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Study of the influence of phosphite fertilisers on the quality of apple fruits in plantings of the 'Fuji' variety

Abstract. The purpose of the study was to establish the effectiveness of foliar fertilisation with phosphite fertilisers by the company LLC "Ecoorganic" in apple plantations of the 'Fuji' cultivar and to determine their influence on the dynamics of accumulation of dry soluble substances, sugars, and organic acids in fruits. The research was conducted in 2022 on the experimental orchards of Uman National University of Horticulture (Ukraine). In the experiment, a control without fertiliser application and variants treated with three types of fertilisers (Poliaktiv Twinfos, Poliaktiv Twinfos Amino, Ecoline Phosphite K-Amino) at a dose of 1.5 L/ha during the fruit ripening phase were compared. Refractometric, spectrophotometric, and titrometric methods were used to assess the biochemical composition of the fruits. The findings showed that foliar fertilisation significantly affected the biochemical indicators of apple fruit quality. During the fruit ripening period, an increase in the content of dry soluble substances was observed in all experimental variants; however, the highest values were recorded when using the fertiliser Poliaktiv Twinfos, where this indicator significantly exceeded the control. A similar pattern was established for sugar accumulation: their maximum content was noted in fruits treated with the fertiliser Poliaktiv Twinfos, while the use of fertilisers Poliaktiv Twinfos Amino and Ecoline Phosphite K-Amino also ensured an increase in this indicator compared to the control. Furthermore, in all variants with foliar fertilisation, a decrease in

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the content of organic acids in fruits was observed, which contributed to the development of a more balanced taste. The most pronounced effect of acidity reduction was established when using the fertiliser Poliaktiv Twinfos. Practical significance of the study consists in the scientific substantiation of the feasibility of foliar fertilisation of the 'Fuji' apple cultivar during the fruit ripening phase to increase sugar content, reduce acidity, and improve the commercial and consumer qualities of fruits under conditions of increasing climate stress

Keywords: foliar fertilisation; biochemical composition of fruits; dry soluble substances; sugar content; organic acids

INTRODUCTION

In contemporary horticulture, the stability of production and the competitiveness of products are largely determined by the ability of plantations to withstand high temperatures and moisture deficiency during the summer period. It is precisely in the phase of fruit filling and ripening that intensive processes of carbohydrate synthesis and accumulation, transformation of organic acids, development of aroma, coloration, and flesh density occur. Disturbances in water balance and heat load during this period negatively affect the accumulation of soluble solids, reduce sugar content, and worsen taste characteristics and the market appearance of fruits. In this regard, the search for effective foliar fertilisation techniques capable of correcting physiological and biochemical processes in plants and increasing their adaptive potential under stressful growing conditions becomes especially relevant.

Analysis of contemporary scientific studies indicates a growing interest in the problem of optimising fruit crop nutrition during periods of climate change. V. Do *et al.* (2024) in their study established that the combination of high temperatures and uneven watering throughout the growing season leads to disturbances in physiological processes in apple trees, in particular, to a decrease in the intensity of photosynthesis, suppression of growth processes, and a reduction in average fruit weight. The researchers concluded that moisture deficiency in critical developmental phases negatively affects the accumulation of soluble solids and worsens the market quality of products, which requires the implementation of adaptive agrotechnical measures to increase plant resistance to climate stresses. Developing this area, S. Świerczyński *et al.* (2021) showed that foliar application of microelements, fertilisers, and biostimulants during the phase of intensive fruit growth activates enzymatic processes, stabilises metabolism, and contributes to increased apple yield under conditions of abiotic stress. The researchers emphasised that such operational correction of mineral nutrition through the leaf apparatus allows plants to quickly respond to changes in the external environment and reduce the negative impact of stressful growing factors.

Similar results were obtained by some Ukrainian researchers who investigated the influence of humic and fulvic acids on plants. In particular, O. Rylskyi *et al.* (2023) noted that the application of humic compounds in plant cultivation contributes to increased plant resistance to abiotic stresses, activation of enzymatic processes, and improvement of product quality indicators, which confirms the appropriateness of using such substances as an element of adaptive agrotechnologies. Contemporary studies emphasise the importance of improving apple foliar feeding systems to increase productivity and quality characteristics of fruits. In particular, V. Leus *et al.* (2023) showed that the application of biostimulant micronutrients within the framework of foliar feeding contributes to increased fruit size, their marketability, and the economic efficiency of cultivation. The application of such preparations stimulates physiological processes in the plant, which ensures more uniform fruit growth and improves their consumer properties.

