activates biochemical and structural defence mechanisms (such as the production of polysaccharides, phytoalexins, or pathogenesis-related proteins) which limit the penetration and spread of pathogens within the plant organism. According to E. Liljeroth *et al.* (2016), phosphites inhibit the development of protozoa, oomycetes, fungi, bacteria, and nematodes, but their effectiveness depends on the ions bound to the phosphites (potassium phosphite, calcium phosphite, etc.) and the application methods (drenching and foliar feeding). The effectiveness of phosphite fertilisers is also influenced by the overall technological level of the farm and the intensity of the plant protection system against diseases involving fungicides and biopreparations.

The increase in tomato yield and the improvement in produce quality when using fertilisers containing phosphorus in the phosphite form are attributed to the reduced development of major tomato diseases and the optimisation of growth processes due to the stimulating effect of the fertiliser.

The mechanism by which phosphite affects plants is not yet fully understood; however, there is some evidence suggesting it is specific to roots and not solely related to a role as a pesticide or fertiliser. For instance, in greenhouse studies conducted by S. Rossall *et al.* (2016) on wheat, oilseed rape, sugar beet, and ryegrass, phosphites improved root biomass by approximately 30%. This enhanced the uptake of nutrients from the substrate, which are essential for developing a productive photosynthetic apparatus. Nevertheless, the fertiliser capacity of phosphites remains a subject of debate. According to F. Bertsch *et al.* (2009), phosphites can be absorbed via roots or leaves and transported through the xylem or phloem, but they cannot be directly utilised as a form of phosphate nutrition and therefore cannot serve as direct substitutes for phosphate fertilisers. However, the ability of soil microorganisms to oxidise phosphites to phosphates presents a possibility for their application as a source of phosphorus nutrition, as noted in the study of M. Manna *et al.* (2016). Microbial oxidation of phosphite is facilitated by the enzyme phosphite dehydrogenase. Consequently, certain *Bacillus* species and other microorganisms are capable of oxidising phosphite and hypophosphite to phosphate.

The mechanism by which phosphite acts on plants is not fully understood; however, there is some evidence to suggest it is specific to roots and not solely associated with a role as a pesticide or fertiliser. For example, in greenhouse studies by S. Rossall et al. (2016) involving wheat, oilseed rape, sugar beet, and ryegrass, phosphites improved root biomass by approximately 30%. This enhanced the uptake of nutrients from the substrate required for the development of a productive photosynthetic apparatus. Although the fertiliser capacity of phosphites is still debated. According to F. Bertsch *et al.* (2009), phosphites can be absorbed through roots or leaves and transported via the xylem or phloem, but they cannot be directly used as a form of phosphate nutrition and thus cannot be direct substitutes for phosphate fertilisers.

It should also be considered that, according to the results of some studies by E. Estrada-Ortiz *et al.* (2011), the effectiveness of phosphites as a partial source of phosphorus for plants is confirmed. In other studies, phosphites either have no significant effect on the growth and yield of agricultural crops or even negatively impact plant productivity. According to H. Thao *et al.* (2008), foliar and root applications of potassium phosphite did not improve the nutrition of spinach (*Spinacia oleracea* L.) and, conversely, strongly inhibited root growth under phosphate deficiency.

Given that in the present study, foliar applications of potassium phosphite contributed to both a reduction in tomato Alternaria leaf blight development with reduced fungicide rates and an increase in yield by 9%-16% due to a stimulating effect on tomato plant growth processes, a dual action of phosphite fertilisers in open-field tomato cultivation can be noted. However, the research programme did not allow for the quantification of the separate contributions of the fungicidal and stimulating effects of phosphite fertilisers on tomato yield. This is potentially related to the close interaction between plant growth processes, mechanisms for increasing plant resistance to phytopathogenic organisms, and the suppression of their development (Vdovenko *et al.*, 2024).

Similar to various studies by other researchers, phosphites demonstrated a positive trend in improving product quality, contributing to an increase in the content of soluble dry matter, total sugars, and vitamin C in tomato fruits. This is particularly important given the increase in crop yield. Frequently, an increase in the yield of vegetable crops is associated with a decrease in the content of biologically active compounds in the produce; hence, the yield level often correlates inversely with the content of vitamins and sugars in the produce.

