Hindawi
Journal of Food Quality
Volume 2024, Article ID 1478849, 17 pages
https://doi.org/10.1155/2024/1478849

Research Article

Enhancing Quality Fruit Composition in Red Currant Cultivars by Foliar Calcium Application across Preharvest and Postharvest Stages

Olga Panfilova,[1] **Ibrahim Kahramanoğlu**,[2] **Gabrijel Ondrasek**,[3] **Nelli Ryago**,[1] **Larisa Leonteva**,[1] **Chunpeng (Craig) Wan**,[4] **Mikhail Tsoy**,[1] **Volkan Okatan**,[5] **Olga Golyaeva**,[1] **Olga Loretts**,[6] **Viktor Kukhar**,[6] **and Mikhail Karpukhin**[6]

[1]*Russian Research Institute of Fruit Crop Breeding (VNIISPK), Zhilina, Orel District, Orel Region 302530, Russia*
[2]*Department of Horticulture, Faculty of Agricultural Sciences and Technologies, European University of Lefke, Gemikonagi, via Mersin 10, Ankara 99780, Northern Cyprus, Türkiye*
[3]*Faculty of Agriculture, University of Zagreb, Zagreb 10000, Croatia*
[4]*Jiangxi Key Laboratory for Postharvest Technology and Nondestructive Testing of Fruits & Vegetables, College of Agronomy, Jiangxi Agricultural University, Nanchang 330045, China*
[5]*Department of Horticulture, Faculty of Agriculture, Eskisehir Osmangazi University, Eskişehir 26160, Türkiye*
[6]*Ural State Agrarian University, ul. Karl Liebknecht, 42, Yekaterinburg 620075, Russia*

Correspondence should be addressed to Olga Panfilova; us@vniispk.ru

Received 18 December 2023; Revised 16 February 2024; Accepted 27 March 2024; Published 12 April 2024

Academic Editor: Mehdi Maqbool

Copyright © 2024 Olga Panfilova et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Foliar calcium (Ca) treatment exhibits strong potential for enhancing yield and quality in some fruit crops. This study aimed to assess the impact of foliar application of Ca-organomineral (Ca-OM) suspension on total soluble solids (TSS) and Ca dynamics in leaves and berries across five red currant cultivars during the vegetation and storage. A randomized block design with two treatments: (1) Control (without Ca-OM treatment) and (2) foliar Ca-OM treatment, with three repetitions, was applied on five different red currant cultivars. Although foliar Ca-OM treatments did not impact Ca or TSS in leaves, they positively influenced Ca and TSS in fruits, displaying significant variability among cultivars. In addition, Ca-OM treatment increased berry density, reduced abscission, and inhibited the development of diseases, extending storage periods for "Lvovyanka," "Vika," and "Gazel" cultivars by three to seven days compared to the Ca-OM untreated control. Ca-OM treatment in the early stages of the ontogenesis of currants provided a high percentage of Ca intake in berries. At the stage of complete maturation, the Ca content in berries decreased and depended on the ripening period of the cultivars. Before harvesting, Ca-OM increased the strength of berries (Fc) and reduced the shedding of berries in the clusters (Fs). At the vegetation stage, Ca-OM increased TSS in berries, and the content of TSS depended on the genotype and weather conditions. The Ca-OM treatment and low temperatures contributed to preserving berry density, reducing the shedding of berries and PLW, and restraining the development of diseases during storage. In addition, the high content of TSS and Ca in berries against the background of a slow rate of decrease in berry density in the Ca-OM variants ensured an extension of the shelf life of "Lvovyanka," "Vika," and "Gazel" by three to seven days compared to the control untreated with Ca-OM. Clustering analyses identified these cultivars as similar in terms of TSS and calcium content in fruits, emphasizing their common traits. The study underscores the potential of foliar Ca treatment to enhance berry quality during growth and storage, significantly improve storage duration, and fortify resistance against adverse factors, presenting promising opportunities for elevating yield and quality in specific red currant cultivars.

1. Introduction

The global demand for cultivating and consuming berry crops has increased in recent decades [1]. This trend is connected, firstly, with the beneficial qualities of berries for human health. Red currant berries are a source of biologically active compounds with a high content of ascorbic acid, phenolic compounds, anthocyanins, and high antioxidant activity [2, 3]; secondly, due to improved agrotechnological methods for growing berry crops. New elements of cultivation technology have made it possible to expand these crops' availability and distribution area [4]. The production of currant berries ranks second in the world after strawberries. According to Faostat 2022, the world's average production of currant berries is 45000 tons. The primary production of currants is located in Europe (Poland, France, Estonia, the Netherlands, Belgium, Russia, and Ukraine) [5]. Berry crops have a high value, so their production and sale can significantly contribute to the economy of the regions of several countries [6]. Most berry crops are intended primarily for use in processed products, but at the same time, the priority is the sale of fresh berry products [7].

Berry products are perishable raw materials [8]. After harvesting, the berries quickly lose their commercial qualities and organoleptic acceptance (berry weight loss, berry density reduction, berry rot) [9], and this affects the marketing of these products, which leads to significant economic losses [10].

To extend the shelf life of fruit and vegetable products and preserve the nutritional value and quality characteristics of fruits, chemical preparations (pesticides, preservatives), biological compounds (plant extracts) [11, 12], and physical methods (ultrasound, ultraviolet, electric field, pressure, temperature regimes) are used [12–15]. However, there is a scientific trend in switching to environmentally friendly and safe plant compounds to reduce crop losses during storage [16].

According to the International Federation of Organic Agriculture Movements (I.F.O.A.M.), such a production system supports the health of soils, ecosystems, and people [17–19]. Many farmers often use freezing to increase the period of consumption of berries. Still, in the process of such storage (−12°C, −18°C, −24°C), several chemical processes change: sucrose is inverted, acidity increases, and the amount of tannins decreases [20]. There is evidence of a decrease in changes in the structure of red currant berries when stored in the refrigerator for up to 7–10 days [21, 22]. Rational nutrition considers the consumption of fresh fruits and berries as a vital factor. The berries' harvest quality is crucial and should be at the right point for improved storage. In this case, biological foliar fertilizing is becoming very important, significantly enhancing metabolic processes, yield, and fruit quality [23, 24]. The mineral composition of fruit crops affects fruits' quality and technological indicators, including their shelf-life capacity. One of the critical problems in ensuring the high quality of products and their safety is providing the optimal calcium content in fruits and berries [25–27].

The role of calcium is crucial to ensure the excellent storage ability of fruits and berry products; the higher the calcium content in berries, the greater and longer their preservation abilities, and, consequently, the possibility of more prolonged consumption of high-quality products rich in essential trace elements and vitamins [26]. Calcium is a critical component in maintaining the hardness of fruits during storage, as it is responsible for the integrity of the cell [25, 26]. Calcium ions create compounds between the peptic molecules in the middle of the plate, which are responsible for the integrity of the cell [25–27]. For instance, it was confirmed that apple fruits with a content of Ca >5 mg/100 g f.w., with a ratio (K + Mg)/Ca <25 mg/100 g f. w. and Ca/Mg >1 mg/100 g f. w. have high resistance to diseases during storage [27, 28]. Thus, the softening of the fruit may result from the loss of calcium in the middle of the plate and/or its absence in the bonds between the peptic molecules [28]. When treated during the preharvest period, the entrance of calcium into fruits delays the fruit's softening and ripening rate, thereby slowing down the decay of cell walls [28]. The preharvest use of calcium can slow down the aging of fruits without adversely affecting the consumer qualities of fruits [29, 30]. There are also studies of the positive effect of calcium-containing drugs on increasing the level of Brix in *Rubus Eubatus* Focke fruits [31]. The storage duration of berry crops, especially currants, is significantly influenced by calcium. It addresses a significant issue where red currants rapidly deteriorate within 3-4 days after the harvest, leading to logistical challenges in their distribution to major retail chains [32].

Thus, this study aimed to elucidate the effects of foliar Ca application in five red currant genotypes on (i) changes in total soluble solids (TSS) and calcium content in the biomass and fruits during the preharvest and postharvest period and (ii) the duration of the shelf life of berries under the influence of low temperatures.

2. Materials and Methods

2.1. Location, Facilities, Weather Conditions, and Agrochemical Measures. The study was conducted in 2021/2022 and 2022/2023 vegetation seasons at the site (0.2 ha) of the primary variety study of VNIISPK red currants. The experimental site was in the north-east of the central Chernozem region of Russia. The soil of the experimental site belonged to the Loamy Haplic Luvisol type (IUSS Working Group W.R.B., 2015), with a surface humus horizon of 0.55 m. During two growing seasons, the soil samples from three repetitions, in triplicates, were taken in spring (before the buds of red currant blossomed) from the rhizosphere at a depth of 0–0.2 m and 0.2–0.4 m and were subjected to chemical analyses. The exchangeable potassium content was determined using a flame photometric method with a flame spectrophotometer. The phosphorus content was determined by the spectrophotometric method using a Bio-RAD SmartSpec plus spectrophotometer (California, U.S.A.). Soil acidity (pH) was determined in a 20 g suspension with the addition of a 0.1 N KCI solution [33].

Measurements were carried out by the pH-150MI device (Moscow, Russia).

The experimental site was presented with five red currant cultivars of different ecological, geographical, and genetic origins: ("Jonkheer Van Tets" ("Faya Plodorodnaya" × "London Market"), Holland; "Vika" ("Chulkovskaya" × "Red Lake"), Russia; "Asya" ("Chulkovskaya" × "Maarses Prominent"), Russia; "Gazel" ("Chulkovskaya" × "Maarses Prominent"), Russia; Lvovyanka ("Weisse Hollandische" × "Jonkheer Van Tets"), Ukraine). The cultivars were of early, medium-early, and late ripening, planted in 2018 with a spacing of 2.8 × 0.5 m, and interrow plowing without irrigation.

The scientific institutions of Russia, Ukraine, and Europe provided the cultivars under the program «A unique scientific set, a collection of living plants of the open field—bioresource collection of VNIISPK».

Ammonium nitrate (NH_4NO_3) was applied in an amount of 60 g. per plant, every vegetation season is in spring, the first decade of April. To protect against *Sphaerotheca mors-uvae*, the experimental plants were treated with a bio-phytoncides complex of botanical extracts on an organo-mineral basis. The preparation of systemic and contact action (pH = 7.5–8.0) has the form of a suspension of minerals of natural origin containing *Quassia amara, Cinnamomum zeylanicum,* and *Azadirachta indica* (the drug was obtained from AgroPlus, Russia). The treatments were performed before bud blossoming, during green berry formation, the initial ripening, and full ripeness, using a 5.0% solution.

The summary of weather conditions during the 2021-2022 and 2022-2023 vegetation seasons is presented in Table 1 and was obtained using a meteorological station iMetes 3.3. (Weiz, Austria) at the experimental site.

2.2. Experiment Design

2.2.1. Vegetation Period. To examine the impact of a foliar Ca application on red currant cultivars, a Ca-organomineral (Ca-OM) suspension derived from the oceanic bio flora containing Ca (1.31%), CaO (0.4%), SiO_2 (5.6%), Fe_2O_3 (0.4%), Al_2O_3 (0.16%), and MgO (0.4%) was applied. To determine the calcium content in the suspension, a solution of 10 ml was taken and subjected to burning in a muffle furnace at a temperature of +450°C. Burning was gradually carried out, raising the oven temperature by 50°C every 30 minutes. The total mineralization time was 8 hours. The resulting ash was dissolved, and a suspension was obtained. The complexometric method determined the calcium content in the test preparation suspension [34].

