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The influence of foliar application of calcium-containing preparations on apple orchard productivity and fruit quality

Abstract. Effective production of high-quality and high-yielding fruit and berries is essential for addressing shortages. However, producers often encounter challenges related to calcium deficiency in apples. This study aimed to evaluate the productivity of late-ripening apple cultivars – Ligol, Jonagold Early Queen, and Fuji – following foliar application of calcium-containing preparations, as well as to assess the quality of their fruit. Field and laboratory research methods were employed to achieve this objective, and the results were subjected to statistical analysis. The study revealed that the Ligol cultivar exhibited the highest yield (19.3 t/ha) when treated with Brexil Ca at a rate of 1.8 L/ha. This represented an 8.3% increase compared to the control and a 12.9% increase compared to the variant treated with HelpRost at a rate of 1.0 L/ha. The highest fruit weight (296.5 g) was recorded for the Ligol cultivar when treated with Brexil Ca at a rate of 1.8 L/ha. Foliar application of Brexil Ca at the same rate was most effective for the Fuji cultivar, resulting in a yield of 24.8 t/ha, which was 9.8% higher than the control and 16.1% higher than the variant treated with Biocalcium (2.0 mL/ha) and HelpRost (1.0 L/ha). For the Jonagold Early Queen cultivar, the highest yield (16.2 t/ha, 8.6% above the control) and fruit weight (249.8 g, 5.4% above the control) were achieved with HelpRost at 1.0 L/ha. The highest flesh firmness in the Ligol cultivar was observed with Biocalcium treatment (2.0 mL/ha), while in the Jonagold Early Queen and Fuji cultivars, it was achieved with HelpRost (1.0 L/ha). The findings provide practical insights for enhancing apple production efficiency, improving fruit quality, and extending storage life

Keywords: Ligol; Jonagold Early Queen; Fuji, calcium-containing preparations; yield; fruit weight; flesh firmness

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INTRODUCTION

According to Law of Ukraine No. 8370-1 "On Food Security in Ukraine" (2011), fruits and berries must be included in the food basket as they are vital to the food balance. Fruit products serve as valuable raw materials for processing (freezing, juice production, jams, baby food, etc.) and provide the human body with easily digestible carbohydrates, organic acids, and vitamins.

In apple cultivation, calcium deficiency has become increasingly evident. According to Z. Wu & P. Chen (2021), extensive orchard management, excessive crop loads, and early harvesting exacerbate the issue of functional disorders in apples. Such disorders significantly affect the economic value of the produce by reducing its marketable quality, diminishing its visual appeal and taste, and, consequently, lowering consumer interest. Under these conditions, the economic efficiency of apple production inevitably declines, reducing growers' motivation to remain engaged in the apple industry.

F. Carrasco-Cuello *et al.* (2024) identified the application of calcium-containing fertilisers as an effective measure to address these challenges. The foliar application method, as examined by J. Morales *et al.* (2023), compared to soil fertilisation, facilitates better absorption of micro- and macronutrients, including calcium, by the fruit.

The use of organo-mineral nutrient complexes significantly enhances the adaptive properties of plants, increases productivity, and improves crop quality. Calcium is among the least efficiently absorbed nutrients, and its deficiency leads to various physiological disorders. Effective and rapid mitigation of calcium deficiency can be achieved through foliar feeding. Calcium fertilisers not only enhance photosynthesis and the growth rate of vegetative plant organs (Liu *et al.*, 2022) but also significantly improve fruit quality (Lin *et al.*, 2020) and increase disease resistance (Yang *et al.*, 2020).

Research by G. Wang *et al.* (2022) demonstrated that spraying apple trees with calciumcontaining fertilisers increases chloroplast content and enhances the photosynthetic capacity of apple leaves. Compared to the control, the photosynthetic rate of apple leaves sprayed with Niucui increased by 4.3-34.6%, while those treated with Naipu 9 exhibited a 15.0-57.4% increase. In addition, spraying with calcium fertilisers improved fruit quality and facilitated the accumulation of essential mineral elements (Ca, Mg, and B) in both fruit and leaves while suppressing copper (Cu) accumulation. The weight and firmness of apples harvested from orchards treated with Niucui and Naipu 9 were higher than those from the control group. Apples from trees treated with Naipu 9 contained higher levels of soluble solids, sugars, and vitamin C, whereas those from orchards treated with Niucui showed a reduction in titratable acids. This effect is attributed to Naipu 9 enhancing the activity of sugar metabolism enzymes, while Niucui increased the activity of enzymes associated with acid synthesis. The researchers concluded that the consumer quality of Fuji apples was optimal, with the most balanced taste when the orchards were treated with Naipu 9.