The literature analysis conducted by R. Yakovenko *et al.* (2025) confirmed that the combination of soil and foliar fertilisation is optimal

for ensuring high yields of apples and pears. They emphasised that balanced plant nutrition not only improves quantitative yield indicators but also contributes to increasing the biochemical quality of fruits, including increasing soluble sugar content and reducing titratable acidity, which directly affects the market and consumer properties of the products. These results were also confirmed by recent studies on other types of foliar fertilisation. Y. Lu *et al.* (2025) showed that foliar application of zerovalent iron nanoparticles significantly improves photosynthetic activity, enzymatic activity of leaves, and fruit quality of 'Yanfu No.6' apples. In the experiment, an increase in fruit weight, vitamin C content, soluble proteins, and overall quality indicators was observed, indicating the effectiveness of foliar microelement application in enhancing the physiological condition of the plants.

In Ukrainian studies, I. Trushev & R. Yakovenko (2023) investigated methods of rational use of fertilisers and foliar feeding in intensive apple orchards, confirming similar results. It was shown that the application of such approaches contributes to improved tree growth, accumulation of nutrients in leaves, and increased overall yield. Additionally, O. Tkachuk & A. Mizeriy (2024) demonstrated that the use of biofertilisers and foliar applications in apple orchards improves the physiological condition of the plants, increases yield, and enhances fruit quality characteristics, including flesh firmness, content of vitamin C and soluble solids. Their results confirm that integrating biofertilisers and foliar feeding is an effective method for improving apple resilience to stress factors and fruit quality.

Phosphite fertilisers attract particular interest in contemporary research as a promising element of the foliar feeding system. X. Han *et al.* (2021) substantiated that phosphite compounds are characterised by systemic mobility and the ability to induce plant defence responses in response to abiotic stresses. The researchers noted that phosphites influence the regulation of metabolic processes associated with plant adaptation to adverse conditions, improving physiological and biochemical reactions, which can contribute to increased yield and product quality under stressful conditions. Further studies show that phosphite compounds can enhance antioxidant protection of plants, improve their water status, and increase resistance to temperature and water stresses. In particular, M. Nyoni *et al.* (2021) demonstrated in apple trees that foliar application of phosphonates contributes to the accumulation of phosphite residues in plant tissues and increases their resistance to abiotic factors. Thus, Z. Li *et al.* (2025) argued that the application of phosphite fertilisers as foliar feeding not only provides effective plant nutrition but also acts as a powerful stimulator of physiological processes that increase plant resistance to abiotic stress. Researchers noted that foliar application of phosphites promotes the regulation of processes of soluble sugar accumulation and reduction of titratable acidity of fruits, which directly affects their market and consumer properties.

The purpose of the study was to evaluate the effect of foliar application of phosphite fertilisers on the development of biochemical indicators of apple fruit quality during their ripening period.

MATERIALS AND METHODS

The study on the effectiveness of foliar application of fertilisers by LLC "Ecoorganic" in apple plantations was conducted in 2022 at the experimental orchards of Uman National University of Horticulture, located in the Mankivka natural-agricultural region of the Middle Dnipro-Bug district of the Right-Bank Forest-Steppe of Ukraine. The object of the study was the 'Fuji' apple cultivar, included in the "Register of Plant Varieties Suitable for Distribution in Ukraine" (UIPVE, n.d.). 'Fuji' apple (*Fuji*) is an autumn-winter cultivar, selected by Japanese breeders in the Fujisaki region (from which its name originates) by crossing the 'Rolls Janet' and 'Red Delicious' cultivars (Fig. 1). The 'Fuji' apple tree is of medium size, 3.0-3.5 m tall, with a compact crown. It begins fruiting in the 3rd year. Flowering occurs in mid-late periods, which reduces the risk of fruit set damage by spring frosts. Fruiting is periodic, and yield is high. The fruits are round, large, with an average weight of approximately 200 g, red-pink in colour with yellow spots beneath the skin. The

Figure 1. Fruits of the 'Fuji' apple cultivar
Source: authors' photo

flesh is creamy, crisp, with a sweet-sour taste and high sugar content. Harvesting is carried out in mid to late October, and the fruits reach consumer ripeness 3-4 weeks after picking. The cultivar is characterised by good winter hardiness, high transportability, and a long storage period. Resistance to diseases is average. The fruits have universal use – suitable for fresh consumption and processing. The experimental design of the study included a control (treated with water) and three variants in which phosphite fertilisers were applied: Poliaktiv Twinfos, Poliaktiv Twinfos Amino, and Ecoline Phosphite K-Amino at a rate of 1.5 L/ha (Table 1).