A randomized block design with two treatments: (1) Control (without Ca-OM treatment) and (2) foliar Ca-OM treatment, with three repetitions, was applied on five different red currant cultivars. There were five plants per treatment, with two plants between each treatment.

Foliar treatments were applied by the RT-16LI knapsack sprayer (Patriot, China), with a 1% Ca-OM solution and a consumption of 0.18 m^3/h. Treatments were carried out following the phases of ontogenesis of red currant plants (Table 2).

The TSS (Brix %) in leaves and fruits was determined using a refractometer (ATAGO, pocket PAL-1. Kyoto, Japan). The selection of plant material was carried out according to the experimental scheme (Table 2). The leaves and berries were selected five days after the treatments. To determine the soluble solids content in the leaves, a sample of 0.7 g was used. To determine the soluble solids content in the berries, a sample of 12 g was used. The sample was a mixture of leaves or berries from five plants of one repetition from the same cultivar.

Determination of the calcium content in the leaf tissue was performed by the complexometric method for organic substances at the beginning stages of the ripening of berries and the full ripening of berries [34, 35]. Dry ash was used for plant samples. Dry samples were burned in a muffle furnace at a temperature of +450°C, and the ash was obtained from a plant sample (Figure 1).

The resulting ash was dissolved and titrated with a 0.01 N. solution of complex III. The calcium content (X) in mmol/100 g of soluble solids was determined in the following formula:

$$X = \frac{a \cdot n \cdot p \cdot 100}{m}, \quad (1)$$

a is the volume of complexon III for titration, sm^3; n –0.01 N solution of complexon III, p is the ratio of the solution amount for dissolving ash to the amount of ash. In this experiment, $p = 20$ $(100:5 = 20)$, m is the weight of the sample, g.

2.2.2. Storage. The berries of tested red currant cultivars were harvested during biological ripening when >90% of the berries from the bush were mature. Berry ripening was accessed visually. To assess the extent of berry maturation, we determined the physico-mechanical parameters of the berries, specifically focusing on separation force and crushing force by the Dina-2 device (Siberian Institute of Physics and Technology of Agrarian Problems, Russia) [36]. The crushing force was determined using the Plodtest-1 device (Siberian Institute of Physics and Technology of Agrarian Problems, Russia). Mature berries were randomly selected from the experimental plants. The number of berries in the cluster varied from 8 to 16 pieces, depending on the genotype. Red currant berries can be stored at room temperature for no more than 20 hours before the appearance of the berries begins to deteriorate [37, 38].

Therefore, according to the experiment's design, the hand-picked berries of the varieties were placed in plastic disposable fruit containers with a volume of 0.8 liters. Within 1 hour, they were transported to the laboratory and stored in the refrigerator Polair CM105-Gm (Switzerland) at +2.8 to +4.0°C (the relative humidity of the air was 95%). The berries were stored for 27 days. The repetition of the experience was threefold. Before laying currant berries for storage, their weight was determined.

Table 1: Weather conditions at the experimental site during the vegetation periods.

Year	2022				2023			
	T average (°C)	T min (°C)	T max (°C)	Precipitation amount (mm)	T average (°C)	T min (°C)	T max (°C)	Precipitation amount (mm)
April								
III decade	7.4	−0.5	17.1	28.7	9.8	−0.5	22.0	26.6
May								
I decade	9.8	1.7	20.8	8.3	7.8	−4.2	21.0	3.7
II decade	11.1	4.0	24.5	11.5	13.8	1.0	25.7	0.4
III decade	11.7	0	23.5	18.5	14.9	3.0	25.5	4.9
June								
I decade	17.9	6.5	28.5	0	14.6	0.5	27.5	1.3
II decade	19.0	8.5	30.5	17.6	16.7	8.0	28.8	1.5
III decade	20.4	10.0	32.0	25.0	16.5	8.0	29.0	34.0
July								
I decade	21.2	7.0	32.5	12.9	19.5	10.0	29.5	24.7
II decade	17.5	8.5	26.5	53.9	17.5	7.5	30.0	23.3

Table 2: Application of Ca-organomineral (Ca-OM) treatment.

Plant ontogenesis phase	Treatment date
Blossom	13.05.2022/4.05.2023
Formation of green berries (A)	16.06.2022/2.06.2023
At the beginning of ripening (20% of berries on the bushes acquired a characteristic color) (B)	24.06.2022/8.06.2023
At the beginning of ripening (50% of berries on the bushes acquired a characteristic color) (C)	30.06.2022/19.06.2023
Berry ripening (more than 90% of the berries acquired a characteristic color and taste) (D)	07.07.2022/26.06.2023

Note. A–D, stages of leaves and berries selection for analysis.

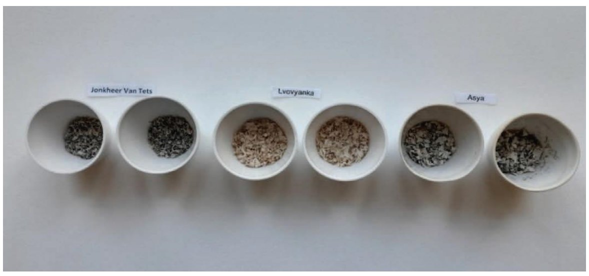


Figure 1: Ash samples of red currant leaves.

The measurements of TSS, the density of the berry skin, and Physiological Loss in Weight (PLW) were carried out at intervals of 3-4 days. Five currant clusters (60 berries) were selected from each container to determine TSS and the density of the berry skin. The TSS (Brix %) examination using a PAL-3 digital refractometer (ATAGO, Japan). The density of the berry skin was determined by the MEGEON 03004 penetrometer (Russia).

The Physiological Loss in Weight (PLW) was defined as the difference between the initial weight of the berries ($M1$) and the subsequent weight of the berries (Mi) in each container. It was determined by the following formula [39]:

$$\text{PLW} = \frac{M1 - \text{Mi}}{M1} \cdot 100\%. \quad (2)$$

The berries were weighed on the Scout Pro SP 202 laboratory scale (OHAUS, Parsippany, NJ, USA).

The values of TSS, the density of the berry skin, PLW, and the visual evaluation of spoiled berries determined the storage period. The maximum shelf life of the berries was the period during which the berries retained the optimal specified qualities, and the PLW did not exceed 10% [40].

The calcium content in berries during the postharvest period was determined by the previously specified method (Section 2.2.1) at three key stages: (a) initial, (b) midpoint, and (c) final phase of storage.

2.3. Statistical Analysis. The raw data were statistically summarized and graphically presented in Microsoft Excel. Then, an independent samples *t*-test (at a 5% significance level) was performed using SPSS version 22.0 to determine whether the control and applied treatments had a statistically different effect on the measured parameters. To compute and visualize the principal component analysis (PCA), the function of res.pca < -prcomp(df, scale = TRUE) from the factoextra R package was used, and to compute and visualize cluster analysis, the function of res.hcpc < -HCPC (res) from the FactoMineR R package was used.

3. Results and Discussion

3.1. Vegetation Period. Foliar treatments in intensive technologies are essential elements in managing growth and production processes in the plant, as well as an important factor in the rapid impact on the processes that determine the yield and quality at the vegetation stage and the storage of fruits [41]. At the same time, Ca has a unique role in the nutrition of plants [28]. Calcium is an element that is not reutilized in the plant body, but young and growing organs and tissues constantly need this element [42]. For many fruit and berry crops, removing calcium per unit of yield is comparable to removing nitrogen [43–45]. The summary of agrochemical soil characteristics at the experimental site is presented in Table 3, confirming the acid soil conditions with a high content of available phosphorus and potassium [46].

The weather conditions guided foliar treatment with the Ca-OM during the growing seasons. In 2022, the beginning of red currant vegetation lagged the average annual values for the test crop by 10–15 days (Table 1). This difference affected the subsequent dates of Ca-OM treatments and physiological processes in the plant (Table 3). In 2023, the weather conditions at the experimental site conformed to the region's average, long-term climatic patterns, with no deviations observed in the progression of the ontogenetic stages of red currant development.

3.1.1. Effect of Foliar Calcium Treatments on Vegetative Mass. Monitoring the phases of ontogenetic development allows for specific adjustments in the implementation of the production process and the yield quality due to agrochemical measures [47]. The stages of fruit formation and quality management are of the most significant interest [48]. The Ca content in currant leaves depends on the cultivar and the vegetation stage. The studies of Hogue et al. [49] in apples, it was reported that the accumulation of Ca in the leaves is a complex process that depends on exogenous factors (weather conditions, abiotic and biotic stress) and endogenous factors (genotype, ontogenetic stages of development). The Ca content in the leaves of fruit crops [50–52] is lower than in berry crops [53]. The leaves of red currants are rich in calcium, potassium, and magnesium, and the content of these elements depends on the date of leaf collection [54–58]. A low seasonal variability of the Ca content in currant leaves is shown in Figure 2. Insignificant dynamics of the Ca content in the apple leaves were found during the growing season [59].

Foliar treatment with Ca-OM did not affect the Ca content in currant leaves. Similar results were obtained using

Table 3: Agrochemical soil indicators of the experimental plot.

Indicator	0–0.2 m	0.2–0.4 m
pH_{KCl}	4.7–4.8	4.7–4.9
Available potassium	41.7 mg·kg^{-1}	21.0 mg·kg^{-1}
Available phosphorus	110.0 mg·kg^{-1}	128.0 mg·kg^{-1}

different concentrations of calcium-containing preparations on strawberry, raspberry, BlackBerry, and blueberry cultivars [49, 59]. Lobos et al. [47] suggested that the elemental composition of the leaf is relatively stable and is little influenced by agrochemical techniques and weather conditions. The Ca content in the leaves increased with their ontogenetic development (Figure 2). The reports of Nour et al. [56] also showed that by the time the berries ripened, the calcium, magnesium, and iron content in currant leaves was the highest. An increase in Ca with leaf age was also revealed in apple cultivars and was explained by the immobility of Ca in leaf tissues and the absence of its redistribution to other plant organs [51]. At the stage of berry ripening, significant differences in the content of Ca in the leaves were in the red current cultivars "Vika," "Asya," "Lvovyanka," and "Jonkheer Van Tets" (Figure 2).

The TSS content in red currant leaves did not exceed 4% (Table 4). In the studies in apples [60] and in *Cydonia oblonga, Chaenomeles japonica, Ribes nigrum, Aronia melanocarpa, Vaccinium macrocarpon,* and *Vaccinium myrtillus* [61], the TSS content in the leaves also did not exceed 10%. Foliar treatments with Ca-OM at different stages of currant development did not significantly impact the TSS content in the leaves (Table 4). However, the reliability of the data is difficult to assess since no information has been found in the literature on the effect of foliar treatments with Ca on the TSS content in the leaves of fruit plants.

A decrease in TSS in leaves during the adverse weather of 2022 is shown (Table 4). A positive correlation was found between TSS in currant leaves and temperature ($r = +0.80–+0.92$). The positive effect of temperature on TSS in leaves is shown in grapes [62].

At the berry ripening stage, the TSS content in the leaves decreased (Table 4). In "Jonkheer Van Tets" and "Lvovyanka" the decrease occurred when 20% of the berries on the bushes acquired a characteristic color; for other cultivars, this pattern occurred later, when a larger percentage of berries acquired a red color. Similar results were obtained in *Persica davidiana* Carr. [63]. The decrease in TSS content in the summer period may be explained by the intensification of hydrolytic processes in the leaves and the outflow of hydrolysis products from the leaves to the ripening fruits [63].