The high economic indicators associated with the use of phosphite fertilisers are linked to two factors: the increase in tomato yield resulting from the stimulating and fungicidal action of the Ecoline Phosphite (K) product, and the savings achieved by reducing the amount of fungicides used (especially with a 50% rate reduction). However, despite the higher yield obtained when using the phosphite fertiliser in combination with 75% of the recommended fungicide rate, the most economically expedient option proved to be the application of Ecoline Phosphite (K) with only a 25% reduction in the fungicide rate, due to the overall economic benefit realised under those conditions. Furthermore, reducing the fungicide rate has an indirect, prolonged positive effect on agrobiocoenosis, reducing the chemical load and decreasing the likelihood of resistance developing in various species of phytopathogenic microorganisms.

Conclusions

Therefore, under irrigated conditions in the Left-Bank Forest-Steppe of Ukraine for tomato cultivation, reducing the rate of recommended fungicides (Ridomil Gold, Luna Experience, Quadris, biopreparations MycoHelp and Phytocid) by 25%-50% in combination with the comprehensive use of Ecoline Phosphite (K) fertiliser is effective. The recommended application schedule for Ecoline Phosphite (K) is 1 L/ha 10 days after transplanting, followed by 1.5 L/ha 20 days after the first application, 1.5 L/ha 20 days after the second, 2 L/ha 20 days after the third, 2 L/ha 15 days after the fourth, and a further 2 L/ha 15 days after the fifth application.

Observed benefits include an increase in tomato plant height by 4.3%-8.7% and the number of trusses by 15.6%-20.0%. Development of Alternaria leaf blight is reduced to a level of 60%-65% (compared to 82% in the control). Under this technological approach, crop yield increases by 4.98.8 t/ha, or 8.95%-15.9%. Fruit quality is also enhanced, with increased content of total soluble solids (up to 3.6%-3.98%), total sugars (up to 2.49%-2.53%), and vitamin C (up to 25.4825.82 mg/100 g).

The maximum impact was noted when using 75% of the fungicide rate in combination with the Ecoline Phosphite (K) application, which also yielded high economic indicators: a profit of 311.1 thousand UAH/ha, profitability of 83.9%, and the lowest production cost (5.69 UAH/kg).

The application of fertilisers containing phosphorus in the phosphite form has proven to be a promising measure for both optimising plant protection and improving tomato growth parameters, yield, and fruit quality under irrigated conditions. The results obtained confirm the ability of phosphites not only to act as inducers of systemic plant resistance but also as a factor contributing to the reduction of pesticide load without compromising the effectiveness of crop protection. Furthermore, their positive influence on the biochemical composition of the fruits was established, which is important for improving the nutritional value of the produce.

Future research perspectives include investigating the mechanisms of action of phosphite fertilisers on biochemical and physiological-molecular processes in tomato plants, particularly their effect on enzymatic activity and the antioxidant system. It would also be pertinent to conduct research into the possibility of complete or partial replacement of traditional phosphorus fertilisers with phosphite forms in conditions of limited available phosphorus in soils and to assess the longterm environmental safety of such application. A separate avenue for future research could focus on evaluating the effectiveness of phosphites under varying levels of water supply, which would allow for the adaptation of this technology to conditions of climate change and increasing water scarcity.

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Conflict of Interest

None.

References

[1] Bertsch, F., Ramírez, F., & Henríquez, C. (2009). Evaluation of phosphite as a source of phosphorus fertiliser via the root and foliar routes. *Agronomía Costarricense*, 33(2), 249-265.

[2] Bondarenko, G.L., & Yakovenko, K.I. (Eds.). (2001). *Methodology of research work in vegetable growing and melon growing*. Kharkiv: Osnova.

[3] Convention on Biological Diversity. (1992, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[4] Costa, L.C., Debona, D., Silveira, P.R., Cacique, I.S., Aucique-Pérez, C.E., Resende, R.S., Oliveira, J.R., & Rodrigues, F.A. (2020). Phosphites of manganese and zinc potentiate the resistance of common bean against infection by *Xanthomonas axonopodis* pv. *phaseoli*. *Journal of Phytopathology*, 168(11), 641-651. doi: 10.1111/jph.12944.

