Plant and Soil Science

Journal homepage: https://agriculturalscience.com.ua/en
Plant and Soil Science, 17(2), 54-64

Received: 06.01.2026 Revised: 23.04.2026 Accepted: 21.05.2026 Published: 29.05.2026

ISSN 2706-7688
e-ISSN 2706-7696

UDC 634.11:631.811:631.559
DOI: 10.31548/plant2.2026.54

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Effect of foliar nutrition on the content of organic compounds in apple fruits (*Malus domestica* Borkh.)

Abstract. The article presents the results of a study on the effect of foliar application of calcium-containing products HelpRost Ca, Brexil Ca and Avangard Ca on the accumulation of soluble solids, sugars, titratable acids and total phenolics in the fruits of apple cultivars 'Ligol', 'Jonagold Early Queen' and 'Fuji'. The cultivar 'Fuji' showed the highest responsiveness to treatments, where the application of Brexil Ca (2.0 kg/ha) and Avangard (6.0 L/ha) increased the soluble solids content to 16.5-16.7% (compared with 14.6% in the control) and sugars to 13.6-13.7%. In the 'Ligol' cultivar, the highest sugar content (9.7-9.8%) was recorded following the application of HelpRost Ca (3.0 L/ha) and Brexil Ca (2.0 kg/ha). The 'Jonagold' cultivar responded positively to HelpRost Ca (3.0 L/ha), with an increase in sugar content of 0.4%. A cultivar-specific dynamics of titratable acids was identified. In 'Ligol', all treatments increased the content of titratable acids, whereas in 'Fuji' a decrease to 0.42% was observed. The highest sugar-acid ratio (32) was recorded in 'Fuji' under the maximum rates of Brexil Ca and Avangard. The highest antioxidant activity was also observed in 'Fuji', where the maximum total phenolic content reached 227 mg/100 g following treatment with Avangard (6.0 L/ha). For 'Ligol', Brexil Ca proved to be the most effective (155 mg/100 g), whereas in 'Jonagold' no statistically significant difference from the control was found for this parameter. The practical value of the results lies in enabling a scientifically grounded selection of calcium foliar treatments and application rates for different apple cultivars

Keywords: calcium-containing preparations; sugars; titratable acidity; carbohydrates; polyphenols

Suggested Citation:
Shevchuk, L., & Tonkha, V. (2026). Effect of foliar nutrition on the content of organic compounds in apple fruits (*Malus domestica* Borkh.). *Plant and Soil Science,* 17(2), 54-64. doi: 10.31548/plant2.2026.54.

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INTRODUCTION

Apple (*Malus domestica* Borkh.) occupies a leading position in global fruit production, owing to the outstanding biochemical composition and excellent storage potential of its fruits. As of 2025, world apple production stood at 81.7 million tonnes, with plantations covering 4.7 million ha (OECD & FAO, 2025). According to O. Shubravska *et al.* (2025), apple orchards in Ukraine occupy 76,000 ha, total production amounts to 1.1 million tonnes, and yields on commercial farms reach 45-65 t/ha. S. Yang *et al.* (2021) emphasised that sugars account for 85-90% of the soluble solids content in apple fruits, with fructose being the dominant sugar, making apples an important component of dietary nutrition. As noted by H. Nybom *et al.* (2020), the sugar-acid ratio – a key determinant of dessert quality and flavour – depends not only on sugar content but also on the concentration of titratable acids. The accumulation of sugars and other biochemical constituents in apple fruits is governed by a combination of factors, among which cultivar characteristics, climatic conditions, ripening stage, as well as the mineral nutrition system and orchard management practices play an important role. In particular, according to I. Ahmad & M. Sajid (2025), agronomic practices, including balanced application of macro- and micronutrients, substantially influence the intensity of synthesis and accumulation of sugars, organic acids, and biologically active compounds, which is directly reflected in fruit quality and nutritional value.