Y. Xu *et al.* (2022) investigated the mechanism by which calcium regulates fruit ripening. To examine changes in proteins and enriched phosphopeptides, labelling was performed on calciumtreated Golden Delicious apples. The resulting dataset provided a comprehensive overview of critical pathways associated with fruit ripening. A total of 47 proteins and 124 phosphoproteins were significantly altered in calcium-treated apples, playing key roles in regulating cell walls, ethylene production, protein modification (especially degradation), as well as primary and secondary metabolism.

P. Kowalik *et al.* (2020) conducted comparative studies on the ultrastructure of epidermal and hypodermal cells, assessing the content and distribution of calcium within the cell walls, cytoplasmic membranes, and cytoplasm of Champion apples. Their findings demonstrated a positive impact of calcium treatments on the ultrastructure of epidermal and hypodermal cells, as evidenced by the preservation of continuous cytoplasmic membranes and stabilised cell structures.

P. Wójcik *et al.* (2019) investigated the yield and fruit quality of Elstar apple trees. Their findings revealed that pre-harvest spraying with $CaCl_2$ increased calcium concentrations in leaves and fruit by an average of 22% and 39%, respectively. Additionally, an improvement in apple flesh firmness was observed.

The study aimed to examine the effects of foliar fertilisation of apple orchards with calciumcontaining preparations on yield and the physical quality parameters of the fruit.

The aim was achieved through the following objectives:

- analysing the yield of apple orchards of various cultivars treated with foliar applications of calcium-containing preparations;
- determining the firmness of apple flesh as an indicator of quality and market value;
- identifying optimal application rates of calcium-containing preparations for foliar treatment in apple orchards.

MATERIALS AND METHODS

Recognising the critical importance of biological diversity and the fact that its preservation is a shared responsibility of humanity, particularly the scientific community, the research was conducted in alignment with the Convention on Biological Diversity (1992) and the Convention on the Trade in Endangered Species of Wild Fauna and Flora (1973) to support environmental conservation and the sustainable use of its components.

The study was carried out at the educational laboratory "Fruit and Vegetable Garden" of the National University of Life and Environmental Sciences of Ukraine, located in the natural and climatic zone of Ukrainian Polissia. The area is characterised by sod-medium podzolic soils formed on fluvioglacial deposits, suitable for horticulture, and a moderately continental climate with mild winters and warm summers.

The research was conducted in 2023 in apple orchards established in 2019, with a planting scheme of 4×2.5 m, M.106 rootstock, rainfed conditions, and a protection and fertilisation system consistent with practices typical of this natural and climatic zone. The study examined the effects of foliar treatments on apple orchard yield, fruit weight, and flesh firmness. The analysis focused on late-ripening apple cultivars, including Fuji, Ligol, and Jonagold Early Queen.

The research was conducted as a three-factor experiment, with the factors being cultivar, type of preparation, and application rate. Each treatment was replicated three times. The following calcium-containing preparations were used for foliar application in the orchards: Biocalcium (Biotech LTD), HelpRost (BTU-Center), Brexil Ca (Valagro), and Avangard (AgroAntal).

The experimental design included: control – water treatment (H_2O); variant 1 – Biocalcium (2 mL/ha); variant 2 – Biocalcium (4 mL/ha); variant 3 – HelpRost (1.0 L/ha); variant 4 – HelpRost (3 L/ha); variant 5 – Brexil Ca (1.8 kg/ha); variant 6 – Brexil Ca (2.0 kg/ha); variant 7 – Avangard (3 L/ha); and variant 8 – Avangard (6 L/ha).

Foliar treatments were performed following the manufacturer's instructions for each preparation. One set of treatments was applied at the dosage recommended by the manufacturer, while another set used a dosage reduced by half. Applications were carried out at four intervals: the first occurred after the June ovary drop (late June), with subsequent treatments at 20-day intervals, and the final application conducted two weeks before harvest. Spraying took place before 10:00, with the volume adjusted to ensure the formation of water droplets on the surface of the leaves or fruit.