3.1.2. The Effect of Foliar Calcium Treatments on Berries. The mechanism of intake and distribution of Ca is complicated and is determined not only by the anatomy of the fruit but also by the genotype and stage of plant development [64].

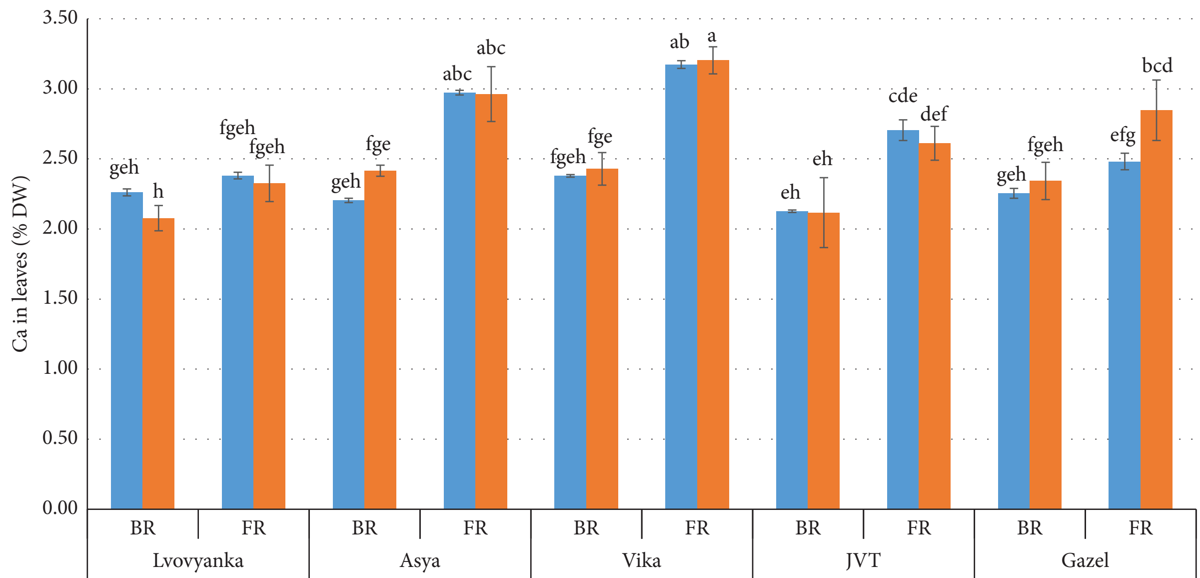
The intake of Ca into the fruits occurs through the stomata on the surface of the fruits. Not only is the conductivity of stomata essential, but so is their number and distribution on the surface of the fruit [65]. A decrease in the number of stomata and a decrease in their conductivity reduce the intake and accumulation of Ca in fruits [47]. The Ca content in immature red currant berries is higher than in leaves (Figures 2 and 3). This is probably due to the functional activity of the stomata of the fruits.

The intake and distribution of Ca in fruits depends on the stage of plant ontogenesis [66, 67]. A high percentage of the Ca accumulation was at the initial stage of the development of currant berries. The Ca accumulation slowed and decreased when the berries were fully ripe (Figure 3). Thus, treating Ca-OM in the early stages of the ontogenesis of red currants provides a high percentage of the Ca intake in berries and ensures the high strength of berries. This again shows Ca's role in the development of fruits and determines their quality. In the early stages of the growth and development of fruits or berries, Ca is involved in cell division and metabolism. Ca is mainly involved in the intercellular junction in the later stages of fruit or berry development [42]. It is known that the movement of Ca through the plant depends on the xylem fluid. When the fruits are fully ripe, the movement of water switches from the xylem to the phloem, so the movement of Ca to other parts of the plant is limited [68]. Calcium accumulation in fruits decreases when the xylem losses function [67, 69]. The effect of dilution of the Ca content is observed as the fruit grows [70, 71].

The genetic characteristics of currants determined the date of the decrease in the content of Ca in fruits. In early-ripening cultivars "Lvovyanka," "Asya," "Vika," and "Jonkheer Van Tets," the decrease in Ca occurred 5-6 days earlier than in the late-ripening cultivar "Gazel." Similar results were obtained in blueberry [65], kiwi [67], and grape cultivars [69].

Varietal differences in the content of Ca in currant berries were revealed. "Asya" and "Gazel" had a significantly high content of it. By the time the berries ripened, Ca-OM minimized the decrease in Ca in the berries, and its content was 20% higher than in the control. Similar results on the content and distribution of Ca during the growing season were obtained in blueberry cultivars. Calcium accumulated rapidly at the initial stage of berry ripening; at the beginning of berry coloring, its accumulation slowed down and stopped when the berries were fully ripe [65].

The physical and mechanical parameters of currant berries (the crushing force of berries ((Fc) and the separation force of berries in the cluster (Fs)) were indicators of the period of biological maturity of the berries [36]. The data on the physical and mechanical qualities of the berries corresponded to the indicators of the Ca content in the fruits (Figure 3). Ca-OM increased the strength of berries (Fc) in currant cultivars and also reduced the shedding of berries in the cluster (Fs) compared to the control (Table 5). This is confirmed by the role of Ca in regulating fruit ripening and its quality. Foliar treatment with Ca stabilizes the cell wall of plants, maintains the elasticity of tissues, and preserves the hardness of fruits [42]. Pectin acid can combine with Ca and form calcium pectate, which is the structural basis of the cell wall, increasing its strength and preventing the gel layer's



	Lvovyanka BR	Lvovyanka FR	Asya BR	Asya FR	Vika BR	Vika FR	JVT BR	JVT FR	Gazel BR	Gazel FR
Control	2.26	2.38	2.20	2.97	2.38	3.17	2.13	2.71	2.25	2.48
Ca-OM	2.08	2.33	2.42	2.96	2.43	3.20	2.12	2.61	2.34	2.85

Figure 2: The impact of foliar Ca-organomineral (Ca-OM) application of Ca content (%) dynamics in leaves among tested red currant cultivars during the growing season. Bars with the same letter are not significantly different according to Tukey's (HSD) test. BR = beginning of berry ripening and FR = full berry ripening.

Table 4: The impact of foliar Ca-organomineral (Ca-OM) application on the content of total soluble solids (TSS; Brix %) in the leaves among tested red currant cultivars during the growing season.

Cultivar	Treatment	2022				2023			
		16.06	23.06	27.06	5.07	2.06	8.06	21.06	26.06
Lvovyanka	Control	1.8*	2.0 ns	1.6*	2.3*	1.8*	2.1*	2.2*	2.3*
	Ca-OM	2.8*	1.9 ns	2.0*	1.8*	2.9*	2.7*	2.7*	2.6*
Asya	Control	1.8 ns	2.4 ns	2.2*	2.3 ns	2.0*	2.6 ns	2.8 ns	2.7 ns
	Ca-OM	2.2 ns	2.3 ns	2.5*	2.2 ns	2.7*	2.7 ns	2.7 ns	2.6 ns
Vika	Control	1.4*	2.2*	1.3 ns	2.1 ns	2.4*	2.4 ns	3.3*	3.0 ns
	Ca-OM	2.0*	2.6*	1.6 ns	2.5 ns	2.5*	2.4 ns	3.8*	2.9 ns
JVT	Control	2.5*	2.5 ns	2.4*	2.8 ns	2.8*	2.7*	2.7*	3.5 ns
	Ca-OM	3.4*	2.2 ns	2.2*	2.6 ns	3.3*	3.3*	3.3*	3.7 ns
Gazel	Control	1.7 ns	2.3 ns	2.0 ns	1.9 ns	3.0*	2.9*	2.7 ns	2.5 ns
	Ca-OM	2.1 ns	2.1 ns	1.9 ns	1.7 ns	3.6*	2.8*	2.7 ns	2.4 ns

The small letters (ns) following the number of values (of the same cultivar) represent nonsignificance according to the *t* test, and the sign *represents the statistically significant difference.

disintegration in the cell [72]. In the studies by Wójcik et al. [73] in cherries, Madani et al. [74] in papaya, Siddiqui et al. [75] in apples, Bonomelli et al. [76] and Martins et al. [77] in table grapes, Lobos et al. [47] in blueberry, and Souza et al. [78] in *Ficus carica* L. it is shown that the use of Ca before harvest increased the hardness of fruits.

The TSS increased in immature berries during the growing season (Table 6). By the time the berries ripened, the TSS in all cultivars exceeded 10%. In "Vika" and "Lvovyanka," a sharp increase in TSS (45–70% of the initial level) corresponded to the stage of TSS decline in the leaves (Table 4). A rise in TSS by the fruit ripening period was noted in grapes. It was explained by the high consumption of sugars at the early stages of berry growth and development. Subsequently, metabolic changes occurred during berry ripening that contributed to the accumulation of sugars in fruits [62, 79]. At the same time, Ca-OM essentially increased TSS in berries. Similar results were observed under foliar treatments of strawberries [80] and apples [81, 82] with Ca at different stages of ontogenesis. The variation coefficient (CV) of this trait in control and experimental variants exceeded 20% over the years of the studies. A sufficiently large spread and minimal alignment of values for the studied characteristics are once again confirmed by the dependence of the trait on climatic conditions and genetic origin. The significant influence of the genotype, stage of

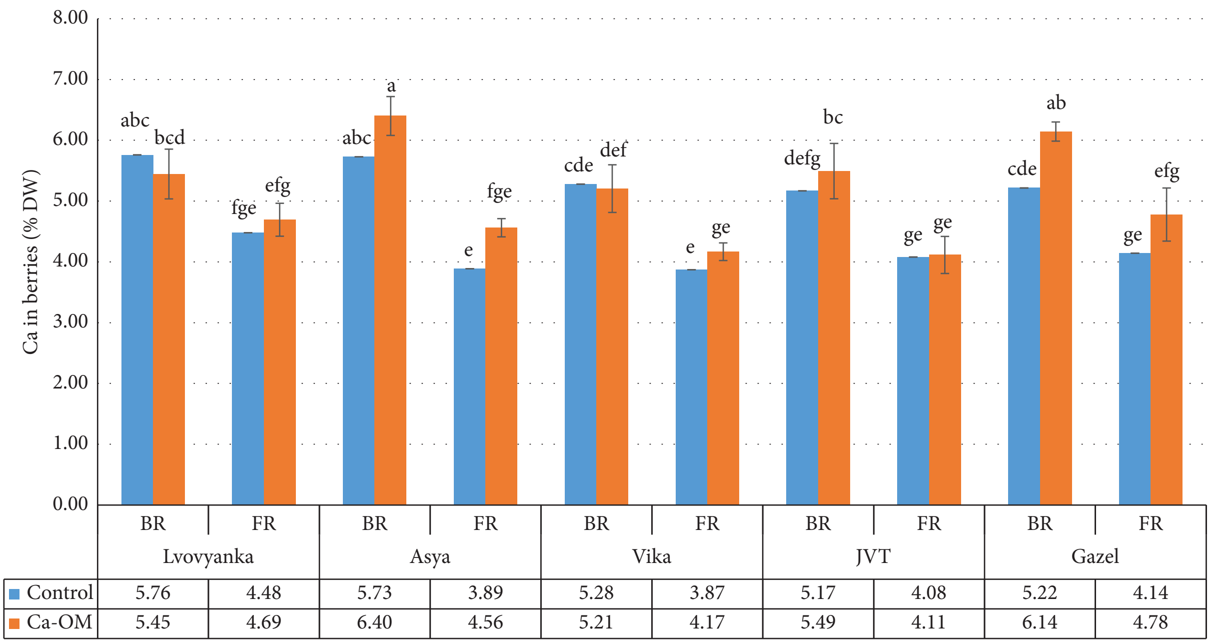


Figure 3: The impact of foliar Ca-organomineral (Ca-OM) application on Ca content (%) dynamics in berries among tested red currant cultivars during the growing season. Bars with the same letter are not significantly different, according to Tukey's (HSD) test. BR = beginning of berry ripening and FR = full berry ripening.