I. Ali *et al.* (2021) demonstrated that foliar application of boron and zinc to trees of the 'Royal Gala' cultivar facilitated improved sugar transport from leaves to fruits. Specifically, the soluble solids content in apples from treatments with foliar feeding was 10-15% higher than in the control. O. Sürücü & Z. Küçükyumuk (2023) noted that treatment of apple orchards with manganese and zinc compounds contributes to the stability of titratable acids even under drought conditions, preventing their excessive degradation. X. Yang *et al.* (2024) demonstrated that the contents of fructose and glucose in apples increase following treatment with amino acid-chelated iron; the researchers attributed this to enhanced photosynthetic activity of leaves and accelerated transport of sugars to fruits via the phloem, whilst the quantity of organic acids remained unchanged. According to S. Soppelsa *et al.* (2020), treatment of apple trees with seaweed as a biostimulant promotes an increase in titratable acids in the fruits, which, as the authors note, is beneficial for cultivars intended for prolonged storage, given that titratable acids serve as a natural preservative and respiratory substrate in apples. Foliar application of macro- and micronutrient complexes to apple trees promotes improvement of the biochemical composition of fruits, in particular an increase in soluble sugars and soluble solids, and also exerts a positive influence on fruit quality and storability (Świerczyński *et al.*, 2022; Xu *et al.*, 2025). A. Hassan *et al.* (2024) reported that the application of nano-potassium and phenylalanine 30 days before harvest increased the concentration of pigment-forming compounds (anthocyanins) and sugars, whilst not causing excessive reduction in organic acid levels, thereby preserving their optimal ratio with sugars – a key indicator of harmonious flavour and high fruit quality.

Given the data obtained by various researchers across different regions and for different apple cultivars, studying the effect of calcium-containing products is necessary for developing a nutritional programme that will ensure not only high contents of organic and biologically active substances, but also optimal storability of fruits during the post-harvest period. The objective of the study was to determine the effect of foliar treatments with calcium-containing products (HelpRost Ca, Brexil Ca, and Avangard) applied at different rates on the contents of soluble solids, sugars, titratable acids, and total phenolics in the fruits of apple cultivars 'Ligol', 'Jonagold Early Queen' ('Jonagold'), and 'Fuji' at harvest maturity.

MATERIALS AND METHODS

Fruits for the study were sampled in the educational and research laboratory orchard "Plidoovochevyi Sad" (Fruit and Vegetable Garden) of the National University of Life and Environmental Sciences of Ukraine (Kyiv, latitude 50.3838° N, longitude 30.5042° E; altitude 188 m a.s.l.), located in the Polissia natural climatic zone of Ukraine. The regional climate is moderately continental, with mild winters and warm summers. According to long-term average data (2015-2025), the mean annual temperature in the region was 10.4°C, the absolute minimum was -20.2°C, the maximum +32.2°C, and mean annual precipitation was 598 mm. The experimental apple orchards of cultivars 'Ligol', 'Jonagold', and 'Fuji' were established in 2019; the planting scheme for the first two cultivars was 4 × 1 m (rootstock M.9), and for 'Fuji' – 4 × 2.5 m (rootstock 54-118). The orchards were managed under rainfed conditions. The soils of the experimental plot are sod-medium podzolised soils on fluvioglacial deposits, suitable for horticultural production. Humus content was 1.8%, pH – 6.5, phosphorus supply – 8 mg/100 g, and potassium – 10 mg/100 g. To raise nutrient levels to their optimum (phosphorus – 10 mg/100 g and potassium – 12 mg/100 g), double superphosphate (60 g/tree) and potassium chloride (125 g/tree) were applied in autumn during 2022-2024. Nitrogen fertilisation was carried out annually in three stages: the first at bud burst, the second two weeks after flowering, and the third after the second wave of fruit drop. Fertilisers were applied to the root zone at a rate of 200 g ammonium nitrate per tree.

Pest and disease management in the apple orchards was conducted in accordance with the standard spray programme for apple orchards developed by Syngenta. In addition, the orchards of the abovementioned cultivars were treated with calcium-containing products throughout the growing season: the first application was carried out at the end of June after fruit drop, subsequent applications at 20-day intervals, and the final application 14 days before harvest. The study was conducted in three separate experiments, with cultivar as the factor; each experiment comprised six treatment variants (including a control) in three replicates of five trees each; the duration of the study was two years. The products used, their application rates, and compositions are presented in Table 1.