Yield was determined by weighing the harvested fruit from each replication of a variant, subsequently recalculated into tonnes per hectare for each treatment. The weight of apples was measured using the gravimetric method with KERN EHA 500-1 scales (Germany). For this purpose, 10 apples were randomly selected from each replication of a treatment, weighed individually, and the average weight per replication and variant was calculated. Apple flesh firmness was assessed using a portable penetrometer, "Wagner FRUIT TEST" (USA), with an FT 30FT716 (USA) probe, 11 mm in diameter. At harvest maturity, three apples were sampled from each replication of a variant. The skin was removed on two opposite sides of each apple using a sharp tool provided by the device, and the probe was slowly inserted into the fruit's flesh. The average value for each fruit was recorded, followed by the calculation of mean values for each replication and treatment.

RESULTS AND DISCUSSION

The yield of the Ligol apple cultivar ranged from 16.8 t/ha in the variant treated with HelpRost at a rate of 1 L/ha to 19.3 t/ha with foliar application of Brexil Ca at 1.8 L/ha. In the variant treated with Avangard at 6 L/ha, the yield exceeded 18.0 t/ha. The fruit weight was also highest in the Brexil Ca treatment at 296.5 g and in the Avangard treatment (3 L/ha) at 294.7 g. The lowest fruit weight for Ligol (252.0 g) was recorded in the variant treated with HelpRost at 1 L/ha (Table 1).

The yield of the Jonagold Early Queen cultivar ranged from 14.7 to 16.2 t/ha, depending on the treatment. The lowest yields were recorded in variants with foliar applications of HelpRost (3 L/ha) and Brexil Ca (2.0 kg/ha), while the highest yield was observed in the variant treated with HelpRost (1.0 L/ha). Similarly, the largest fruit weight for this cultivar (249.8 g) was recorded in the same treatment, while the lowest weight (228.3 g) was observed in apples harvested from trees treated with Biocalcium at 2 mL/ha (Table 1).

Table 1. Yield and average fruit weight of apples, harvest 2023

Cultivar	Ligol		Jonagold Early Queen		Fuji	
	Fruit weight, g	Yield, t/ha	Fruit weight, g	Yield, t/ha	Fruit weight, g	Yield, t/ha
Control	271.7 ± 10.2	17.7 ± 0.7	236.2 ± 21.4	14.8 ± 0.5	162.1 ± 10.1	22.0 ± 1.1
Biocalcium (2.0 mL/ha)	277.6 ± 11.0	17.3 ± 0.4	228.3 ± 10.9	15.0 ± 0.6	155.1 ± 14.4	21.1 ± 1.4
Biocalcium (4.0 mL/ha)	285.6 ± 10.9	18.6 ± 0.6	231.2 ± 11.2	15.6 ± 0.8	167.5 ± 11.5	22.8 ± 1.1
HelpRost (1.0 L/ha)	252.0 ± 10.9	16.8 ± 0.6	249.8 ± 29.9	16.2 ± 0.9	155.2 ± 15.6	21.1 ± 1.4
HelpRost (3.0 L/ha)	268.3 ± 14.8	17.4 ± 0.5	234.5 ± 13.4	14.7 ± 0.6	180.3 ± 10.7	24.5 ± 1.0
Brexil Ca (1.8 kg/ha)	296.5 ± 17.1	19.3 ± 2.1	240.0 ± 16.1	15.0 ± 1.0	182.3 ± 14.8	24.8 ± 0.6
Brexil Ca (2.0 kg/ha)	275.7 ± 12.2	17.9 ± 0.8	235.3 ± 18.2	14.7 ± 1.1	179.1 ± 11.6	24.3 ± 1.4
Avangard (3.0 L/ha)	294.7 ± 15.3	19.2 ± 2.5	237.3 ± 12.4	14.8 ± 0.8	172.6 ± 10.7	23.5 ± 0.7
Avangard (6.0 L/ha)	277.5 ± 16.9	18.0 ± 1.1	238.8 ± 21.0	14.9 ± 1.5	177.2 ± 12.6	24.1 ± 1.1
Mean ± SE	*278.3 ± 13.2*	*18.0 ± 1.0*	*236.8 ± 17.2*	*15.1 ± 0.8*	*170.1 ± 12.4*	*23.1 ± 1.1*
Min	*252.0 ± 10.9*	*16.8 ± 0.6*	*228.3 ± 10.9*	*14.7 ± 0.6*	*155.1 ± 14.4*	*21.1 ± 1.4*
Max	*285.6 ± 10.8*	*19.3 ± 2.1*	*249.8 ± 29.9*	*16.2 ± 0.9*	*182.3 ± 14.8*	*24.8 ± 0.6*