[5] DSTU 4954:2008. (2008). *Products of fruit and vegetable processing. Methods for the determination of sugars*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=74270.

[6] DSTU 7803:2015. (2015). *Products of fruit and vegetable processing. Methods for the determination of vitamin C*. Retrieved from https://surli.cc/qcrwcx.

[7] DSTU 7804:2015. (2016). *Fruit and vegetable processing products. Methods for determining dry matter or moisture*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=80802.

[8] DSTU ISO 6632-2001. (2001). *Fruits, vegetables and processed products. Determination of volatile acidity (ISO 6632:1981, IDT)*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=84782.

[9] Estrada-Ortiz, E., Trejo-Téllez, L.I., Gómez-Merino, F.C., Núñez-Escobar, R., & Sandoval-Villa, M. (2011). Biochemical responses in strawberry plants supplying phosphorus in the form of phosphite. *Revista Chapingo Serie Horticultura*, 17(3), 129-138.

[10] Fagundes-Nacarath, I.R.F., Debona, D., Brás, V.V., Silveira, P.R., & Rodrigues, F.A. (2018). Phosphites attenuate *Sclerotinia sclerotiorum*-induced physiological impairments in common bean. *Acta Physiologiae Plantarum*, 40, article number 198. doi: 10.1007/s11738-018-2776-7.

[11] Garcia-Velasco, R., Mora-Herrera, M. E., Mejía-Carranza, J., Aguilar-Medel, S., & González-Millán, M. (2020). Potassium phosphites in the management of peronospora sparsa berkeley and floral quality of the rose cv Samouraï crop. *Acta Agrícola y Pecuaria*, 7(1), 1-10.

[12] Kuts, O.V., Kokoiko, V.V., Mykhailyn, V.I., Onyshchenko, O.I., & Syromyatnikov, Y.M. (2024). Impact of nutrient management on physiological processes, biochemical properties, and productivity of table beetroot (*Beta vulgaris* L.). *Agricultural Science and Practice*, 11(3), 61-71. doi: 10.15407/agrisp11.03.061.

[13] Lagunas, B., Dodd, I.C., & Gifford, M.L. (2019). A 'nodemap' to sustainable maize roots: Linking nitrogen and water uptake improvements. *Journal of Experimental Botany*, 70(19), 5036-5039. doi: 10.1093/jxb/erz315.

[14] Liljeroth, E., Lankinen, A., Wiik, L., Burra, D.D., Alexandersson, E., & Andreasson, E. (2016). Potassium phosphite combined with reduced doses of fungicides provides efficient protection against potato late blight in large-scale field trials. *Crop Protection*, 86(1), 42-55. doi: 10.1016/j.cropro.2016.04.003.

[15] Manna, M., Achary, V.M.M., Islam, T.M., Agrawal, P.Q., & Reddy, M.K. (2016). The development of a phosphite-mediated fertilization and weed control system for rice. *Scientific Reports*, 6(1), article number 24941. doi: 10.1038/srep24941.

[16] Minfin. (n.d.). *Prices for products. Vegetables: Tomatoes*. Retrieved from https://index.minfin.com.ua/ua/markets/wares/prods/fruits-vegetables/vegetables/tomato/.

[17] Mohammadi, M.A., *et al.* (2021). ROS and oxidative response systems in plants under biotic and abiotic stresses: Revisiting the crucial role of phosphite triggered plants defense response. *Frontiers in Microbiology*, 12, article number 631318. doi: 10.3389/fmicb.2021.631318.

[18] Panfili, I., Bartucca, M.L., Marrollo, G., Povero, G., & Del Buono, D. (2019). Application of a plant biostimulant to improve maize (*Zea mays*) tolerance to metolachlor. *Journal of Agricultural and Food Chemistry*, 67(44), 12164-12171. doi: 10.1021/acs.jafc.9b04949.

[19] Rossall, S., Qing, C., Paneri, M., Bennett, M., & Swarup, R. (2016). A 'growing' role for phosphites in promoting plant growth and development. *Acta Horticulturae*, 1148, 61-67. doi: 10.17660/ActaHortic.2016.1148.7.