Table 5: The physical-mechanical parameters of red currant berries before they are removed for storage.

Cultivar	Parameters	Treatment	
		Control	Ca-OM
Lvovyanka	Fc	4.1 ns	4.3 ns
	Fs	0.81 ns	0.76 ns
Asya	Fc	4.44*	5.65*
	Fs	0.86 ns	0.89 ns
Vika	Fc	5.01*	5.52*
	Fs	0.65*	0.89*
JVT	Fc	5.65 ns	5.73 ns
	Fs	0.72*	0.84*
Gazel	Fc	4.89*	5.43*
	Fs	0.75*	0.90*

The small letters (ns) following the number of values (of the same cultivar) represent nonsignificance according to the t-test, and the sign *represents the statistically significant difference. Fc, force crushing of berry (*N*); Fs, force separation of berry from branches (*N*).

plant development, and climate conditions on the TSS content in berries ($p \leq 0.05$) is shown in the blueberry studies of Yang et al. [65].

3.2. Storage Period. In storing berry products, there are several problems: a decrease in the hardness of berries, a color change (darkening), and the abscission of berries in the bunches, and the development of diseases [83].

The TSS of level and the density of berries are essential in assessing the quality of berries and extending their shelf life [83].

In red currant varieties, the TSS content increased slightly during storage until a certain period (Tables 7 and 8). This is due to the loss of moisture in the berries and the hydrolysis of carbohydrates to soluble sugars [84].

The introduction of Ca-OM increased the total TSS content in berries, and the decrease in TSS in the cultivars "Lvovyanka," "Vika," and "Gazel" was slower than in control ($p \leq 0.05$). This is explained by the role of calcium cations in slowing down metabolic processes and cell respiration. Slowing down metabolic processes and respiration leads to a decrease in the rate of fruit ripening during storage [85]. Respiration slowdown reduces the synthesis and utilization of metabolites and decreases fruit TSS. Our results are consistent with those obtained in tomatoes [86] and strawberries [87]. Studies have reported that the amount of free sugars gradually increased during storage, and calcium cations noticeably slowed this increase.

The content of TSS is related to the strength of the fruit. A positive correlation between these indicators was noted in apples during storage [88, 89].

Table 6: The impact of foliar Ca-organomineral (Ca-OM) application on the content of total soluble solids (TSS; Brix %) in the berries among tested red currant cultivars during the growing season.

Cultivar	Treatment	2022				2023			
		16.06	23.06	27.06	5.07	2.06	8.06	21.06	26.06
Lvovyanka	Control	3.1*	5.0 ns	6.7 ns	10.4*	4.7*	9.7*	10.8*	11.0*
	Ca-OM	5.0*	4.6 ns	6.9 ns	11.2*	9.0*	10.6*	11.9*	12.4*
Asya	Control	6.1*	4.5*	6.5*	10.7 ns	8.2 ns	10.5 ns	10.5*	11.5*
	Ca-OM	5.2*	6.4*	6.2*	11.0 ns	9.4 ns	10.3 ns	11.8*	12.4*
Vika	Control	2.1*	2.2*	7.9*	7.8*	9.1*	9.8*	11.7*	11.8*
	Ca-OM	4.8*	5.2*	8.4*	11.2*	10.3*	11.2*	12.1*	12.7*
JVT	Control	3.0*	5.1*	6.4 ns	9.7*	9.3 ns	9.7*	9.2*	10.7 ns
	Ca-OM	4.8*	5.9*	6.2 ns	10.4*	9.4 ns	10.6*	10.9*	10.8 ns
Gazel	Control	4.4 ns	4.5*	6.5*	10.8 ns	9.6*	10.6 ns	10.0*	11.6*
	Ca-OM	4.7 ns	4.7*	7.0*	11.2 ns	10.4*	10.6 ns	11.5*	12.1*

The small letters (ns) following the number of values (of the same cultivar) represent nonsignificance according to the t test, and the sign *represents the statistically significant difference.

Table 7: The impact of foliar Ca-organomineral (Ca-OM) application on the content of total soluble solids (TSS; Brix %) in the berries among tested red currant cultivars during storage in 2022.

Cultivars	Treatments	Day 0	Day 4	Day 8	Day 12	Day 15	Day 18	Day 21	Day 24	Day 27
Lvovyanka	Control	10.0*	10.2*	10.9*	10.8*	11.0*	10.8*			
	Ca-OM	11.2*	11.7*	11.5*	11.6*	12.1*	13.2*	12.4		
Asya	Control	14.2 ns	14.3 ns	13.8*	15.0*	14.0 ns	12.1 ns			
	Ca-OM	14.2 ns	14.0 ns	14.3*	13.9*	14.1 ns	11.9 ns			
Vika	Control	12.0 ns	11.8*	11.7*	11.6*	12.3*	12.3*			
	Ca-OM	12.3 ns	12.5*	12.1*	12.3*	13.5*	12.8*	13.4	12.5	
JVT	Control	13.6*	12.4 ns	12.7 ns	13.2*	12.5 ns	11.9*			
	Ca-OM	12.6*	12.4 ns	12.8 ns	12.1*	12.7 ns	12.7*			
Gazel	Control	12.6*	12.1 ns	11.8 ns	12.0 ns	12.4*	12.4*	12.1*	11.8*	
	Ca-OM	12.3*	12.2 ns	11.9 ns	12.2 ns	12.7*	13.4*	14.5*	14.5*	11.7

The small letters (ns) following the number of values (of the same cultivar) represent nonsignificance according to the t test, and the sign *represents the statistically significant difference.

Table 8: The impact of foliar Ca-organomineral (Ca-OM) application on the content of total soluble solids (TSS; Brix %) in the berries among tested red currant cultivars during storage in 2023.

Cultivars	Treatments	Day 0	Day 4	Day 8	Day 12	Day 15	Day 18	Day 21	Day 24	Day 27
Lvovyanka	Control	13.8 ns	14.2 ns	13.6*	14.1*	14.2*	14.1*			
	Ca-OM	13.8 ns	14.4 ns	14.3*	14.7*	15.4*	14.7*	12.5		
Asya	Control	10.7*	11.6 ns	11.6*	11.4*	11.9 ns	12.5 ns			
	Ca-OM	11.6*	11.5 ns	11.4*	11.1*	12.0 ns	12.2 ns			
Vika	Control	13.8*	13.8*	14.6*	15.5*	14.8*	14.2*	12.9*		
	Ca-OM	15.8*	14.6*	15.0*	16.2*	16.7*	16.8*	16.2*	13.7	
JVT	Control	10.9 ns	10.1*	10.2 ns	10.2*	11.3 ns	11.8*	11.9*		
	Ca-OM	10.7 ns	10.8*	10.4 ns	10.9*	11.3 ns	11.6*	11.5*		
Gazel	Control	13.4*	12.6*	13.0*	13.6*	14.2*	14.2*	11.6*		
	Ca-OM	14.0*	13.7*	14.0*	14.3*	14.6*	14.9*	14.9*	11.7	

The small letters (ns) following to the number of values (of the same cultivar) represent nonsignificance according to the *t* test, and the sign *represents the statistically significant difference.

In this experiment, the density of berries gradually decreased, but the rate of decrease in berry density was slower in the variants with Ca-OM (Tables 9 and 10).

"Lvovyanka," "Vika," and "Gazel" in the Ca-OM variant maintained a high berry density compared to the control over a long storage period. The results of the study are consistent with data from Gupta et al. [90] and Rombaldi et al. [91] in peach, Changhoo et al. [92] in kiwi, and Ciccarese et al. [93] in grapes. Studies have reported that the addition increases the strength of fruits and prolongs the storage period of fruit products.

Gao et al. [30] and Vicente et al. [90] have shown that the use of Ca increases the density of the intercellular layer of the cell wall, prevents the penetration of hydrolase and the

Table 9: The impact of foliar Ca-organomineral (Ca-OM) application on the density in the berries among tested red currant cultivars during storage in 2022 (*N*).

Cultivars	Treatments	Day 0	Day 4	Day 8	Day 12	Day 15	Day 18	Day 21	Day 24	Day 27
Lvovyanka	Control	3.1*	2.9*	2.5*	2.5*	1.7*	1.0*			
	Ca-OM	3.8*	3.6*	3.9*	3.6*	2.5*	2.2*	1.0		
Asya	Control	2.5*	2.6*	1.4*	1.3*	0.7*	0.8 ns			
	Ca-OM	3.2*	3.0*	2.5*	1.2*	0.9*	0.9 ns			
Vika	Control	2.3*	2.3*	2.7*	2.3*	1.6*	1.9*	1.0*		
	Ca-OM	2.8*	3.3*	3.6*	3.0*	2.3*	2.4*	1.9*	0.9	
JVT	Control	2.2*	2.5*	1.9*	1.6*	1.3*	1.1 ns			
	Ca-OM	2.9*	3.0*	2.4*	2.1*	1.8*	1.1 ns			
Gazel	Control	2.4*	2.6*	2.1*	2.0*	1.8*	1.7*	1.0*	0.9*	
	Ca-OM	2.7*	3.6*	2.7*	2.5*	2.2*	2.2*	1.6*	1.3*	0.9

The small letters (ns) following to the number of the values (of the same cultivar) represent nonsignificance according to the t test, and the sign * represents the statistically significant difference.

Table 10: The impact of foliar Ca-organomineral (Ca-OM) application on the density in the berries among tested red currant cultivars during storage in 2023 (*N*).

Cultivars	Treatments	Day 0	Day 4	Day 8	Day 12	Day 15	Day 18	Day 21	Day 24	Day 27
Lvovyanka	Control	2.2 ns	2.6 ns	2.8*	2.8*	1.7*	1.0*			
	Ca-OM	2.2 ns	2.6 ns	3.2*	2.2*	2.0*	1.5*	0.9		
Asya	Control	3.5*	4.5 ns	4.2 ns	3.4*	2.0 ns	1.0 ns			
	Ca-OM	4.4*	4.4 ns	4.2 ns	3.7*	2.2 ns	1.0 ns			
Vika	Control	4.6*	4.0*	3.8 ns	2.5*	2.4*	1.6*	1.0*		
	Ca-OM	4.9*	4.9*	3.8 ns	3.7*	3.4*	2.2*	1.8*	1.0	
JVT	Control	4.5 ns	3.9 ns	3.3*	2.0*	1.5 ns	0.9 ns			
	Ca-OM	4.4 ns	3.9 ns	3.5*	2.3*	1.5 ns	1.0 ns			
Gazel	Control	3.6*	3.9*	2.8*	2.9*	1.8*	1.7*	0.9*		
	Ca-OM	4.3*	4.2*	4.0*	3.4*	2.1*	1.8*	1.1*	1.0	0.9

The small letters (ns) following to the number of the values (of the same cultivar) represent nonsignificance according to the t test, and the sign * represents the statistically significant difference.

disintegration of the jelly-like layer, and also affects changes in the pectin component of the cell wall, thereby maintaining the stability of the cell wall and the hardness of fruits. Calcium, which is part of the structure of the cell wall of fruits, can reduce the availability of enzymes that destroy the cell wall and help preserve the postharvest qualities of fruits [95, 96]. Also, Ca, together with abscisic acid (A.B.A.), participates in the transmission of ethylene signals, which regulates the processes of softening, aging, and ripening of fruits [42, 90]. It has been proven that calcium is involved in transmitting the ethylene signal, where the SR1 gene encodes several calcium sensors (CaM, CML, and C.D.P.K.) responsible for fruit maturation. [97].

