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Effect of Selenium Application on Quality, Phytochemical Composition and Mineral Content Properties of Red Currant (*Ribes rubrum* L.) and Jostaberry (*Ribes ×nidigrolaria* Bauer)

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Abstract. **Selenium is an essential mineral for both humans and animals. Around 0.5–1 billion individuals globally suffer from selenium deficiency, which can result in a range of illnesses. Hence, the cultivation of selenium-enriched agricultural items can serve as a potent strategy to mitigate selenium deficiency. This study aimed to examine the effect of selenium on the quality, and phytochemical and mineral content of red currant (Red Lake) and jostaberry. The study was conducted in 2022 and 2023. Different doses of selenium (0, 4, and 8 mg·kg^{-1}) were sprayed on the fruits three times with 10-days intervals starting from the first formation of the fruits after flowering. Upon completion of the study, various factors were assessed including cluster and berry properties, water-soluble dry matter content, pH levels, titratable acid content, ascorbic acid levels, antioxidant activity, and total phenolics content. The mineral composition of the fruit peel, pulp, and seed was also measured. In jostaberry, the highest values of cluster weight, cluster height, and 100-berry weight were obtained with 8 mg·kg^{-1} selenium application. As the selenium dosage increased, the levels of ascorbic acid, antioxidant activity, and total phenolic content increased, with the highest values determined to be 0.063 mg·mL^{-1}, 63.23% DPPH, and 3752.22 mg·g^{-1}, respectively, at 8 mg·kg^{-1}. In the Red Lake variety, it has been determined that the 4 mg·kg^{-1} dose is effective in terms of cluster weight, cluster width, and cluster height attributes. The highest values for ascorbic acid, antioxidant activity, and total phenolic content were determined to be 0.029 mg·mL^{-1}, 53.42% DPPH, and 3117.17 mg·g^{-1}, respectively, at the 4 mg·kg^{-1} dose. The selenium content was found to be highest in the peel and pulp of jostaberry at 8 mg·kg^{-1}, and in Red Lake, it was obtained at the 4 mg·kg^{-1} application. As a result, an 8 mg·kg^{-1} dose of selenium could be recommended for jostaberry, and a 4 mg·kg^{-1} dose could be recommended for Red Lake.**

Currant and jostaberry, both belonging to the *Ribes* L. genus of the Grossulariaceae family, yield grape-like fruits. The genus *Ribes* encompasses ∼150 species that are geographically spread across various regions of the world (Ropelewska 2022). Commercially, the preferred species include blackcurrant (*Ribes nigrum* L.), redcurrant (*Ribes rubrum* L.), reddish-black berry (*Ribes biebersteinii* Berl.), east black sea currant (*Ribes orientalis* L.), and alpine currant (*Ribes alpinum* L.). The jostaberry (*Ribes ×nidigrolaria* Bauer) is a crossbreed between a currant and a gooseberry (Djordjevic et al. 2013; Sun et al. 2021).

Blackcurrants, redcurrants, jostaberries, and berries are recognized for their high content of phenolic chemicals, specifically anthocyanins. Anthocyanins are a subclass of flavonoid pigments that give these fruits their intense purple hue. Extensive research has been conducted on these chemicals because of their potential health advantages, which include antioxidant and anti-inflammatory characteristics. Blackcurrants and similar fruits are a valuable addition to a healthy diet due to their high anthocyanin content (Okatan 2020; Pereira et al. 2018). Moreover, currants possess substantial quantities of flavonoids, particularly anthocyanins, and flavonols, which have been associated with improved blood circulation and potential protection against diseases such as breast cancer. The notable antioxidant activity and phytoestrogenic qualities of selenium further augment its potential in the prevention of cardiovascular and neurological disorders, cancer, and diabetes (Cortez and Gonzalez de Mejia 2019; Nour et al. 2014; Sun et al. 2021).