Source: developed by the authors

The yield of the Fuji apple cultivar varied between 21.1 and 24.8 t/ha, depending on the method of foliar application. The lowest yield was recorded in variants treated with Biocalcium at a rate of 2 mL/ha and HelpRost at 1 L/ha. The highest yield was achieved in the variant treated with Brexil Ca (1.8 kg/ha). The heaviest fruit weight was also observed in the Brexil Ca treatment (1.8 kg/ha) at 182.3 g, while the lightest fruits were recorded following treatments with Biocalcium (2 mL/ha) and HelpRost (1.0 L/ha), at 155.1 g and 155.2 g, respectively.

When comparing foliar treatments for the Ligol cultivar, Brexil Ca applied at 1.8 kg/ha proved to be the most effective. The least favourable result was obtained in the variant treated with HelpRost at 1 L/ha (Fig. 1). The fruit weight of apples harvested from trees treated with Brexil Ca (1.8 kg/ha) was 24.8 g (9.1%) greater than in the control and 44.5 g (17.6%) higher than the weight of apples from trees treated with HelpRost (1.0 L/ha). Similarly, the yield of apple trees treated with Brexil Ca at 1.8 kg/ha exceeded the control by 9.0% or 1.6 t/ha. Compared to HelpRost (1.0 L/ha), Brexil Ca (1.8 kg/ha) resulted in a 14.9% or 2.5 t/ha higher yield. When comparing treatment methods for the Jonagold Early Queen apple cultivar, the most effective was the application of HelpRost at a rate of 1 L/ha, while the least effective was HelpRost at 3 L/ha (Fig. 2).

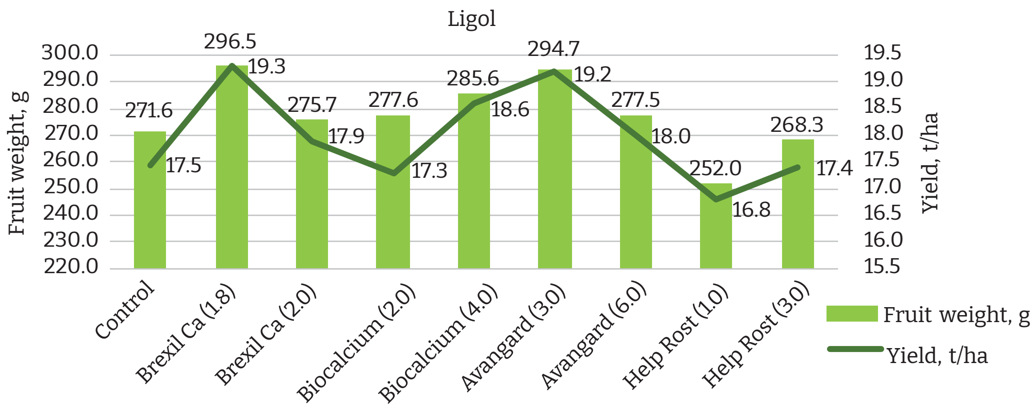

Figure 1. Yield and average fruit weight of Ligol apple cultivar, 2023

Source: developed by the authors

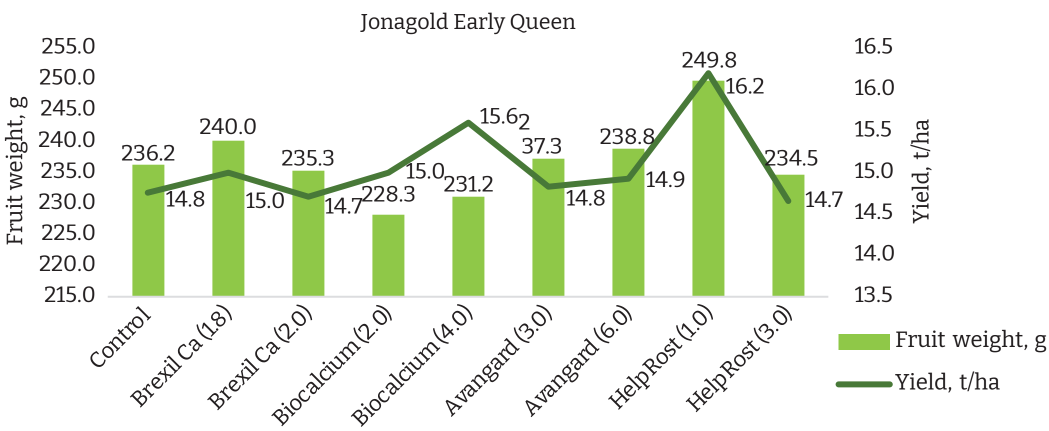

Figure 2. Yield and average fruit weight of Jonagold Early Queen apple cultivar, 2023