Table 1. Products for foliar fertilisation of apple cultivars 'Ligol', 'Jonagold', and 'Fuji', application rates, and composition

Product (variant)	Application rate	Composition
Control	600 L/ha	**H_2O – 100%**
HelpRost Ca	1.0 L/ha	CaO – 150 g/L; N – 40-60 g/L; amino acids (more than 16 types) – 50 g/L; vitamins; polysaccharides
HelpRost Ca	3.0 L/ha	
Brexil Ca	1.8 kg/ha	Ca – 20%; B – 0.5%
Brexil Ca	2.0 kg/ha	
Avangard Calcium+M/E (Avangard)	3.0 L/ha	N – 100 g/L; CaO – 180 g/L; MgO – 10 g/L; B – 0.25 g/L; Fe – 0.25 g/L; Mn – 0.1 g/L; Cu – 0.4 g/L; Zn – 0.4 g/L; Mo – 0.02 g/L; Co – 0.01 g/L
Avangard Calcium+M/E (Avangard)	6.0 L/ha	

Source: developed by the authors

Analytical examination of apple fruits grown under the different foliar fertilisation variants was carried out at the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine. Fruits were sampled at harvest maturity, determined by the degree of starch degradation. For the studied cultivars, this indicator corresponded to a score of 6. Soluble solids content was determined using a portable refractometer ATAGO PAL-1 (Japan). Fruit quality parameters were assessed using the standard methods described by P.V. Kondratenko *et al.* (2008). For the preparation of analytical samples, fruits (5-7 specimens) were homogenised, after which a drop of juice was expressed through muslin onto the refractometer prism; temperature correction was applied when recording readings. Data were expressed as a percentage on a fresh weight basis. Sugar content was determined by a spectrophotometric method. For this purpose, a ground sample of apples was washed with hot distilled water. The resulting extract was purified from proteins and pigments by precipitation with lead acetate. Sucrose was hydrolysed to glucose and fructose by heating in the presence of 10% hydrochloric acid. The hydrolysis products were oxidised with Fehling's solution. The optical density of the resulting solutions was measured on a ULAB 102UV spectrophotometer at a wavelength of 640 nm. The sugar content in the sample was calculated using the calibration curve equation. To construct the calibration curve relating optical density (absorbance units) to glucose concentration (mg/mL), standard glucose solutions of varying concentrations were used. Data were expressed as a percentage on a fresh weight basis. Titratable acid content was determined by alkalimetric titration to a colour endpoint. For acid extraction, a 25 g ground sample was transferred without losses – by rinsing with hot distilled water in a volume not exceeding 150 mL – into a 250 mL volumetric flask. The flask was held in a water bath at 80°C for 30 min and then cooled. The contents were brought to volume with distilled water and filtered through a filter paper into a 250 mL conical flask. A 20 mL aliquot of the extract was transferred by pipette into a 250 mL conical flask, 3-4 drops of phenolphthalein were added, and the mixture was titrated with 0.1 N sodium hydroxide solution until the appearance of a pale pink colour corresponding to pH 7.0. The titratable acid content in the sample was calculated from the formula, taking into account the titre of the 0.1 N sodium hydroxide solution and the conversion factor for citric acid. Data were expressed as a percentage on a fresh weight basis. The sugar-acid ratio was calculated as the ratio of total sugar content to titratable acid content in apple fruits.