Studies of current cultivars have revealed genotypic differences in the calcium content of berries during storage. Foliar Ca-OM treatments increased the calcium content in berries (Figures 4 and 5).

There was a significant calcium increase compared with the control in "Lvovyanka," "Vika," and "Gazel." Similar results were obtained by Tromp [70] in apples and by Fuentes et al. [25, 98] in grapes.

Changes in the calcium content in fruits are explained by the different viability of the cells of the genotypes of fruit crops to retain moisture for a specific time, thereby minimizing the percentage of calcium loss by fruits [42, 99].

In this experiment, an increase in the calcium content during storage was observed.

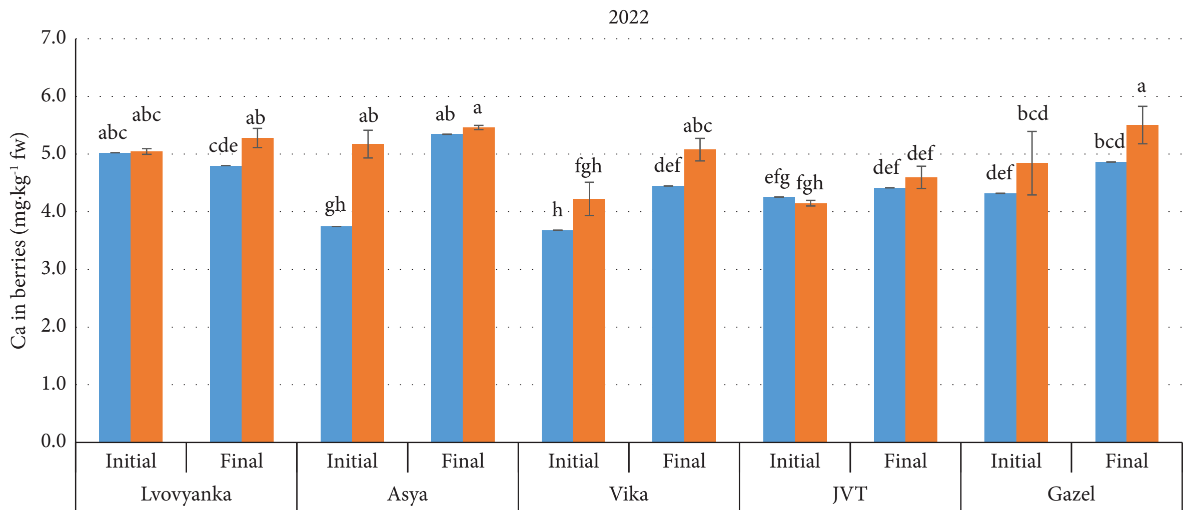
According to the research of White and Broadley [64], this result is explained, firstly, by the physiological loss of fruit weight and, secondly, by the peculiarity of calcium not being reutilized in the plant. In this experiment, physiological weight loss averaged 2–4% every three days.

Physiological Weight Loss (PLW) increased during the storage period (Table 11).

These results are similar to those of Dhillon et al. in mango [100], Gupta et al. in peach [90], Gangwar et al. in aonla [101], and Mahajan et al. in guava [102].

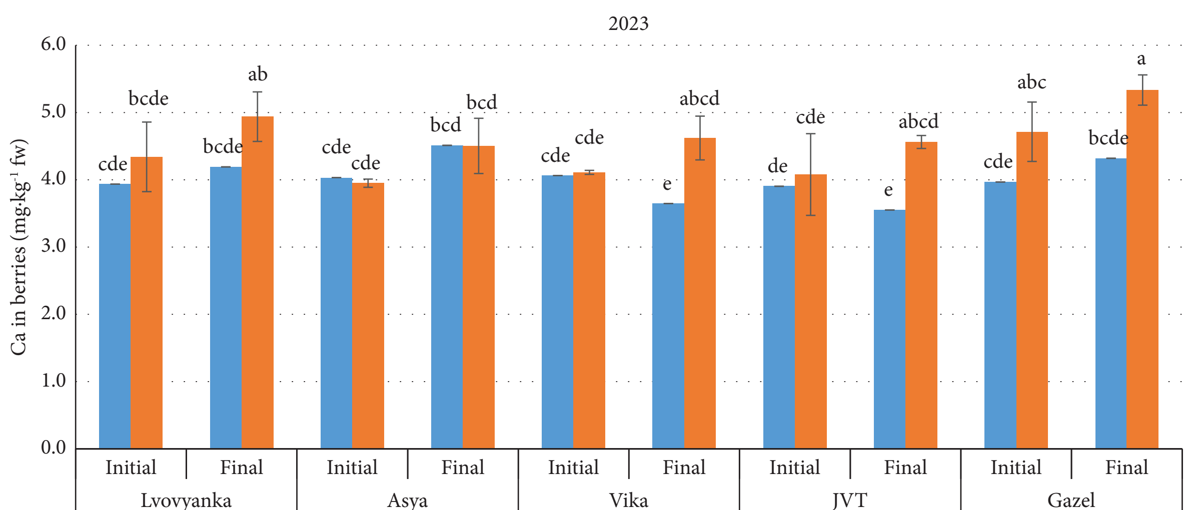
It is reported that calcium is adequate for maintaining the integrity of cell membranes, and it reduces the loss of phospholipids, proteins, and ions, which may be the reasons for reducing weight loss during storage [103].

The influence of the cultivar and the use of Ca-OM on the duration of storage and preservation of the quality of currant berries have been revealed. Ca-OM extended the shelf life of "Lvovyanka," "Vika," and "Gazel" berries by an average of 3–7 days compared to the control (Tables 7–11). These data are consistent with the results of Blažek et al. [104], Pissard et al. [105], and Tokala et al. [106] for apples. The shelf life is reported depending on the cultivar and cultivation technology and storage technology.



	Lvovyanka Initial	Lvovyanka Final	Asya Initial	Asya Final	Vika Initial	Vika Final	JVT Initial	JVT Final	Gazel Initial	Gazel Final
Control	5.0	4.8	3.7	5.3	3.7	4.4	4.3	4.4	4.3	4.9
Ca-OM	5.0	5.3	5.2	5.5	4.2	5.1	4.1	4.6	4.8	5.5

Figure 4: The impact of foliar Ca-organomineral (Ca-OM) application on the dynamics of Ca content (mg·kg^{-1} f.w.) in berries during storage in 2022. Bars with the same letter are not significantly different according to Tukey's (HSD) test.



	Lvovyanka Initial	Lvovyanka Final	Asya Initial	Asya Final	Vika Initial	Vika Final	JVT Initial	JVT Final	Gazel Initial	Gazel Final
Control	3.9	4.2	4.0	4.5	4.1	3.6	3.9	3.6	4.0	4.3
Ca-OM	4.3	4.9	4.0	4.5	4.1	4.6	4.1	4.6	4.7	5.3

Figure 5: The impact of foliar Ca-organomineral (Ca-OM) application on the dynamics of Ca content (mg·kg^{-1} f.w.) in berries during storage in 2023. Bars with the same letter are not significantly different according to Tukey's (HSD) test.

This is due to the varietal reactions to foliar application of Ca and the peculiarity of Ca cations that slow down the processes of spoilage of berries. At low temperatures, the additional content of Ca-pectate can contribute to the thickening of cell walls and slowing down metabolic processes in cells [107]. Under visual observation, the shedding of berries, the development of spoilage, and the darkening of berries decreased in "Lvovyanka," "Vika," and "Gazel" treated with Ca-OM (Figure 6). Symptoms of a decrease in the quality of berries were observed in the treated cultivars "Lvovyanka," "Vika," and "Gazel" after 18 days of storage.

3.3. Cluster Analysis and Variety Similarity. The results of PCA biplot according to Ca and TSS content in leaves and fruits of five different berry cultivars during growth periods are given in Figure 7 [108]. According to the results, it can be concluded that the cultivars closest to each other (with similar characteristics) are the "Asya" and "Gazel" cultivars [109]. These two cultivars are primarily similar in terms of TSS content in the control treatment and Ca content in the fruits of the Ca-OM treatment.

The Ca content was notably higher in the fruits of the control of the "Lvovyanka" cultivar than the "Gazel" and "Asya" cultivars, highlighting a distinctive characteristic of

Table 11: The impact of foliar Ca-organomineral (Ca-OM) application on the physiological loss in weight (PLW) in the berries among tested red currant cultivars in a standard atmosphere at a storage temperature +2.8 to +4.0°C (%).

Cultivars	Year	Treatments	Day 0	Day 4	Day 8	Day 12	Day 15	Day 18	Day 21	Day 24	Day 27
Lvovyanka	2022	Control	0	1.0*	3.2*	3.8*	7.6*	15.1*			
		Ca-OM	0	0	1.1*	1.2*	3.4*	6.6*	10.3		
	2023	Control	0	0.9*	2.9*	4.4*	8.5*	17.7*			
		Ca-OM	0	0	0.8*	1.0*	2.7*	8.9*	11.2		
Asya	2022	Control	0	0	2.0*	3.4*	6.7*	11.2 ns			
		Ca-OM	0	0	0.7*	2.9*	5.4*	10.9 ns			
	2023	Control	0	0.4 ns	1.8 ns	4.1*	6.0 ns	12.0 ns			
		Ca-OM	0	0.1 ns	1.5 ns	3.0*	5.5 ns	11.8 ns			
Vika	2022	Control	0	0.5	1.0*	2.1*	4.4*	7.1*	10.1*		
		Ca-OM	0	0	0.2*	1.0*	1.9*	3.2*	7.0*	10.9	
	2023	Control	0	0.2	0.9 ns	1.9*	3.4*	6.4*	12.1*		
		Ca-OM	0	0	0.5 ns	0.8*	1.2*	3.1*	6.4*	11.8	
JVT	2022	Control	0	0.9*	3.9*	8.8*	10.9 ns				
		Ca-OM	0	0.1*	2.8*	4.1*	10.1 ns				
	2023	Control	0	1.0 ns	4.6*	8.1*	11.2 ns				
		Ca-OM	0	0.8 ns	2.1*	6.4*	10.6 ns				
Gazel	2022	Control	0	0.9	2.4*	4.8*	6.9*	7.7*	8.4*	11.8*	
		Ca-OM	0	0	0.6*	2.1*	4.0*	5.2*	7.1*	9.1*	12.2
	2023	Control	0	0.2	1.8*	3.1*	7.7*	9.6*	11.2*		
		Ca-OM	0	0	0.4*	1.7*	2.5*	3.3*	5.1*	7.8	10.4

The small letters (ns) following to the number of the values (of the same cultivar) represent nonsignificance according to the *t* test, and the sign * represents the statistically significant difference.