Table 1. Experimental design

Application phase	Control	Variant 1 – Polyactive Twinphos	Variant 2 – Polyactive Twinphos Amino	Variant 3 – Ecoline Phosphite K-Amino
Fruit ripening period	Water treatment	1.5 L/ha	1.5 L/ha	1.5 L/ha

Source: the research scheme was approved by Ecoorganic (n.d.)

Fertilisers were applied on August 6, 15, and 25, 2022, during the fruit ripening period of the 'Fuji' cultivar (Fig. 2).

Figure 2. Images of trees of the experimental variants
Note: 1 – Polyactive Twinphos, 2 – Polyactive Twinphos Amino, 3 – Ecoline Phosphite K-Amino
Source: authors' photo

During the development of the experimental design and methodology, the main methodological recommendations of Ukrainian researchers G. Karpenchuk & A. Melnyk (1987) and V. Moiseychenko & V. Eshchenko (1994), and the authors' original methods, were used. For all experimental variants, the control was foliar treatment of the trees with water. During the fruit formation period on the tree, the content of the main organic substances was determined: dry soluble substances – by refractometric method according to DSTU ISO 2173-2007 (2009); sugars – by spectrophotometric method according to DSTU 4954-2008 (2009), organic titratable acids – by titration with 0.1N NaOH solution. The study was conducted in accordance with ethical standards of the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973).

RESULTS AND DISCUSSION

The investigation of the effect of foliar fertilisation of 'Fuji' apple trees on the development of biochemical indicators of fruits showed that the accumulation of main soluble dry substances (SDS) largely depended on the type of fertilisers and the time of application. A. Hernández-Rodríguez *et al.* (2021) emphasised that

foliar nutrition significantly affects fruit quality, including the content of soluble dry substances and sugars, which confirms the relevance of the study. The results indicate that during fruit ripening there was a gradual accumulation of SDS. The maximum SDS values were recorded in the variants treated with phosphite fertilisers, particularly Poliactiv Twinfos, which indicates the effectiveness of this preparation in increasing the biochemical value of fruits. Notably, direct studies on the effect of phosphite fertilisers on the accumulation of SDS and sugars in 'Fuji' apples are currently absent, therefore, the current findings are the first to demonstrate the positive effect of phosphite foliar applications on the biochemical composition of fruits of this cultivar.

Similar tendencies were observed in studies of foliar fertilisation with microelements and complex fertilisers. Thus, F. Mirzavandi *et al.* (2025) noted that foliar application of microelements, including phosphorus, contributes to the increase in the content of soluble dry substances and sugars in apple fruits. D. Ljavić *et al.* (2023) showed that foliar fertilisation changes the concentration of nutrients in leaves and affects the development of the biochemical composition of fruits. Thus, the increase of SDS in the variants with Poliactiv Twinfos corresponds to the general tendency of improving fruit quality due to foliar nutrition. At the beginning of September, SDS ranged from 11.0% in the control to 12.4% in the variant with Poliactiv Twinfos. At the end of the second ten days of September, the SDS level slightly decreased due to about 100 mm of precipitation, which led to the dilution of soluble substances in fruits. During the entire observation period, the lowest SDS content (11.2%) was recorded in the control, and the highest (12.8%) – with the treatment of Poliactiv Twinfos (Fig. 3).

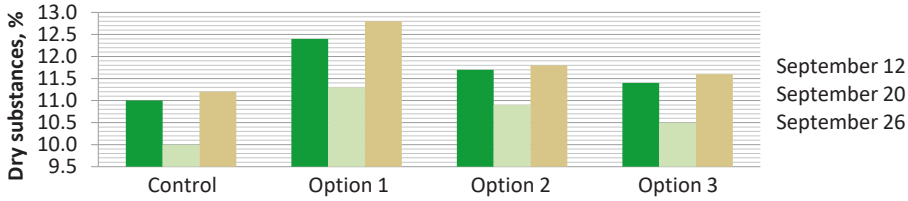

Figure 3. Dynamics of dry soluble substances (DSS) accumulation in 'Fuji' apple fruits during ripening depending on foliar treatment of plantations
Source: developed by the authors

Thus, the results indicate the effectiveness of foliar application of phosphite fertilisers in increasing the biochemical value of fruits of the 'Fuji' apple and confirm the importance of foliar nutrition for optimising fruit quality under conditions of summer heat and water stress. The same tendencies were observed in the assessment of the soluble sugar content, which was also the highest in the variant with Poliactiv Twinfos (9.6%), while the application of Poliactiv Twinfos Amino and Ecoline Phosphite K-Amino provided 8.85% and 8.7% of sugars, respectively (Fig. 4).