For polyphenol extraction, a weighed sample was ground in a porcelain mortar with the addition of a small quantity of ethanol and filtered under vacuum through a Büchner funnel using a blue-ribbon filter paper into a Büchner flask. The residue on the filter was washed with small portions of ethanol until complete decolorisation of the sample. The volume of ethanol used (mL) was recorded. Into a test tube, 7.9 mL of distilled water, 0.1 mL of the extract, and 1 mL of Folin-Denis reagent were introduced, mixed, and after 3 minutes 1 mL of saturated sodium carbonate solution was added and mixed again. After one hour, the optical density of the tube contents was measured on a ULAB 102UV spectrophotometer at a wavelength of 640 nm. The blank was prepared as follows: 8 mL of distilled water and 1 mL of Folin-Denis reagent were placed in a test tube, mixed, after 3 minutes 1 mL of saturated sodium carbonate solution was added and mixed again. No fewer than three replicate measurements were taken and the mean optical density value was calculated. The polyphenol content in the sample was calculated using the calibration curve equation. To construct the calibration curve relating optical density (absorbance units) to chlorogenic acid concentration (μg/mL), standard chlorogenic acid solutions of varying concentrations were used. Data were expressed as mg/100 g fresh weight. All research involving plant material was conducted in compliance with international ethical requirements for the use of biological resources in accordance with the provisions of the Convention on Biological Diversity (1992). Meteorological data for the study years were obtained from a Vantage Pro2 Plus weather station located at the educational and research orchard laboratory of the National University of Life and Environmental Sciences of Ukraine. Statistical assessment of the effect of foliar treatments on the biochemical parameters of apple fruits was performed using one-way analysis of variance (ANOVA). The analysis was conducted separately for each cultivar, with 'Treatment variant' (including the untreated control) as the independent factor. Prior to analysis, data were tested for normality of distribution (Shapiro-Wilk test) and homogeneity of group variances (Levene's test). Assessment of the significance of differences between means within each cultivar was carried out using Tukey's test.

RESULTS AND DISCUSSION

The soluble solids content in fruits of the 'Ligol' cultivar ranged from 11.7% (control and the Avangard variant at 3.0 L/ha) to 12.4% in the variant with Brexil Ca (1.8 kg/ha). A significantly higher soluble solids content compared with the control was recorded, in addition to the abovementioned variant, in fruits grown with the application of HelpRost Ca (3.0 L/ha). In the variants with Brexil Ca (2.0 kg/ha) and both Avangard variants, the soluble solids content was within the margin of statistical error (Table 2).

Table 2. Soluble solids and sugar contents in apple fruits depending on foliar treatment with calcium-containing products, % per 100 g fresh weight

Variant	Soluble solids			Sugars		
	'Ligol'	'Jonagold'	'Fuji'	'Ligol'	'Jonagold'	'Fuji'
Control	11.7±0.1	13.5±0.1	14.6±0.2	8.7±0.2	9.4±0.1	11.7±0.2
HelpRost Ca (1.0 L/ha)	11.8±0.2	13.8±0.3	14.5±0.2	8.6±0.3	9.6±0.3	12.9±0.2[a]
HelpRost Ca (3.0 L/ha)	12.1±0.2[a]	14.1±0.2[a]	14.6±0.2	9.7±0.1[a]	9.8±0.2[a]	13.5±0.2[a]
Brexil Ca (1.8 kg/ha)	12.4±0.1[a]	13.8±0.2	16.0±0.2[a]	9.8±0.1[a]	9.4±0.2	13.0±0.2[a]
Brexil Ca (2.0 kg/ha)	11.8±0.2	13.6±0.2	16.5±0.2[a]	9.0±0.2	9.4±0.2	13.6±0.2[a]
Avangard (3.0 L/ha)	11.7±0.3	14.2±0.1[a]	16.6±0.2[a]	9.0±0.2	9.8±0.1[a]	12.6±0.3[a]
Avangard (6.0 L/ha)	11.8±0.2	14.2±0.1[a]	16.7±0.2[a]	9.2±0.2[a]	9.4±0.1	13.7±0.2[a]

Note: [a] indicates values that differ significantly from the control variant
Source: developed by the authors