Figure 6: The effect of Ca-OM treatment on the prolongation of the storage period and external qualities of red currant berries at low temperatures.

this cultivar. Similarly, TSS fruit content increased with Ca-OM treatment, but it was not determined as a defining characteristic for any cultivar. On the other hand, the "Vika" cultivar was determined to have a defining characteristic, especially regarding calcium content in leaves. The "Jonkheer Van Tets" cultivar was determined to be superior in terms of TSS content in leaves compared to other cultivars. It can be observed from Figure 7 that the OMP application did not have a significant effect on the TSS content in the leaves.

Consistent with the results analysis, the cluster analysis (CA) results (Figure 8) revealed similar groupings among the tested cultivars. Specifically, "Gazel" and "Asya" cultivars were grouped, demonstrating comparable calcium and TSS,

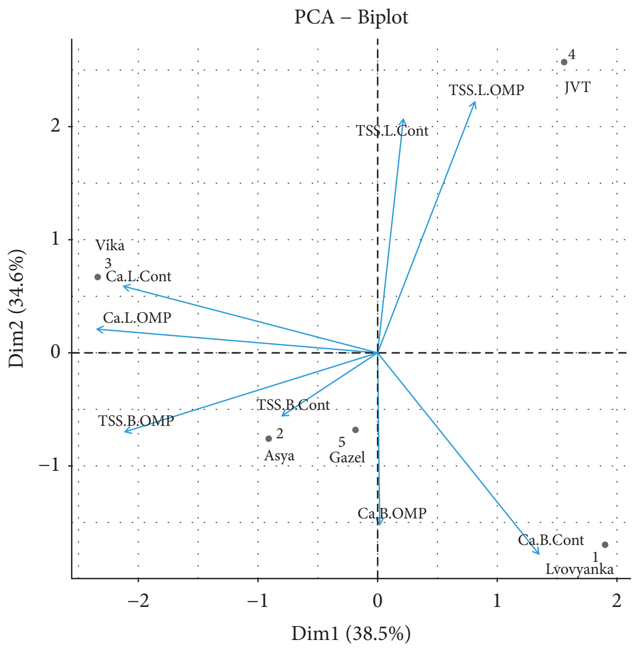


Figure 7: PCA biplot analysis among tested red currant cultivars concerning the Ca and TSS content in the leaf and fruit (berry) tissues.

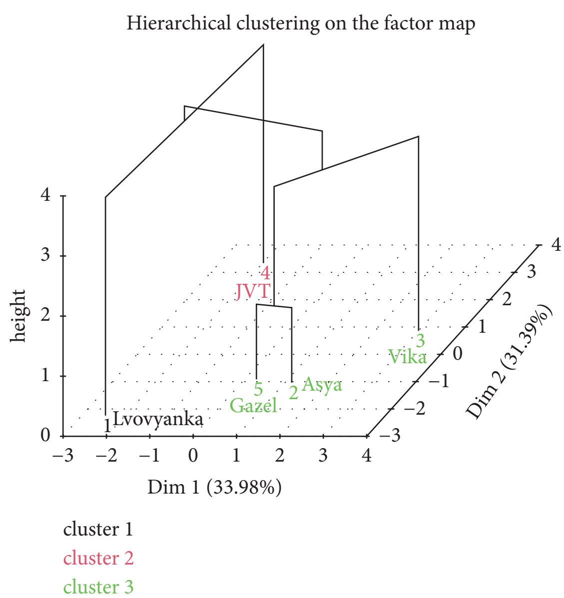


Figure 8: Hierarchical clustering analyses (CA) among tested red currant cultivars concerning the Ca and TSS content in the leaf and fruit (berry) tissues.

and this grouping was also observed with the "Vika" cultivar. The remaining cultivars exhibited similarity at the 4th level of significance, indicating a considerable distance from each other in terms of these characteristics.

4. Conclusion

The application of foliar Ca-OM treatment should be strategically timed with different periods of plant ontogenesis, considering the specific characteristics of the cultivar and the prevailing climatic conditions during cultivation. Ca-OM treatment in the early stages of the ontogenesis of red currants provides a high percentage of Ca intake in berries. It improves berries' physical and mechanical parameters by the period of full ripening. Notably, the stability of calcium content in leaves was less influenced by agrotechnical and natural factors than by fruits, underscoring its potential as a consistent indicator. The significant reduction in calcium content during the full ripening of red currant berries was attributed to their inherent biological characteristics. Additionally, the content of TSS in both vegetative mass and berries is contingent on genotype, ontogenetic stage, and weather factors.

Furthermore, exposing red currant berries to low temperatures during storage and applying Ca-OM in the berry vegetation stage demonstrated favorable outcomes, including increased TSS and berry density, reduced berry abscission within the bunch, and an extension of the storage period for "Lvovyanka," "Vika," and "Gazel."

Notably, CA identified these cultivars as similar to TSS and calcium content in fruits, emphasizing their common traits. Moreover, the elevated calcium content in berries emerged as a positive influence, enhancing consumer characteristics. Contrary to this trend, the results from PCA biplot indicated that for "Asya" and "Jonkheer Van Tets," TSS content does not determine berry quality during the storage period.

In summary, the findings of this experiment pave the way for the development of agrochemical methods aimed at managing the quality of berry products, offering valuable insights for interventions during both the vegetation and storage stages, taking into account the cultivar characteristics of berry crops. The obtained data are relevant both for agricultural producers and researchers studying the role of calcium in the growth and development of horticulture crops [94].

Data Availability

All the data included in the study will be available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

All authors contributed to writing the conception, designing the study, analyzing the data, and discussing the findings. All authors have read and approved the final manuscript submission for publication.

Acknowledgments

This research work was funded by the Ministry of Science and Higher Education of the Russian Federation, project FGZS-2022-0007.

References

[1] D. Bourn and J. A. Prescott, "A comparison of the nutritional value, sensory qualities, and food safety of organically and conventionally produced foods," *Critical Reviews in Food Science and Nutrition*, vol. 42, pp. 1–34, 2002.

[2] S. T. Talcott, "Chemical components of berry fruits," in *Fruit, Value-Added Products for Health Promotion*, Y. Zhao, Ed., pp. 51–72, CRC, Taylor and Francis Group, Boca Raton, FL, USA, 2007.

[3] W. Aneta, O. Jan, M. Magdalena, and W. Joanna, "Phenolic profile, antioxidant and antiproliferative activity of black and red currants (Ribes spp.) from organic and conventional cultivation," *International Journal of Food Science and Technology*, vol. 48, no. 4, pp. 715–726, 2013.

[4] S. C. Debnath and A. Ghosh, "Phenotypic variation and epigenetic insight into tissue culture berry crops," *Frontiers in Plant Science*, vol. 13, Article ID 1042726, 2022.

[5] Fao, "Faostat," 2023, https://www.fao.org/faostat/en/#data/QCL.

[6] G. Reinecke and A. Posthuma, "The link between economic and social upgrading in global supply chains: experiences from the Southern Cone," *International Labour Review*, vol. 158, no. 4, pp. 677–703, 2019.

[7] R. M. Brennan, P. D. S. Caligari, J. R. Clark et al., "Berry crops," in *Horticulture: Plants for People and Places*, G. Dixon and D. Aldous, Eds., vol. 1, pp. 301–325, Springer, Dordrecht, Netherlands, 2014.

[8] M. G. González-Ramírez, V. H. Santoyo-Cortés, J. J. Arana-Coronado, and M. Muñoz-Rodríguez, "The insertion of Mexico into the global value chain of berries," *World Development Perspectives*, vol. 20, Article ID 100240, 2020.

[9] A. Riaz, R. M. Aadil, A. M. O. Amoussa, M. Bashari, M. Abid, and M. M. Hashim, "Application of chitosan-based apple peel polyphenols edible coating on the preservation of strawberry (Fragaria ananassa cv Hongyan) fruit," *Journal of Food Processing and Preservation*, vol. 45, no. 1, Article ID e15018, 2021.

[10] W. Zhang, C. Shu, Q. Chen, J. Cao, and W. Jiang, "The multilayer film system improved the release and retention properties of cinnamon essential oil and its application as coating in inhibition to penicillium expansion of apple fruit," *Food Chemistry*, vol. 299, Article ID 125109, 2019.

[11] M. Safdar, S. A. Naqvi, F. Anjum et al., "Microbial biofilm inhibition, antioxidants, and chemical fingerprints of Afghani pomegranate peel extract documented by gas chromatography–mass spectrometry and Fourier transformation infrared," *Journal of Food Processing and Preservation*, vol. 45, no. 7, Article ID 15657, 2021.

[12] I. Ahmad, Z. Xiong, X. Hanguo et al., "Microstructural study of enzymatically and non-enzymatically hydrolyzed potato powder," *Journal of Food Processing and Preservation*, vol. 46, no. 11, Article ID e16998, 2022.

[13] G. Yildiz and R. M. Aadil, "Comparison of high temperature-short time and sonication on selected parameters of strawberry juice during room temperature storage," *Journal of Food Science and Technology*, vol. 57, no. 4, pp. 1462–1468, 2020.

[14] M. H. Rashid, M. R. Khan, U. Roobab et al., "Enhancing the shelf stability of fresh-cut potatoes via chemical and non-thermal treatments," *Journal of Food Processing and Preservation*, vol. 45, no. 6, Article ID e15657, 2021.

[15] Y. Zhao and R. Zheng, "Combination of fruit and vegetable storage and fresh-keeping with postharvest heat treatment," *Journal of Chemistry*, vol. 2022, Article ID 8681499, 12 pages, 2022.

[16] M. U. Shahbaz, M. Arshad, K. Mukhtar et al., "Natural plant extracts: an update about novel spraying as an alternative of chemical pesticides to extend the postharvest shelf life of fruits and vegetables," *Molecules*, vol. 27, no. 16, p. 5152, 2022.

[17] G. Ondrasek, J. Horvatinec, M. B. Kovačić et al., "Land resources in organic agriculture: trends and challenges in the twenty-first century from global to Croatian contexts," *Agronomy*, vol. 13, no. 6, p. 1544, 2023.

[18] İ. Kahramanoğlu, O. Panfilova, T. G. Kesimci, A. U. Bozhüyük, R. Gürbüz, and H. Alptekin, "Control of postharvest gray mold at strawberry fruits caused by botrytis cinerea and improving fruit storability through Origanum onites L. and Ziziphora clinopodioides L. volatile essential oils," *Agronomy*, vol. 12, no. 2, p. 389, 2022.

[19] S. Álvarez-García, M. Moumni, and G. Romanazzi, "Antifungal activity of volatile organic compounds from essential oils against the postharvest pathogens Botrytis cinerea, Monilinia fructicola, Monilinia fructigena, and Monilinia laxa," *Frontiers in Plant Science*, vol. 14, Article ID 1274770, 2023.

[20] A. N. Rashchepkin, I. A. Korotkiy, and E. V. Korotkaya, "Influence of low-temperature processing on blackcurrants quality factors," *Food Processing: Techniques and Technology*, vol. 1, no. 32, pp. 101–105, 2014.

[21] E. Ropelewska, "Assessment of the influence of storage conditions and time on red currants (Ribes rubrum L.) using image processing and traditional machine learning," *Agriculture*, vol. 12, no. 10, p. 1730, 2022.

[22] E. Ropelewska, "Application of imaging and artificial intelligence for quality monitoring of stored black currant (Ribes nigrum L.)," *Foods*, vol. 11, no. 22, p. 3589, 2022.