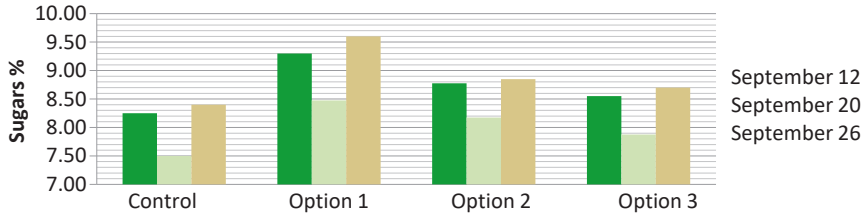

Figure 4. Dynamics of sugar accumulation in 'Fuji' apple fruits during ripening depending on foliar treatment of plantations
Source: developed by the authors

H.-F. Xu *et al.* (2025) in their paper noted that the application of amino acid and mineral foliar fertiliser contributes to an increase in soluble sugars in the 'Snick' apple cultivar, simultaneously improving Brix values and the accumulation of soluble dry substances. In addition, they noted that amino acid fertilisation stimulates fruit metabolism and contributes to increased sweetness while maintaining optimal acidity. Similar results were described by S. Mousavi *et al.* (2024), who showed that the use of seaweed extract in 'Golden Delicious' not only increased the content of soluble sugars by 1.2-1.5% compared to the control, but also improved the sugar-to-acid ratio, which positively affects the taste quality of fruits. The researchers also noted that foliar treatments increased the activity of enzymes involved in sugar synthesis, which fully corresponds to observations regarding the effectiveness of Poliactiv Twinfos in the current study.

Regarding organic acids, the present data showed their decrease with the application of phosphite preparations. In September, the acid content in fruits ranged from 0.304% in the control variant (water treatment) to 0.272% in the variant with Poliactiv Twinfos, 0.278% – in the variant with Poliactiv Twinfos Amino, and 0.288% – with the treatment of Ecoline Phosphite K-Amino (Fig. 5). The use of Poliactiv Twinfos during the fruit ripening period led to a reduction in organic acid content by 0.033% compared to the control.

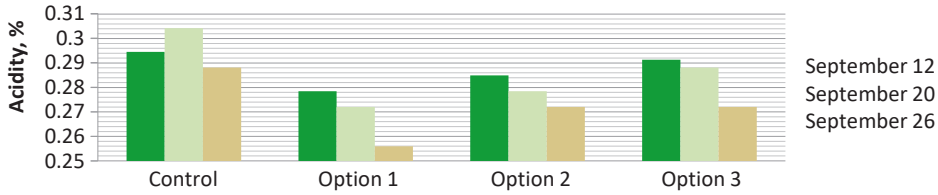

Figure 5. Dynamics of organic acid accumulation in 'Fuji' apple fruits during ripening depending on foliar treatment of plantations
Source: developed by the authors

Similar tendencies are observed in other studies. S. Yang *et al.* (2023) noted that foliar fertiliser based on seaweed extract contributes to a moderate decrease in acidity and a simultaneous increase in the sugar content of 'Fuji' fruits. F. Mirzavandi *et al.* (2025) showed that the combined application of phosphorus with nitrogen and iron increases the concentration of soluble sugars in fruits and moderately reduces acidity. In addition, S. Banyal (2021) noted that foliar application of mineral fertilisers during the fruit filling period increases sweetness and SDS, while acidity decreases within 0.02-0.04%, which corresponds well to the observations regarding the effect of Poliactiv Twinfos. Thus, the results indicate that phosphite fertilisation not only stimulates the accumulation of soluble dry substances and sugars in fruits, but also provides a moderate reduction in organic acidity, which contributes to the optimal combination of sweetness and taste properties of 'Fuji' apples.