In the 'Jonagold' cultivar, the soluble solids content was significantly higher than in the control (13.5%) in the variants where HelpRost Ca (3.0 L/ha) and Avangard (at both rates) were applied foliarly. When HelpRost Ca (1.0 L/ha) and Brexil Ca at rates of 1.8 and 2.0 kg/ha were used for foliar feeding, no significant difference from the control was established. Fruits of the 'Fuji' cultivar grown in orchards treated with HelpRost Ca at rates of 1.0 and 3.0 L/ha were characterised by a soluble solids content at the level of the control, namely 14.5 and 14.6% respectively, compared with 14.6% in the control. However, 'Fuji' fruits grown with the foliar application of Brexil Ca (1.8 and 2.0 kg/ha) and Avangard (3.0 and 6.0 L/ha) accumulated significantly more soluble solids than those grown in the control. The sugar content in 'Ligol' fruits in the control was 8.7%. Values at the level of the control (within the margin of statistical error) were recorded in the variants with HelpRost Ca (1.0 L/ha), Brexil Ca (2.0 kg/ha), and Avangard (3.0 L/ha), namely 8.6 and 9.0% in the latter two variants respectively. A higher sugar content than in the control was found in apples from trees treated with HelpRost Ca at 3.0 L/ha (9.7%), Brexil Ca at 2.0 kg/ha (9.8%), and Avangard at 6.0 L/ha (9.2%). 'Jonagold' apples harvested from the variants with HelpRost Ca (3.0 L/ha) and Avangard (3.0 L/ha) contained 0.4% more sugar than the untreated control. No significant increase in sugar content was established in the other 'Jonagold' variants; in particular, apples from trees treated with Brexil Ca at both studied rates and with Avangard (6.0 L/ha) had a sugar content at the level of the control – 9.4%. In the 'Fuji' cultivar, the sugar content in all treatment variants with calcium-containing products was significantly higher than in the control, where it stood at 11.7%. A sugar content exceeding 13.5% was recorded in apples grown with Avangard (6.0 L/ha) and Brexil Ca (2.0 kg/ha), at 13.7 and 13.6% respectively (Table 2).

In the variants with calcium-containing product treatments of 'Ligol' apple orchards, the titratable acid content was higher than in the water control. The greatest difference from the control (by 0.20%) was observed with Avangard at both rates (3.0 and 6.0 L/ha), where the titratable acid content was 0.80%. The smallest difference from the control was recorded with Brexil Ca (2.0 kg/ha), at 0.95% (Table 3).

Table 3. Titratable acid content in apple fruits and sugar-acid ratio depending on foliar treatment with calcium-containing products

Variant	Titratable acids, % per 100 g fresh weight			Sugar-acid ratio		
	'Ligol'	'Jonagold'	'Fuji'	'Ligol'	'Jonagold'	'Fuji'
Control	0.60±0.03	0.66±0.01	0.50±0.2	15	14	24
HelpRost Ca (1.0 L/ha)	0.76±0.01[a]	0.62±0.01[b]	0.52±0.2	11	16	25
HelpRost Ca (3.0 L/ha)	0.80±0.07[a]	0.65±0.02	0.48±0.2	12	15	28
Brexil Ca (1.8 kg/ha)	0.75±0.05[a]	0.64±0.02	0.42±0.3[b]	13	15	31
Brexil Ca (2.0 kg/ha)	0.69±0.07[a]	0.74±0.01[a]	0.42±0.3[b]	13	13	32

Table 3, Continued

Variant	Titratable acids, % per 100 g fresh weight			Sugar-acid ratio		
	'Ligol'	'Jonagold'	'Fuji'	'Ligol'	'Jonagold'	'Fuji'
Avangard (3.0 L/ha)	0.80 ± 0.05[a]	0.57 ± 0.01[b]	0.43 ± 0.3[b]	11	17	29
Avangard (6.0 L/ha)	0.80 ± 0.05[a]	0.73 ± 0.02[a]	0.42 ± 0.3[b]	12	13	32

Note: [b] indicates values that differ significantly from the control variant
Source: developed by the authors

In the 'Jonagold' cultivar, the titratable acid content in the variants with HelpRost Ca (3.0 L/ha) and Brexil Ca (2.0 kg/ha) was within the margin of the control error, at 0.65 and 0.64% respectively. The most significantly elevated acidity was recorded in 'Jonagold' fruits grown in the variants with Brexil Ca at 2.0 kg/ha (0.74%) and Avangard at 6.0 L/ha (0.73%). The titratable acid content in 'Fuji' fruits in the variants with HelpRost Ca (1.0 and 3.0 L/ha) was within the margin of the control error, at 0.52 and 0.48% respectively. In the remaining treatment variants, the titratable acid content in 'Fuji' fruits was significantly lower than in the untreated control and ranged from 0.42% in the variants with Brexil Ca at both rates and Avangard (3.0 L/ha) to 0.43% in the Avangard (6.0 L/ha) variant. The sugar-acid ratio in 'Ligol' fruits ranged from 15 (control) to 11 in the Avangard variant at 3.0 L/ha. In the 'Jonagold' cultivar, the sugar-acid ratio was higher than in the control (14) in the HelpRost Ca variants at both rates – 16 and 15 respectively – and also in the variant with Brexil Ca (1.8 kg/ha). In the 'Fuji' cultivar, the sugar-acid ratio reached its maximum value (32) in two treatment variants: Brexil Ca (2.0 kg/ha) and Avangard (6.0 L/ha). Values below 30 for this flavour indicator were recorded in the control and in the variant with HelpRost Ca at 1.0 L/ha (Table 3).