[20] Silva, O., Santos, A.A., Deschamps, C., Dalla-Pria, M., & May-Mio, L. (2013). Sources of phosphite and acibenzolar-S-methyl associated with fungicides for the control of foliar diseases in the soya crop. *Tropical Plant Pathology*, 38(1), 72-77. doi: 10.1590/S1982-56762013000100012.

[21] Syromyatnikov, Y., Kuts, O., & Rudyi, S. (2024). Soil biological activity in sugar beet crops depending on various combinations of agrotechnology elements. *Agrobiology*, 2, 117-127. doi: 10.33245/2310-9270-2024-191-2-117-127.

[22] Thao, H., Yamakawa, T., Myint, A., & Sarr, P. (2008). Effects of phosphite, a reduced form of phosphate, on the growth and phosphorus nutrition of spinach (*Spinacia oleracea* L.). *Soil Science and Plant Nutrition*, 54(5), 761-768. doi: 10.1111/j.1747-0765.2008.00290.x.

[23] Vdovenko, S., Palamarchuk, I. , Mazur, O., Mazur, O., & Havrys, I. (2024). Influence of biological preparations on organic cultivation of vegetable plants. *Plant and Soil Science*, 15(1), 9-25. doi: 10.31548/plant1.2024.09.

[24] Xi, Y., Han, X., Zhang, Z., Joshi, J., Borza, T., Mohammad, M.A., Zhang, B., Yuan, H., & Wang-Pruski, G. (2020). Exogenous phosphite application alleviates the adverse effects of heat stress and improves thermotolerance of potato (*Solanum tuberosum* L.) seedlings. *Ecotoxicology and Environmental Safety*, 190, article number 110048. doi: 10.1016/j.ecoenv.2019.110048.

[25] Yáñez-Juárez, M.G., López-Orona, C.A., Ayala-Tafoya, F., Partida-Ruvalcaba, L., Velázquez-Alcaraz, T.J., & Medina-López, R. (2018). Phosphites as alternative for the management of phytopathological problems. *Revista Mexicana de Fitopatologia*, 36(1), 79-94. doi: 10.18781/r.mex.fit.1710-7.

Ефективність фосфітних добрив в технології вирощування помідору

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Анотація. Метою досліджень було визначення ефективності використання добрив з фосфітною формою фосфору за вирощування помідору в зрошуваних умовах Лівобережного Лісостепу України. Польові дослідження проводилися впродовж 2022-2024 років в Інституті овочівництва і баштанництва Національної аграрної академії наук України на чорноземі типовому малогумусному важкосуглинковому на лесовидному суглинку. Встановлено, що за вирощування помідору ефективним було зменшення норми рекомендованих фунгіцидів (Ридоміл голд, Луна екпірієнс, Квадріс, біопрепарати Мікохелп та Фітоцид) на 25-50 % в поєднанні з комплексним використанням добрив Еколайн фосфітний К (через 10 днів після висадки розсади 1 л/га + через 20 днів після першої обробки 1,5 л/га + через 20 днів після другої обробки 1,5 л/га + через 20 днів після третьої обробки + через 15 днів після четвертої обробки + через 15 днів після п'ятої обробки по 2 л/га). Вказані технологічні підходи забезпечили зростання висоти рослин помідору на 4,3-8,7 %, кількості китиць – на 15,6-20,0 %, зниження розвитку альтернаріозу до рівні 60-65 % (на контролі 82 %). За вказаного технологічного заходу урожайність культури зростала на 4,9-8,8 т/га, підвищувався вміст у плодах сухої розчинної речовини (до рівня 3,6-3,98 %), загального цукру (до 2,49-2,53 %), вітаміну С (до рівня 25,48-25,82 мг/100 г). Максимальний вплив зазначається за використання 75 % норми фунгіцидів у поєднанні з внесення Еколайн фосфітний К, що також має високі економічні показники: прибуток на рівні 311,1 тис. грн./га, рентабельність – 83,9 % та найменша собівартість продукції (5,69 грн./кг)

Ключові слова: *Solanum lycopersicum* L.; фосфорне живлення; біометричні параметри рослин; урожайність; біохімічний склад продукції; рентабельність