Source: developed by the authors

The fruit weight of Jonagold Early Queen apples grown in orchards treated with HelpRost (1 L/ha) was 13.6 g (5.7%) greater than in the water-treated control and 15.3 g (6.5%) higher than in the variant treated with HelpRost at 3 L/ha. Similarly, the yield of apple trees treated with HelpRost (1 L/ha) exceeded the control by 9.4% or 1.4 t/ha. The yield in this variant was also 10.2% or 1.5 t/ha higher than that obtained from trees treated with HelpRost (3 L/ha) (Fig. 2).

The fruit weight of Jonagold Early Queen apples treated with calcium-based foliar applications was generally higher compared to the control. Specifically, treatments with Avangard at 3.0 L/ha increased fruit weight by 1.1 g (0.5%), Avangard at 6.0 L/ha by 2.6 g (1.1%), Brexil Ca at 1.8 kg/ha by 3.8 g (1.6%), and HelpRost at 1.0 L/ha by 13.6 g (5.7%). The yield of Jonagold Early Queen orchards treated with foliar applications was also higher compared to the control. For example, Avangard (6.0 L/ha) increased yield by 0.1 t/ha (0.7%), Biocalcium (2.0 mL/ha) by 0.2 t/ha (1.3%), Brexil Ca (1.8 kg/ha) by 0.2 t/ha (1.3%), Biocalcium (4.0 mL/ha) by 0.8 t/ha (5.4%), and HelpRost (1.0 L/ha) by 1.4 t/ha (9.4%) (Fig. 2).

The yield of apple orchards treated with HelpRost at 3.0 L/ha and Brexil Ca at 2.0 kg/ha was 0.7% lower than the control. Similarly, the average fruit weight was reduced in variants treated with Biocalcium (2.0 mL/ha), Biocalcium (4.0 mL/ha), HelpRost (3.0 L/ha), and Brexil Ca (2.0 kg/ha) by 3.3%, 2.1%, 0.7%, and 1.6%, respectively (Fig. 2).

For foliar treatments in Fuji apple orchards, Brexil Ca at 1.8 kg/ha proved the most effective. The least effective treatment was Biocalcium at 2.0 mL/ha (Fig. 3).

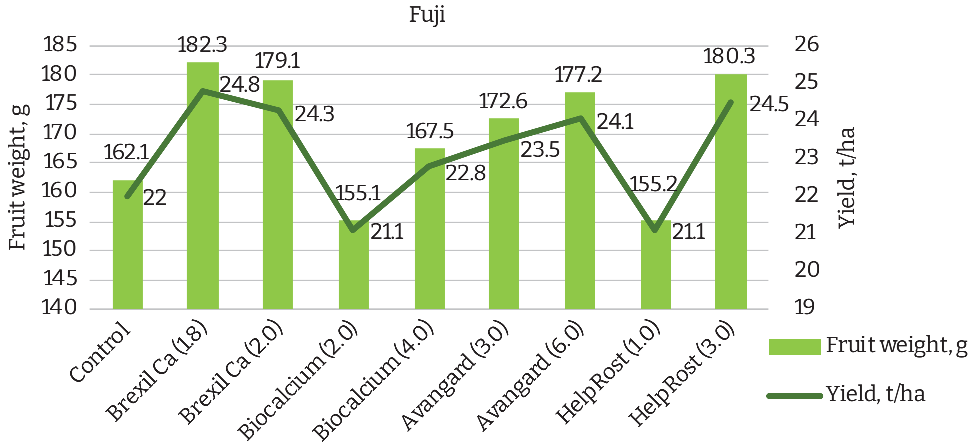

Figure 3. Yield and average fruit weight of Fuji apple cultivar, 2023
Source: developed by the authors

The fruit weight of Fuji apples harvested from trees treated with Brexil Ca (1.8 kg/ha) was 20.0 g (12.4%) higher than the control and 27.2 g (17.5%) greater than apples grown on trees treated with Biocalcium (2.0 mL/ha). Correspondingly, the yield of orchards treated with Brexil Ca (1.8 kg/ha) exceeded the control by 12.7% or 2.8 t/ha and surpassed the yield of Biocalcium-treated trees (2.0 mL/ha) by 17.5% or 3.7 t/ha (Fig. 3).