The total phenolic content in 'Ligol' apple fruits in the control was 123 mg/100 g; significantly higher values were recorded in the variant with Brexil Ca at 2.0 kg/ha (155 mg/100 g), as well as with HelpRost Ca at 1.0 L/ha (149 mg/100 g) and Avangard at 3.0 L/ha (141 mg/100 g). In the remaining variants, the total phenolic content in 'Ligol' apple fruits was within the margin of the control error (Table 4).

Table 4. Total phenolic content in apple fruits depending on foliar treatment with calcium-containing products, mg/100 g fresh weight

Variant	'Ligol'	'Jonagold'	'Fuji'
Control	123 ± 7	148 ± 17	190 ± 6
HelpRost Ca (1.0 L/ha)	149 ± 12[a]	152 ± 12	213 ± 7[a]
HelpRost Ca (3.0 L/ha)	139 ± 7[a]	150 ± 16	212 ± 8[a]
Brexil Ca (1.8 kg/ha)	119 ± 8	162 ± 11	209 ± 5[a]
Brexil Ca (2.0 kg/ha)	155 ± 11[a]	144 ± 5	218 ± 8[a]
Avangard (3.0 L/ha)	141 ± 8[a]	138 ± 14	215 ± 7[a]
Avangard (6.0 L/ha)	140 ± 12	134 ± 15	227 ± 7[a]

Source: developed by the authors

The total phenolic content in 'Jonagold' apple fruits ranged from 134 to 162 mg/100 g. The maximum value was recorded in the variant with Brexil Ca (1.8 kg/ha), whilst the minimum was observed with Avangard (6.0 L/ha). It should be noted that no statistically significant difference from the control was found in any of the experimental variants for total phenolic content. In 'Fuji' fruits, the maximum total phenolic content was recorded in the Avangard variant at 6.0 L/ha, amounting to 227 mg/100 g, which significantly exceeded the control by 37 mg/100 g. Application of the same product at a lower rate also yielded a value above the control, at 215 mg/100 g. The use of HelpRost Ca at 1.0 and 3.0 L/ha increased total phenolic content by 23 and 22 mg/100 g respectively compared with the control. In the Brexil Ca variants, the control values were exceeded by 19 mg/100 g (at 1.8 kg/ha) and by 28 mg/100 g (at 2.0 kg/ha).

The study established that foliar treatment of 'Ligol', 'Jonagold', and 'Fuji' apple orchards with calcium-containing products affects the soluble solids content in fruits differently, which can be explained by the genetic response of each cultivar to the products applied. In particular, a weak response to most products was established for 'Ligol'. Researchers J. Lanauskas *et al*. (2012) noted that 'Ligol' possesses a genetically determined threshold for sugar accumulation that is difficult to alter through exogenous intervention. The increase in sugar content in fruits of 'Ligol' (up to 9.8%) and 'Fuji' (up to 13.7%) under the influence of Brexil Ca and Avangard is consistent with the findings of S. Murtić *et al*. (2017), who established that foliar treatments with calcium-containing products promote an increase in soluble solids content in fruits. This is associated with the role of calcium as a signalling element that activates carbohydrate metabolism enzymes, in particular sucrose phosphate synthase, which is responsible for sucrose synthesis. The most effective variants for 'Jonagold' were those with Avangard (3.0 and 6.0 L/ha) and HelpRost Ca (3.0 L/ha), where an increase in soluble solids content compared with the control of 0.7 and 0.6% respectively was observed.