The use of nutrients in agricultural production is essential for improving both productivity and quality. The macronutrient elements, notably nitrogen, phosphorus, potassium, calcium, and magnesium, have crucial functions in the metabolic processes of plants and facilitate plant growth. Micronutrient elements are essential for plants in trace amounts and are elements of critical importance for the growth, development, and metabolism of plants (Fageria 2016). In the absence or excess of micronutrient elements, not only is the growth and development of plants adversely affected, but the quality of the produce is also compromised. Selenium is also one of these important microelements (Gui et al. 2022).

It has been determined that selenium, when used in appropriate doses, increases yield and quality in beans (Aggarwal et al. 2011), pak choi (Li et al. 2015), lamb's lettuce (Hawrylak-Nowak et al. 2018), pomegranate (Zahedi et al. 2019a), and grapes (Sucu and Yağci 2023; Yin et al. 2020; Zhu et al. 2019); affects the taste of strawberries (Mimmo et al. 2017); and positively impacts both quality and shelf life in peaches and pears (Pezzarossa et al. 2012). Selenium has also been shown to protect plants from oxidative damage, improve their antioxidant properties, and enhance resistance against abiotic and biotic stresses in okra (Ali et al. 2020), strawberries (Zahedi et al. 2019b), and cucumbers (Balal et al. 2016; Shekari et al. 2019).

Selenium is widely recognized for being very important for humans, protecting them from various diseases through its antioxidant effects. Selenium deficiency can cause various health issues, including immune, thyroid, and reproductive disorders, as well as cancer and even death (Gupta and Gupta 2017; Řezáčová et al. 2016). Selenium intake for humans depends on the presence of selenium in the soil and the consumption of products high in selenium content (Winkel et al. 2015). Consequently, recent years have seen an increase in efforts to enhance the selenium content of products.

This study aimed to assess the quality and phytochemical composition of selenium at varying doses in jostaberry and red currant varieties. In addition, the impact of selenium on the mineral substance content in the peel, pulp, and seed of these fruits, which has not been previously investigated in these species, was examined.

Materials and Methods

Plant material and experimental design. The study was carried out on 4-year-old Red Lake cultivar red currants and jostaberry plants at the Agricultural Application and Research Center (lat. 40°06′48.3″N, long. 30°00′08.4″E) of Bilecik Şeyh Edebali University during the years 2022 to 2023.

Selenium application was applied by spraying the fruits three times on the 10th (23.05.2022/26.05.2023), 20th (02.06.2022/05.06.2023), and 30th (12.06.2022/15.06.2023) days after the initial formation of fruits following

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flowering in both years (Zhu et al. 2017). Spraying was applied to all fruits until runoff, with three repetitions, five plants in each repetition.

In the experiment, three different doses of selenium were applied: 0 (for the control group), 4, and 8 $mg \cdot kg^{-1}$. Selenium was in the form of sodium selenate (Na_2SeO_4; Merck, Inc., Darmstadt, Germany), and it was prepared with distilled water according to the respective doses.

Meteorological data and soil characteristics. Figure 1 provides data on climate factors, namely the monthly average temperature and total precipitation amount. Data were obtained from the Turkish State Meteorological Service of Bilecik (Fig. 1). The trial area has a loamy soil texture, with an organic matter content of 2.86% and a pH of 7.80.

Botanical characteristics determination. The fruits were harvested once all the berries in the cluster reached the stage of maturity (Mikulic-Petkovsek et al. 2012). For each replication, 10 bunches were selected at random. The width and length of each bunch were measured in millimeters using a caliper (OEM KMP200 Digital caliper). The weight of each bunch and the weight of 100 berries were measured in grams using a precision scale that is sensitive to 0.01 g (Kern PNS600). The grain width and length were measured in mm by picking 30 berries and using a caliper (OEM KMP200 Digital caliper).