Variants treated with Brexil Ca and Avangard, in both application rates, as well as HelpRost (3.0 L/ha) and Biocalcium (4.0 mL/ha), demonstrated higher yields and fruit weights for the Fuji cultivar compared to the control (Fig. 3). In contrast, lower yields were observed in orchards treated with Biocalcium (2.0 mL/ha) and HelpRost (1.0 L/ha), which were 4.1% lower than the control. Fruit weights in these variants were also lower by 4.3% and 4.2%, respectively, compared to the control (Fig. 3). The firmness of fruit flesh is a critical parameter influencing consumer and market value. It serves as an indicator of fruit quality, ripeness, and suitability for long-term storage and transportation.

The firmness of the flesh in the Jonagold Early Queen cultivar at harvest maturity was highest in the variant treated with HelpRost (1.0 L/ha). In other variants, the flesh firmness ranged from 9.3 kg/cm^2 (control) to 10.7 kg/cm^2 (variant treated with HelpRost (3.0 L/ha)) (Table 2).

Table 2. Flesh firmness of apple cultivars under study, kg/cm2, 2023

Experimental variants	Cultivars		
	Jonagold Early Queen	Ligol	Fuji
Control	9.3±0.2	9.6±0.2	10.4±0.3
Biocalcium (2.0 mL/ha)	10.1±0.3	10.1±0.3	10.1±0.3
Biocalcium (4.0 mL/ha)	9.8±0.2	9.5±0.3	9.5±0.3
HelpRost (1.0 L/ha)	10.8±0.2	9.7±0.3	10.8±0.5
HelpRost (3.0 L/ha)	10.7±0.4	9.7±0.3	10.7±0.3
Brexil Ca (1.8 kg/ha)	10.1±0.4	9.0±0.3	10.1±0.3
Brexil Ca (2.0 kg/ha)	9.8±0.4	9.3±0.3	9.8±0.3
Avangard (3.0 L/ha)	9.3±0.4	9.3±0.3	9.3±0.2

Table 2, Continued

Experimental variants	Cultivars		
	Jonagold Early Queen	Ligol	Fuji
Avangard (6.0 L/ha)	9.8 ± 0.1	9.8 ± 0.3	9.8 ± 0.4
Mean ± SE	*10.1 ± 0.3*	*9.6 ± 0.3*	*10.2±0.3*
Min	*9.3 ± 0.2*	*9.0 ± 0.3*	*9.3 ± 0.2*
Max	*10.8 ± 0.2*	*10.1 ± 0.3*	*10.8 ± 0.5*

Source: developed by the authors

For the Ligol cultivar, the highest flesh firmness at harvest maturity was recorded in the variant treated with Biocalcium at 2.0 mL/ha, reaching 10.1 kg/cm^2. In other variants, flesh firmness varied from 9.8 kg/cm^2 (in the variant treated with Avangard at 6.0 L/ha) to 9.3 kg/cm^2 (in variants treated with Brexil Ca at 2.0 kg/ha and Avangard at 3.0 L/ha).

In the Fuji cultivar, the firmest flesh (10.8 kg/cm^2) was observed in apples treated with HelpRost at 1.0 L/ha. In other variants, firmness ranged from 9.3 kg/cm^2 (variant treated with Avangard at 3.0 L/ha) to 10.7 kg/cm^2 (variant treated with HelpRost at 3.0 L/ha).

The role of calcium and calcium-sensitive receptors in plant physiology has been extensively studied. Q. Gao *et al.* (2019) investigated their involvement in regulating fruit development and ripening, as well as the molecular mechanisms underlying these physiological processes. The findings of A.G. Levin *et al.* (2019) confirm a direct or indirect correlation between calcium content in fruits and the health and resistance of apple trees to various diseases, including bitter pit, core rot, and cracking at different stages of fruit maturity. L.L. Yang *et al.* (2020) proposed solutions to these issues through the application of calcium-based fertilisers. In experimental conditions, the most satisfactory results were achieved with three applications of calcium nitrate, amounting to a total of 0.72 kg per tree.