The absence of a significant sugar increment in 'Jonagold' with certain rates of Brexil Ca (9.4%, at the level of the control) is consistent with the data of L.C. Argenta *et al*. (2022), who established that excessive or untimely calcium application may sometimes lead to antagonism with other elements – namely potassium: when the Ca/K balance shifts too strongly towards calcium, this can slow the rate of carbohydrate accumulation. A. Asgharzade *et al*. (2012) demonstrated that the effect of calcium fertilisers on the biochemical composition of apples is substantially dependent on the weather conditions of the growing year; in particular, in dry years calcium may retain moisture, thereby reducing sugar content. Of all the cultivars studied, 'Fuji' showed the best soluble solids response to foliar feeding. The soluble solids content of 16.0-16.7% achieved with Brexil Ca and Avangard is high, which is consistent with the results of A.G. Shewa *et al*. (2022), who noted that 'Fuji' has a tendency towards high accumulation of sorbitol and sugars, and that additional feeding with calcium and micronutrient products enhances this potential by improving the osmotic balance of cells. The significant increase in sugar content in 'Fuji' across all treatment variants may be related to the genetic characteristic of this cultivar for late fruit ripening. As noted by I. Ahmad & M. Sajid (2025), late-maturing cultivars have a longer period of carbohydrate complex formation, and calcium protection of cell membranes during this period prevents premature starch degradation, allowing sugars to accumulate gradually and consistently.

For the 'Ligol' cultivar, application of Avangard and Brexil Ca contributed to the maintenance of a higher acid content compared with the control. The increase in acidity by 0.20% with Avangard indicates effective penetration of Ca^{2+} ions into the fruit mesocarp. This is consistent with the data of M. Serrano *et al*. (2004), who noted that exogenous calcium inhibits the activity of enzymes responsible for the degradation of malic acid, which is the principal substrate for respiratory processes during ripening. Similar data were obtained by P. Wójcik (2023), who established that calcium contributes to the maintenance of a higher level of acidity, which is critical for cultivars with moderate acidity, of which 'Ligol' is one. In the 'Jonagold' cultivar, the greatest increase in acidity was observed in the Brexil Ca variants (0.74%). As stated by M. Serrano *et al*. (2004), this allows for the maintenance of the metabolic status of the cell at a higher level. In the 'Fuji' cultivar, in contrast to 'Ligol' and 'Jonagold', a tendency towards a reduction in acidity under the influence of the studied calcium-containing products was established (to 0.42-0.43%). According to the findings of P.R. Ernani *et al*. (2008), in certain cultivars – particularly those with late ripening – an excess of calcium may stimulate specific enzymatic pathways that accelerate the conversion of organic acids to sugars, especially under conditions of high insolation characteristic of the ripening period of 'Fuji'. The highest sugar-acid ratio values (up to 32) were recorded in 'Fuji', which indicates the genetic predisposition of this cultivar towards intensive sugar accumulation against a background of low acidity. The 'Fuji' cultivar is characterised by intensive carbohydrate accumulation, and the application of exogenous calcium (in particular in the form of foliar treatments) promotes an increase in soluble solids content through the activation of sugar metabolism enzymes, notably sucrose phosphate synthase (Murtić *et al*., 2017).

The increase in total phenolic content in 'Ligol' and 'Fuji' in the treatment variants is consistent with the findings of N. Ahmed *et al*. (2024), who noted the important role of micronutrients in the regulation of secondary metabolite biosynthesis, particularly phenolic compounds. Moreover, phenylalanine ammonia-lyase is the key enzyme of the phenylpropanoid pathway, and calcium may indirectly influence its activity through signalling mechanisms, thereby promoting phenolic accumulation (Lang *et al*., 2025). Exogenous calcium is capable of enhancing the activity of antioxidant enzymes and promoting the accumulation of phenolic compounds and flavonoids in plant tissues, as confirmed by a number of studies, as noted by Y. Gao *et al*. (2024). Similar patterns were established by Y. Xi *et al*. (2016) for apple, where treatment with bioactive compounds stimulates the antioxidant system and accumulation of phenolic compounds. The effectiveness of Brexil Ca in promoting phenolic accumulation is attributed to the presence of lignosulphonate in its composition, which facilitates better penetration of calcium through the leaf cuticle, thereby activating phenylpropanoid metabolism (Val *et al*., 2018). The results obtained confirmed that the optimisation of calcium nutrition should be based on the genetic characteristics of the cultivar and growing conditions in order to achieve the maximum quality effect in fruits.