[23] L. Van Dang, N. Phuong Ngoc, and N. N. Hung, "Effects of foliar fertilization on nutrient uptake, yield, and fruit quality of pomelo (citrus grandis osbeck) grown in the mekong delta soils," *International Journal of Agronomy*, vol. 2022, Article ID 7903796, 11 pages, 2022.

[24] M. A. Lateef, A. M. Noori, Y. M. Saleh, and D. K. Al-Taey, "The effect of foliar spraying with salicylic acid and calcium chloride on the growth, yield, and storage traits of two strawberry cultivars, Fragaria × ananassa Duch," *International Journal of Agricultural and Statistical Sciences*, vol. 17, no. 2, pp. 611–615, 2021.

[25] N. A. Abbasi, M. Shafique, I. Ali, A. A. Qureshi, and I. A. Hafiz, "Pre-harvest foliar application of calcium chloride improves berry quality and storage life of table grape cvs. 'perlette'and 'Kings's ruby," *Journal of Pure and Applied Algebra*, vol. 5, no. 2, pp. 104–115, 2020.

[26] V. T. B. Nguyen, D. H. H. Nguyen, and H. V. H. Nguyen, "Combination effects of calcium chloride and nano-chitosan on the postharvest quality of strawberry (Fragaria x ananassa Duch.)," *Postharvest Biology and Technology*, vol. 162, Article ID 111103, 2020.

[27] E. V. Leonicheva, T. A. Roeva, and L. I. Leonteva, *Elemental Composition of Apple Fruits at Different Modes of mineral Nutrition*, VNIISPK, Orel, Russia, 2020.

[28] C. Watkins, J. Schupp, and D. Rosenberger, "Calcium nutrition and control of calcium-related disorders," *New York Fruit Ortley*, vol. 12, no. 2, pp. 15–21, 2004.

[29] J. Lanauskas, N. Kviklienė, N. Uselis et al., "The effect of calcium foliar fertilizers on cv. Ligol apples," *Plant Soil and Environment*, vol. 58, no. 10, pp. 465–470, 2012.

[30] Q. Gao, T. Xiong, X. Li, W. Chen, and X. Zhu, “Calcium and calcium sensors in fruit development and ripening,” *Scientia Horticulturae*, vol. 253, pp. 412–421, 2019.

[31] O. V. Ladyzhenskaya, T. S. Aniskina, and V. A. Kryuchkova, “Elements of container technology for growing blackberry varieties Ouachita,” *IOP Conference Series: Earth and Environmental Science*, vol. 1045, no. 1, Article ID 12033, 2022.

[32] O. Panfilova, V. Okatan, M. Tsoy, O. Golyaeva, S. Knyazev, and İ. Kahramanoğlu, “Evaluation of the growth drought tolerance and biochemical compositions of introduced red currant cultivars and Russian breeding genotypes in temperate continental climate,” *Folia Horticulturae*, vol. 33, no. 2, pp. 309–324, 2021.

[33] V. G. Mineev, V. G. Sychev, O. A. Amelyanchik et al., *Workshop on Agrochemistry*, MSU, Moscow, Russia, 2nd edition, 2001.

[34] E. V. Leonicheva, T. A. Roeva, V. T. Stolyarov, and L. I. Leonteva, *Study of mineral Composition of Fruits (Methodical Recommendations)*, VNIISPK, Orel, Russia, 2018.

[35] G. H. Neilsen and D. Neilsen, “Consequences of potassium, magnesium sulphate fertilization of high density Fuji apple orchards,” *Canadian Journal of Soil Science*, vol. 91, no. 6, pp. 1013–1027, 2011.

[36] O. Panfilova, O. Kalinina, O. Golyaeva, S. Knyazev, and M. Tsoy, “Physical and mechanical properties of berries and biological features of red currant growth for mechanized harvesting,” *Research in Agricultural Engineering*, vol. 66, no. 4, pp. 156–163, 2020.

[37] M. C. N. Nunes, J. P. Emond, M. Rauth, S. Dea, and K. V. Chau, “Environmental conditions encountered during typical consumer retail display affect fruit and vegetable quality and waste,” *Postharvest Biology and Technology*, vol. 51, no. 2, pp. 232–241, 2009.

[38] P. A. Popescu, I. C. Nicolae, A. C. Miteluț et al., “Minimally processing and preservation methods for shelf-life prolonging of different types of fruits,” *Scientific Papers. Series B. Horticulture*, vol. 66, no. 1, pp. 863–871, 2022.

[39] P. Y. Kumar, A. Poshadri, K. Pavan, S. G. Charan, and R. Palthiya, “Postharvest management of tomato in tribal areas of adilabad district,” *International Journal of Agriculture Sciences*, vol. 10, no. 5, pp. 5368–5370, 2018.

[40] N. B. Pavlovski, “Influence of package and storage modes of highbush blueberry fruits on their storability,” *Fruit Growing*, vol. 24, no. 1, pp. 301–306, 2012.

[41] I. Lara, “Preharvest sprays and their effects on the postharvest quality of fruit,” *Stewart Postharvest Review*, vol. 9, pp. 1–12, 2013.

[42] B. Hocking, S. D. Tyerman, R. A. Burton, and M. Gilliham, “Fruit calcium: transport and physiology,” *Frontiers in Plant Science*, vol. 7, p. 569, 2016.

[43] A. I. Kuzin, Y. V. Trunov, and A. V. Solovyev, “Effect of fertigation on yield and fruit quality of apple (Malus domestica Borkh.) in high-density orchards on chernozems in Central Russia,” *Acta Horticulturae*, vol. 2017, no. 1217, pp. 343–350, 2018.

[44] V. Martins, M. Unlubayir, A. Teixeira, A. Lanoue, and H. Gerós, “Exogenous calcium delays grape berry maturation in the white cv. Loureiro while increasing fruit firmness and flavonol content,” *Frontiers in Plant Science*, vol. 12, Article ID 742887, 2021.

[45] P. Wójcik, “Effects of preharvest sprays of iodine, selenium and calcium on apple biofortification and their quality and storability,” *PLoS One*, vol. 18, no. 3, Article ID 282873, 2023.

[46] V. G. Mineev, *Agrochemistry*, Kolos, Moscow, Russia, 2nd edition, 2004.

[47] T. E. Lobos, J. B. Retamales, A. Luengo Escobar, and E. J. Hanson, “Timing of foliar calcium sprays improves fruit firmness and antioxidants in “Liberty” blueberries,” *Journal of Soil Science and Plant Nutrition*, vol. 21, no. 1, pp. 426–436, 2021.

[48] D. Darshan, D. Hota, R. Devi, and J. Kumar Shukla, “Micronutrients and plant growth regulators affecting the yield and quality of fruit crops: a review,” *Emergent Life Sciences Research*, vol. 08, no. 02, pp. 92–103, 2022.

[49] E. J. Hogue, G. H. Neilsen, J. L. Mason, and B. G. Drought, “The effect of different calcium levels on cation concentration in leaves and fruit of apple trees,” *Canadian Journal of Plant Science*, vol. 63, no. 2, pp. 473–479, 1983.

[50] E. Rozpara, Z. S. Grzyb, and T. Olszewski, “The mineral nutrient content in the leaves of two sweet cherry cvs with interstem,” *Acta Horticulturae*, vol. 274, pp. 405–412, 1990.

[51] G. R. Nachtigall and A. R. Dechen, “Seasonality of nutrients in leaves and fruits of apple trees,” *Scientia Agricola*, vol. 63, no. 5, pp. 493–501, 2006.

[52] E. V. Leonicheva, T. A. Roeva, and L. I. Leonteva, “Some features of calcium dynamics in the “apple fruit- leaves-shoots” system,” *Contemporary horticulture*, vol. 3, pp. 1–8, 2018.

[53] A. J. Vance, P. Jones, and B. C. Strik, “Foliar calcium applications do not improve quality or shelf life of strawberry, raspberry, blackberry, or blueberry fruit,” *HortScience*, vol. 52, no. 3, pp. 382–387, 2017.

[54] R. Niskanen, “Nutritional status in commercial currant fields,” *Agricultural and Food Science*, vol. 11, no. 4, pp. 301–310, 2002.

[55] W. Bednarek, H. Bednarek, and S. Dresler, “Contents and uptake of phosphorus, potassium and magnesium by cocksfoot grass in relation to meteorological conditions,” *Acta Agrophysica*, vol. 13, pp. 587–600, 2009.

[56] V. Nour, I. Trandafir, and S. Cosmulescu, “Antioxidant capacity, phenolic compounds and minerals content of blackcurrant (Ribes nigrum L.) leaves as influenced by harvesting date and extraction method,” *Industrial Crops and Products*, vol. 53, pp. 133–139, 2014.

[57] M. Staszowska-Karkut and M. Materska, “Phenolic composition, mineral content, and beneficial bioactivities of leaf extracts from black currant (Ribes nigrum L.), raspberry (Rubus idaeus), and aronia (Aronia melanocarpa),” *Nutrients*, vol. 12, no. 2, p. 463, 2020.

[58] M. Ziobroń, A. Kopeć, J. Skoczylas, K. Dziadek, and J. Zawistowski, “Basic chemical composition and concentration of selected bioactive compounds in leaves of black, red and white currant,” *Applied Sciences*, vol. 11, no. 16, p. 7638, 2021.

[59] W. W. Zheng, C. X. You, Z. J. Du, and H. Zhai, “Dynamic changes in the calcium content of several apple cultivars during the growing season,” *Agricultural Sciences in China*, vol. 5, no. 12, pp. 933–937, 2006.

[60] A. K. Parker, R. W. Hofmann, C. van Leeuwen, A. R. G. McLachlan, and M. C. T. Trought, “Manipulating the leaf area to fruit mass ratio alters the synchrony of total soluble solids accumulation and titratable acidity of grape berries,” *Australian Journal of Grape and Wine Research*, vol. 21, no. 2, pp. 266–276, 2015.

[61] M. Teleszko and A. Wojdyło, “Comparison of phenolic compounds and antioxidant potential between selected

edible fruits and their leaves," *Journal of Functional Foods*, vol. 14, pp. 736–746, 2015.

[62] E. Duchêne, V. Dumas, N. Jaegli, and D. Merdinoglu, "Deciphering the ability of different grapevine genotypes to accumulate sugar in berries," *Australian Journal of Grape and Wine Research*, vol. 18, no. 3, pp. 319–328, 2012.

[63] G. Korniliyev and L. Komar-Tyomnaya, "Study of chemical composition of Persica davidiana Carr. leaves during vegetation," *Studia Biologica*, vol. 5, no. 1, pp. 125–130, 2011.

[64] P. J. White and M. R. Broadley, "Calcium in plants," *Annals of Botany*, vol. 92, no. 4, pp. 487–511, 2003.

[65] F. Yang, L. W. DeVetter, B. C. Strik, and D. R. Bryla, "Stomatal functioning and its influence on fruit calcium accumulation in northern highbush blueberry," *HortScience*, vol. 55, no. 1, pp. 96–102, 2020.

[66] G. Montanaro, B. Dichio, and C. Xiloyannis, "Significance of fruit transpiration on calcium nutrition in developing apricot fruit," *Journal of Plant Nutrition and Soil Science*, vol. 173, no. 4, pp. 618–622, 2010.

[67] G. Montanaro, B. Dichio, A. Lang, A. N. Mininni, and C. Xiloyannis, "Fruit calcium accumulation coupled and uncoupled from its transpiration in kiwifruit," *Journal of Plant Physiology*, vol. 181, pp. 67–74, 2015.