In examining the key aspects of calcium's influence on the quality and yield of fruits and berries through an analysis of existing research in the field, Y. Huang *et al.* (2020) identified its positive effects on yield, product quality, and post-harvest storage duration. Following foliar application of amino acid-chelated calcium, grape berry mass increased by 22.5%, vertical diameter by 8.8%, and transverse diameter by 10.8%. Additionally, fruit firmness improved by 35.7%, titratable acidity decreased by 23.2%, and soluble sugar content increased by 38.7%. L. Xinming *et al.* (2021) corroborated these findings, demonstrating that calcium fertilisation enhanced grape quality, with calcium content in the skin and pulp exceeding the control by 1.36 and 1.73 times, respectively. Pulp firmness increased by 19.28%, and soluble solids content rose by 5.71% compared to the control. Calcium treatment also influenced the qualitative and physiological characteristics of Japanese pears. The results indicated preserved fruit firmness, significant reductions in ethylene production and malondialdehyde accumulation, increased protopectin content, and reduced soluble pectin levels. Furthermore, there was a decrease in polygalacturonase and cellulase activity. J. Zhou *et al.* (2018) concluded that foliar calcium application significantly improved pear fruit storage quality. Similarly, M. Matteo *et al.* (2024) confirmed the effectiveness of foliar calcium fertilisation in sweet cherries, which reduced fruit cracking during rainy periods, enhanced firmness, and prolonged shelf life during storage. These researchers noted that calcium uptake by fruits was most effective in the early stages of development. The mechanism of calcium penetration through the skin and pedicel of cherries was further validated by A. Winkler & M. Knoche (2021). They demonstrated that spraying calcium salt solutions on berries increased calcium content within the fruit. Collectively, these findings underline the scientific interest in studying calcium's effects on fruit and berry quality. The observed mechanisms generally confirm their beneficial impact, regardless of the research subject, suggesting a consistent trend. However, unresolved issues related specifically to apple production remain, motivating the authors to continue their investigations.

Y.X. Xu *et al.* (2023) elucidated a potential mechanism for delaying post-harvest ripening in apples through the application of calcium ions. Their research confirmed the suppression of ethylene biosynthesis in fruits, which extends storage life – a subject of significant interest to the authors. Y.X. Xu *et al.* (2023) identified a transcription factor in apples that functions as an activator of a gene involved in ethylene biosynthesis. Upon calcium treatment, a phosphorylation-mediated process was observed, leading to the degradation of this transcription factor. These findings demonstrated the efficacy of calcium ions in extending storage duration and improving product quality. However, the authors' hypothesis regarding significant variations in results among different apple cultivars was not substantiated. Furthermore, alternative biochemical pathways, beyond ethylene production, may contribute to post-harvest ripening. Various researchers have periodically investigated the inhibition of ethylene synthesis (Soto *et al.*, 2012) and chlorophyll degradation (Wei *et al.*, 2021) in apples to mitigate spoilage during storage. The findings of P.T. Yue *et al.* (2020) indicate that auxin, a plant hormone, induces ethylene biosynthesis in apple fruits by activating the expression of auxin response transcription factors via naphthaleneacetic acid. Such mechanisms encourage the exploration of counteracting factors, as identified by A. Soto *et al.* (2012). Their study demonstrated that methyl jasmonate, a source of the phytohormone jasmonate, inhibits the expression of ethylene-related genes, thereby delaying fruit ripening. Y. Wei *et al.* (2021) investigated the regulation of chlorophyll degradation through post-translational modifications. The overexpression of the ethylene-related module MdPUB24 in apple fruits was found to accelerate chlorophyll degradation by increasing the expression of chlorophyll catabolic genes (CCG). These studies revealed potential mechanisms for mitigating undesirable processes, among which exogenous calcium may prove effective. However, the primary focus of the research was the impact of calcium on apple yield and physical quality attributes. G. Wang *et al.* (2022) demonstrated that calcium-based fertiliser sprays improved the quality of apple fruits. Compared to the control, the mass of individual fruits, firmness, soluble solid content, and vitamin C concentration increased by 12.1%, 16.1%, 12.0%, and 29.4%, respectively. Additionally, the application of calcium fertilisers enhanced sugar content and reduced acidity, improving the flavour profile of the apples. In a subsequent study, G. Wang *et al.* (2023) developed calcium-encapsulated carbon dots as a nanofertiliser for apple production. The results indicated that this approach facilitated efficient nutrient uptake and increased calcium concentration in the fruits. Post-harvest spraying with nano-calcium carbonate yielded the lowest levels of total fruit damage (3.569%), respiratory intensity (2.636 mg CO_2/kg/hour), and total acidity (0.214%), alongside the highest fruit firmness (1.007 kg/cm^2), sugar content (12.06%), ascorbic acid concentration (15.93 mg/100 mL), and calcium content in the fruits (895.9 mg/L).