CONCLUSIONS

The 'Fuji' cultivar proved to be the most responsive to foliar treatments with calcium-containing products. The application of Brexil Ca and Avangard contributed to a significant increase in soluble solids content, to 16.0-16.7% compared with 14.6% in the control. For 'Ligol', the best soluble solids result was obtained in the Brexil Ca (1.8 kg/ha) variant; for 'Jonagold' – with HelpRost Ca (3.0 L/ha) and Avangard at both rates. In the 'Fuji' cultivar, all treatment variants ensured a significant increase in sugar content (reaching a maximum of 13.7%), whilst in 'Ligol' and 'Jonagold' the positive effect was selective and dependent on the specific product rate. Foliar feeding affected acidity differently depending on the cultivar. In 'Ligol', treatments contributed to acid accumulation (up to 0.80-0.95%), which is important for prolonged storage. In contrast, in 'Fuji' a decrease in acid content was observed (to 0.42%). The highest flavour quality indices (sugar-acid ratio – 32) were recorded in 'Fuji' with the application of high rates of Brexil Ca (2.0 kg/ha) and Avangard (6.0 L/ha). For 'Jonagold', the best variant was HelpRost Ca. The 'Fuji' cultivar demonstrated the greatest capacity for phenolic compound accumulation under the influence of calcium fertilisers, reaching a maximum of 227 mg/100 g (Avangard, 6.0 L/ha), which is 19.5% above the control. The most universally positive effect on the biochemical composition of fruits (particularly in 'Fuji') was demonstrated by Avangard at 6.0 L/ha and Brexil Ca at 2.0 kg/ha. It was established that foliar calcium application is an effective tool not only for improving storability but also for enhancing the nutritional and flavour characteristics of apples. Further research should focus on optimising the timing and rates of foliar calcium application, taking into account cultivar characteristics, weather conditions, and interactions with other nutritional elements, in order to improve fruit quality and storability.

ACKNOWLEDGEMENTS

None.

FUNDING

None.

CONFLICT OF INTEREST

None.

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Вплив позакореневого живлення на вміст органічних речовин у плодах яблуні (*Malus domestica* Borkh.)

Анотація. У статті представлено результати досліджень впливу позакореневого підживлення препаратами HelpRost Ca, Brexil Ca та Авангард Ca на накопичення сухих розчинних речовин, цукрів, титрованих кислот та загальних фенолів у плодах яблуні сортів ‘Лігол’, ‘Джонаголд Ерлі Квін’ та ‘Фуджі’. Найбільшу чутливість до обробок виявив сорт ‘Фуджі’, де застосування Brexil Ca (2,0 кг/га) та Авангарду (6,0 л/га) забезпечило зростання вмісту сухих розчинних речовин до 16,5-16,7 % (проти 14,6 % у контролі) та цукрів до 13,6-13,7 %. У сорту ‘Лігол’ максимальний вміст цукрів (9,7-9,8 %) зафіксовано при застосуванні HelpRost Ca (3,0 л/га) та Brexil Ca (2,0 кг/га). Сорт ‘Джонаголд’ позитивно зреагував на HelpRost Ca (3,0 л/га), збільшивши цукристість на 0,4 %. Встановлено сортову специфіку динаміки титрованих кислот. У сорту ‘Лігол’ всі варіанти обробок підвищували вміст титрованих кислот, тоді як у сорту ‘Фуджі’ спостерігалося їх зниження до 0,42 %. Найвищий цукрово-кислотний індекс (32) зафіксовано у сорту ‘Фуджі’ при застосуванні максимальної норми Brexil Ca та Авангарду. Найвищу антиоксидантну активність продемонстрував сорт ‘Фуджі’, де зафіксовано максимальний вміст загальних фенолів – 227 мг/100 г (при обробці Авангардом 6,0 л/га). Для сорту ‘Лігол’ ефективним виявився Brexil Ca (155 мг/100 г), тоді як у сорту ‘Джонаголд’ статистично значущої різниці з контролем за цим показником не виявлено. Практична цінність отриманих результатів полягає в можливості науково обґрунтованого добору препаратів і норм позакореневого підживлення кальцієм для різних сортів яблуні

Ключові слова: кальцієвмісні препарати; цукри; титровані кислоти; вуглеводи; поліфеноли