CONCLUSIONS

As a result of the conducted studies, it was established that foliar feeding of 'Fuji' apple trees with the phosphite fertilisers Polyactive Twinphos, Polyactive Twinphos Amino, and Ecoline Phosphite K-Amino has a significant positive effect on the development of fruit quality indicators. In particular, an increase in soluble sugar content and a simultaneous decrease in titratable acidity were noted compared to the control variant, which directly affects the taste properties of the fruits and their consumer attractiveness. The improvement of the chemical composition of fruits is conditioned by the activation of key biochemical processes during the ripening period, in particular, the optimisation of carbohydrate metabolism, transformation of organic acids, increased activity of enzymes responsible for the synthesis of biologically active compounds, and improvement of the antioxidant potential of the fruits. This indicates a systemic effect of phosphite fertilisers on the physiological and

biochemical processes of the plant, ensuring more uniform fruit development and increasing their market value.

Based on the obtained results, for commercial plantings of 'Fuji' apple trees, it is advisable to carry out foliar feeding during the fruit ripening phase using the Polyactive Twinphos fertiliser at a rate of 1.5 L/ha, which will contribute to an increase in the consumer quality of the fruits and improvement of their taste characteristics. The use of other phosphite preparations, such as Polyactive Twinphos Amino and Ecoline Phosphite K-Amino, is also effective; however, it is advisable to carry out comparative testing to determine the optimal rate and frequency of application. Prospects for further research lie in a comprehensive study of the effect of phosphite fertilisers on morpho-physiological and biochemical indicators of apple trees of different varieties at various phases of vegetation, and in combination with other adaptive agrotechnical measures (irrigation, mulching, biostimulant application). Particularly relevant is the study of the mechanisms of phosphite action under conditions of summer heat and water stress, and their impact on the storage duration of fruits and the development of resistance to physiological disorders. In addition, it is advisable to investigate the economic efficiency of their use in commercial plantings by evaluating the ratio of fertiliser costs to product quality improvement.

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CONFLICT OF INTEREST

The publication of the research data has been agreed upon between the authors and the company "Ecoorganic".

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Дослідження впливу дії фосфітних добрив на якість плодів яблуні в насадженнях сорту ‘Фуджі’

Анотація. Метою роботи було встановлення ефективності застосування позакореневого підживлення фосфітними добривами компанії ТОВ «Екоорганік» в насадженнях яблуні сорту ‘Фуджі’ та визначення їх впливу на динаміку накопичення сухих розчинних речовин, цукрів і органічних кислот у плодах. Дослідження проводили у 2022 році в умовах дослідних насаджень Уманського національного університету садівництва (Україна). У досліді порівнювали контрольний варіант без внесення добрив і варіанти з обробкою трьома видами добрив («Поліактив Твінфос», «Поліактив Твінфос Аміно», «Еколайн Фосфітний К-Аміно»), у дозі 1,5 л/га у фазу дозрівання плодів. Для оцінки біохімічного складу плодів використовували рефрактометричні, спектрофотометричні та титрометричні методи аналізу. Результати досліджень засвідчили, що позакореневе підживлення істотно впливало на біохімічні показники якості плодів яблуні. Упродовж періоду дозрівання плодів у всіх дослідних варіантах спостерігалося зростання вмісту сухих розчинних речовин, однак найвищі їх значення зафіксовано при застосуванні добрива «Поліактив Твінфос», де цей показник достовірно перевищував контроль. Аналогічну закономірність установлено щодо накопичення цукрів: максимальний їх вміст відзначено у плодах за обробки добривом «Поліактив Твінфос», тоді як застосування добрив «Поліактив Твінфос Аміно» та «Еколайн Фосфітний К-Аміно» також забезпечувало підвищення цього показника порівняно з контролем. Водночас у всіх варіантах із позакореневим підживленням спостерігалося зниження вмісту органічних кислот у плодах, що сприяло формуванню більш збалансованого смаку. Найбільш виражений ефект зменшення кислотності встановлено при використанні добрива «Поліактив Твінфос». Практична цінність роботи полягає в науковому обґрунтуванні доцільності застосування позакореневого підживлення яблуні сорту ‘Фуджі’ у фазу дозрівання плодів з метою підвищення цукристості, зниження кислотності та покращення товарних і споживчих якостей плодів в умовах зростання кліматичних стресів

Ключові слова: позакореневе підживлення; біохімічний склад плодів; сухі розчинні речовини; вміст цукрів; органічні кислоти