Studies presented in the scientific literature confirm the effectiveness of calcium-containing fertilisers in horticultural production. However, each study has its specific context, limiting the generalisation of results across all cultivars, application methods, and other conditions. This consideration was acknowledged by the authors, who identified this as a critical objective at the outset of their research.

CONCLUSIONS

Foliar application of calcium-based fertilisers to apple orchards significantly affects productivity and fruit quality, with a specific impact depending on the application rate and the source of the active substance. The highest yield for Ligol apples was observed with the application of Brexil Ca at a rate of 1.8 L/ha, reaching 19.3 t/ha, which was 8.3% higher than the control and 12.9% greater than the lowest yield in the study. This treatment also produced the highest fruit mass – 296.5 g – exceeding the control by 8.4% and the lowest recorded value by 15.0%. For Jonagold Early Queen, the highest yield was achieved with the application of HelpRost at a rate of 1.0 L/ha, exceeding the control by 8.6% and the lowest value in the study by 9.2%. The same treatment also resulted in the highest fruit mass, which was 5.4% greater than the control and 8.6% higher than the lowest recorded value. The highest yield for Fuji apples was achieved with Brexil Ca applied at 1.8 L/ha, producing 24.8 t/ha – 9.8% more than the control. This treatment also resulted in the largest fruit mass of 182.3 g, 11.1% higher than the control.

The firmness of Ligol apple flesh was greatest with the application of Biocalcium at 2.0 mL/ha, showing a 4.9% increase compared to the control. For Jonagold Early Queen and Fuji apples, the greatest flesh firmness was observed with the application of HelpRost at 1.0 L/ha, showing increases of 13.9% and 3.7% over the control, respectively. Future research will focus on evaluating the effects of calcium-containing nanofertilisers on the organic matter content and mineral composition of apples.

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None.

CONFLICT OF INTEREST

None.

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Вплив позакореневого обробітку насаджень яблуні кальцієвмісними препаратами на урожайність та якість плодів

Анотація. Ефективне виробництво плодів та ягід з високою якістю та урожайністю є важливим для уникнення дефіциту, але виробники часто стикаються з проблемами, пов'язаними з нестачею кальцію в яблуках. Метою проведення досліджень стало вивчення продуктивності насаджень яблуні, сортів пізніх термінів достигання – Лігол, Джонаголд Ерлі Квін, Фуджі, позакоренево оброблених кальцієвмісними препаратами, а також дослідження якості їх плодів. Для реалізації поставленої мети застосовували польові та лабораторні методи досліджень, отримані результати були статистично опрацьовані. У результаті досліджень встановлено, що урожайність сорту Лігол була найвищою (19,3 т/га) у варіанті із застосуванням препарату Brexil Ca у нормі 1,8 л/га, що більше ніж у контролі на 8,3 % та на 12,9 % ніж у варіанті з обробкою Helprost у нормі 1,0 л/га. Маса плоду була найвищою у сорту Лігол (296,5 г) у варіанті із застосуванням Brexil Ca (1,8 л/га). Позакоренева обробка насаджень сорту Фуджі препаратом Brexil Ca у нормі 1,8 л/га виявилася найбільш ефективною, зокрема урожайність становила 24,8 т/га, що на 9,8 % вище ніж у контролі та на 16,1 % ніж у варіанті із Біокальцієм (2,0 мл/га) і препаратом Helprost (1,0 л/га). Найкращу урожайність та найвищу масу плоду сорт Джонаголд Ерлі Квін мав у варіанті із використанням препарату Helprost у нормі 1 л/га – відповідно 16,2 т/га, що на 8,6 % більше ніж у контролі та 249,8 г на 5,4 % вище за контроль. Твердість м'якоті плодів сорту Лігол була найбільша у варіанті з обробкою препаратом Біокальцій (2,0 мл/га), а сортів Джонаголд Ерлі Квін і Фуджі у варіанті, де застосовували Helprost (1,0 л/га). Отримані результати практично дають можливість підвищити ефективність виробництва плодів яблуні, покращити їх якість та подовжити тривалість зберігання

Ключові слова: Лігол; Джонаголд Ерлі Квін; Фуджі; кальцієвмісні препарати; урожайність; маса плоду; твердість м'якоті