[68] B. C. Hanger, "The movement of calcium in plants," *Communications in Soil Science and Plant Analysis*, vol. 10, no. 1-2, pp. 171–193, 1979.

[69] S. Y. Rogiers, D. H. Greer, J. M. Hatfield, B. A. Orchard, and M. Keller, "Mineral sinks within ripening grape berries (Vitis vinifera L.)," *Vitis*, vol. 45, pp. 115–123, 2006.

[70] M. Keller, Y. U. N. Zhang, P. M. Shrestha, M. Biondi, and B. R. Bondada, "Sugar demand of ripening grape berries leads to recycling of surplus phloem water via the xylem," *Plant, Cell and Environment*, vol. 38, no. 6, pp. 1048–1059, 2015.

[71] M. C. Saure, "Calcium translocation to fleshy fruit: its mechanism and endogenous control," *Scientia Horticulturae*, vol. 105, no. 1, pp. 65–89, 2005.

[72] L. Zhang, J. W. Wang, J. Chen et al., "Preharvest spraying calcium ameliorated aroma weakening and kept higher aroma related genes expression level in postharvest' Nanguo' pears after long-term refrigerated storage," *Scientia Horticulturae*, vol. 247, pp. 287–295, 2019.

[73] P. Wójcik, H. Akgül, İ. Demirtaş, C. Sarısu, M. Aksu, and H. Gubbuk, "Effect of preharvest sprays of calcium chloride and sucrose on cracking and quality of 'Burlat' sweet cherry fruit," *Journal of Plant Nutrition*, vol. 36, no. 9, pp. 1453–1465, 2013.

[74] B. Madani, A. Mirshekari, A. Sofo, M. Tengku Muda Mohamed, and M. Mohamed, "Preharvest calcium applications improve postharvest quality of papaya fruits (Carica papaya L. Cv. Eksotika II)," *Journal of Plant Nutrition*, vol. 39, no. 10, pp. 1483–1492, 2016.

[75] S. Siddiqui and F. Bangerth, "Effect of pre-harvest application of calcium on flesh firmness and cell-wall composition of apples-influence of fruit size," *Journal of Horticultural Science*, vol. 70, no. 2, pp. 263–269, 1995.

[76] C. Bonomelli and R. Ruiz, "Effects of foliar and soil calcium application on yield and quality of table grape cv. Thompson Seedless," *Journal of Plant Nutrition*, vol. 33, no. 3, pp. 299–314, 2010.

[77] V. Martins, A. Garcia, C. Costa, M. Sottomayor, and H. Gerós, "Calcium- and hormone-driven regulation of secondary metabolism and cell wall enzymes in grape berry cells," *Journal of Plant Physiology*, vol. 231, pp. 57–67, 2018.

[78] J. M. A. Souza, S. Leonel, M. Leonel et al., "Calcium nutrition in fig orchards enhance fruit quality at harvest and storage," *Horticulturae*, vol. 9, no. 1, p. 123, 2023.

[79] L. D. Falcão, E. S. Chaves, V. M. Burin et al., "Maturity of Cabernet Sauvignon berries from grapevines grown with two different training systems in a new grape growing region in Brazil," *Ciencia e investigación agraria*, vol. 35, no. 3, pp. 321–332, 2008.

[80] M. Salman, S. Ullah, K. Razzaq et al., "Combined foliar application of calcium, zinc, boron and time influence leaf nutrient status, vegetative growth, fruit yield, fruit biochemical and anti-oxidative attributes of "Chandler" strawberry," *Journal of Plant Nutrition*, vol. 45, no. 12, pp. 1837–1848, 2022.

[81] A. Asgharzade, G. A. Valizade, and M. Babaeian, "Effect of Calcium Chloride (CaCl2) on some quality characteristic of apple fruits in Shirvan region," *African Journal of Microbiology Research*, vol. 6, no. 9, pp. 2000–2003, 2012.

[82] S. Solhjoo, A. Gharaghani, and M. Nazari, "Preharvest foliar spray of various potassium sources and calcium chloride affect fruit color, storability, and bruise susceptibility of apples (malus × domestica borkh. Cv. "red delicious")," *Erwerbs-obstbau*, vol. 65, no. 4, pp. 607–619, 2023.

[83] G. Giacalone and V. Chiabrando, "Problems and methods to improve the market-life of berry fruit," *Berries: Properties, Consumption and Nutrition*, NOVA Publishers, Hauppauge, NY, USApp. 179–196, 2012.

[84] A. Tefera, T. Seyoum, and K. Woldetsadik, "Effect of disinfection, packaging, and storage environment on the shelf life of mango," *Biosystems Engineering*, vol. 96, no. 2, pp. 201–212, 2007.

[85] A. Rohani, W. A. Nazni, L. V. Ngo, J. Ibrahim, and H. L. Lee, "Adulticidal properties of the essential extracts of some Malaysian plants on vector mosquitoes," *Tropical Biomedicine*, vol. 14, no. 5–9, 1997.

[86] B. Haleema, A. Rab, S. A. Hussain et al., "Influence of calcium concentrations and sources on the fruit quality of tomato (Lycopersicon esculentum mill) at different storage conditions," *Fresenius Environmental Bulletin*, vol. 29, no. 3, pp. 1866–1877, 2020.

[87] F. Cheour, C. J. Willemot, Y. Arul, J. Desjardins, P. M. Makhlouf, and A. Gosselin, "Effects of foliar application of CaCl2 on postharvest strawberry ripening," *Journal of the American Society for Horticultural Science*, vol. 115, pp. 789–792, 1990.

[88] I. Jan and A. Rab, "Influence of storage duration on physico-chemical changes in fruit of apple cultivars," *Journal of Animal and Plant Sciences*, vol. 22, no. 3, pp. 708–714, 2012.

[89] S. N. Jha, D. R. Rai, and R. Shrama, "Physico-chemical quality parameters and overall quality index of apple during storage," *Journal of Food Science and Technology*, vol. 49, no. 5, pp. 594–600, 2012.

[90] N. Gupta, S. K. Jawandha, and P. S. Gill, "Effect of calcium on cold storage and post-storage quality of peach," *Journal of Food Science and Technology*, vol. 48, no. 2, pp. 225–229, 2011.

[91] C. V. Rombaldi, J. A. Silva, L. B. Machado et al., "Ponto de colheita e período de armazenamento refrigerado na qualidade de pêssegos (Prunus Persica, L.) de mesa, cv. chiripá," *Ciência Rural*, vol. 31, no. 1, pp. 19–25, 2001.

[92] L. Changhoo, S. Kim, J. Ko, and C. Kim, "Changes in cell wall metabolism of kiwi fruits during low temperature storage by postharvest calcium application," *Journal of the Korean Society for Horticultural Science*, vol. 42, pp. 91–94, 2001.

[93] A. Ciccarese, A. M. Stellacci, G. Gentilesco, and P. Rubino, "Effectiveness of pre- and post-veraison calcium applications to control decay and maintain table grape fruit quality during storage," *Postharvest Biology and Technology*, vol. 75, pp. 135–141, 2013.

[94] A. R. Vicente, G. A. Manganaris, G. O. Sozzi, and C. H. Crisosto, "Nutritional quality of fruits and vegetables," in *Postharvest Handling: A Systems Approach*, W. J. Florkowski, R. L. Shewfelt, B. Brueckner, and S. E. Prussia, Eds., pp. 57–106, Academic Press, Cambridge, MA, USA, 2009.

[95] T. Yang, B. D. Whitaker, and W. S. Conway, "Perspective of utilizing ethylene responsive SR/CAMTA for postharvest improvement," *The 8th International Symposium on the Plant Hormone Ethylene*, Cornell University, Ithaca, New York, USA, 2008.

[96] M. S. Aghdam, M. B. Hassanpouraghdam, G. Paliyath, and B. Farmani, "The language of calcium in postharvest life of fruits, vegetables and flowers," *Scientia Horticulturae*, vol. 144, pp. 102–115, 2012.

[97] T. Xiong, Q. Tan, S. Li, C. Mazars, J.-P. Galaud, and X. Zhu, "Interactions between calcium and A.B.A. signaling pathways in the regulation of fruit ripening," *Journal of Plant Physiology*, vol. 256, Article ID 153309, 2021.

[98] T. Garde-Cerdán, M. González-Lázaro, D. Alonso-Ortiz de Urbina et al., "Foliar applications of calcium, silicon and their combination: a tool to improve grape composition and quality," *Applied Sciences*, vol. 13, no. 12, p. 7217, 2023.

[99] R. Lufu, A. Ambaw, and U. L. Opara, "Water loss of fresh fruit: influencing pre-harvest, harvest and postharvest factors," *Scientia Horticulturae*, vol. 272, Article ID 109519, 2020.

[100] B. S. Dhillon and K. Sukhjit, "Effect of postharvest application of calcium chloride on storage life of mango var. dushehari fruits," *HortFlora Research Spectrum*, vol. 2, no. 3, pp. 265–267, 2013.

[101] S. Gangwar, H. S. Shukla, D. Katiyar, and V. Pandey, "Effect of calcium nitrate on physcio-chemical changes and shelf life of aonla (Embrlica officinales gacrtn.) fruits," *HortFlora Res. Spectrum*, vol. 1, no. 3, pp. 253–258, 2012.

[102] B. V. C. Mahajan, B. S. Ghuman, and H. K. Bons, "Effect of postharvest treatments of calcium chloride and gibbrellic acid on storage behavior and quality of guava fruits," *Journal of Horticultural Science & Ornamental Plants*, vol. 3, no. 1, pp. 38–42, 2011.

[103] G. E. Lester and M. A. Grusak, "Field application of chelated calcium: postharvest effects on cantaloupe and honeydew fruit quality," *HortTechnology*, vol. 14, no. 1, pp. 29–38, 2004.

[104] J. Blažek, I. Hlušičková, and A. Varga, "Changes in quality characteristics of Golden Delicious apples under different storage conditions and correlations between them," *Horticultural Science*, vol. 30, no. 3, pp. 81–89, 2003.

[105] A. Pissard, J. A. Fernández Pierna, V. Baeten et al., "Non-destructive measurement of vitamin C, total polyphenol and sugar content in apples using near-infrared spectroscopy," *Journal of the Science of Food and Agriculture*, vol. 93, no. 2, pp. 238–244, 2013.

[106] Y. Tokala, Z. Singh, and P. N. Kyaw, "Postharvest quality of 'Cripps Pink' apple fruit influenced by ethylene antagonists during controlled atmosphere storage with photocatalytic oxidation," *Journal of the Science of Food and Agriculture*, vol. 102, no. 11, pp. 4484–4490, 2022.

[107] B. V. C. Mahajan, J. S. Randhawa, H. Kaur, and A. S. Dhatt, "Effect of postharvest application of calcium nitrate and gibberellic acid on the storage life of plum," *Indian Journal of Horticulture*, vol. 65, pp. 94–96, 2008.

[108] M. P. Uddin, M. A. Mamun, M. I. Afjal, and M. A. Hossain, "Information-theoretic feature selection with segmentation-based folded principal component analysis (P.C.A.) for hyperspectral image classification," *International Journal of Remote Sensing*, vol. 42, no. 1, pp. 286–321, 2021.

[109] N. V. Ryago, "Features of micro clone reproduction of some currant representatives of the genus Ribes spp: review," *Agrarian Bulletin of the*, vol. 23, no. 10, pp. 69–80, 2023.