Biochemical characteristics determination. The amount of water-soluble dry matter was determined by passing the fruits through coarse filter paper after homogenizing them and dropping the fruit juice onto a hand refractometer (0–53 scale, Refractometer PAL−1) and the results were expressed as "°Brix" (Cemeroglu 2007). The titratable acid content was quantified using the titratable acidity method, based on the acidity of the fruit's citric acid. The results were reported as a percentage. The pH values were ascertained by use of a digital pH meter (HANNA edge® Dedicated pH/ORP Meter) (Cemeroglu 2007).

Determination of phytochemical properties. Ascorbic acid content, total phenolic substances, and antioxidant amounts were determined only in 2023. By adopting the Jagota and Dani (1982) methodology, it became possible to ascertain the ascorbic acid content. The fruit extract was prepared by pulverizing 5 g of the fruit sample with 50 mL of distilled water and combining it in a centrifuge spinning at 3000 rpm A total of 200 µL of fruit extract was combined with 800 µL of trichloroacetic acid (TCA) solution, which had a concentration of 10%. The mixture was then placed on ice for 5 min and subsequently centrifuged at a speed of 3000 rpm for 5 min. Subsequently, a 2-mL aliquot of pure water and Folin reagent was introduced to the extract, thoroughly mixed, and after 10 min, the absorbance at 760 nm was quantified using a spectrophotometer (Pharo 300; Merck, Darmstadt, Germany). The quantity of ascorbic acid was determined using the standard graph (Unal et al. 2023).

Total phenolic substance content was determined by the Folin-Ciocalteu method (López et al. 2011) with some modifications. A 100-µL aliquot of fruit extract, 2.8 mL of pure water, 2 mL of 20% sodium carbonate, and 50% Folin reagent were combined in the tubes and stirred. Following incubation at ambient temperature in a lightless setting for 1 h, the absorbance was measured using a spectrophotometer at a wavelength of 765 nm (Unal et al. 2023). The results were quantified in terms of gallic acid equivalents (GAEs).

Level of antioxidants. The researchers were Unal et al. (2022), the 2.2-diphenyl-1-picrylhydrazyl (DPPH) technique used was modified to reach a determination. Following the homogenization of a 3-g fruit sample in 25 mL of methanol, the mixture was stored in a dark environment at a temperature of 4 °C for 12 h. On centrifugation at a speed of 15,000 rpm for 20 min, the liquid portion (150 µL) was moved to a fresh tube and combined with a DPPH solution (2.85 mL). The samples were incubated for 24 h under dark conditions at room temperature and read in a spectrophotometer at 515 nm. Controls were 2.85 mL DPPH and 50 µL distilled water.

$$\% \text{ Reactive oxygen scavenging capacity} = \left[(\text{AbsDPPH} - \text{Abssample})/\text{AbsDPPH}\right] \times 100$$

Determination of mineral composition. The concentrations of iron, selenium, potassium, calcium, magnesium, and phosphorus elements in the berry peel, pulp, and seed were analyzed in wet-fired samples from both years using the ICP-OES apparatus (Machat et al. 2002).

Statistical analysis. The experiment was carried out with three replications using a randomized block design. The application averages were compared using the least significant difference multiple comparison test after doing variance analysis. The statistical analyses used the MSTAT-C software program (version 2.10; Michigan State University, East Lansing, MI, USA).

Results and Discussion

Impact of selenium treatment on botanical and biochemical characteristics. The results indicate that selenium exerts a beneficial influence on the growth and productivity of crops (Du et al. 2019; Marques et al. 2020; Yan et al. 2021). Table 1 provides the plant characteristics of the two varieties used in the study. On analyzing the interaction table between variety and treatment, it was found that applying 8 $mg \cdot kg^{-1}$ (7.65 g) of selenium to jostaberry and 4 $mg \cdot kg^{-1}$ (3.77 g) of selenium to the Red Lake variety increased bunch weight. When examining the average doses based on cluster characteristics (cluster weight,

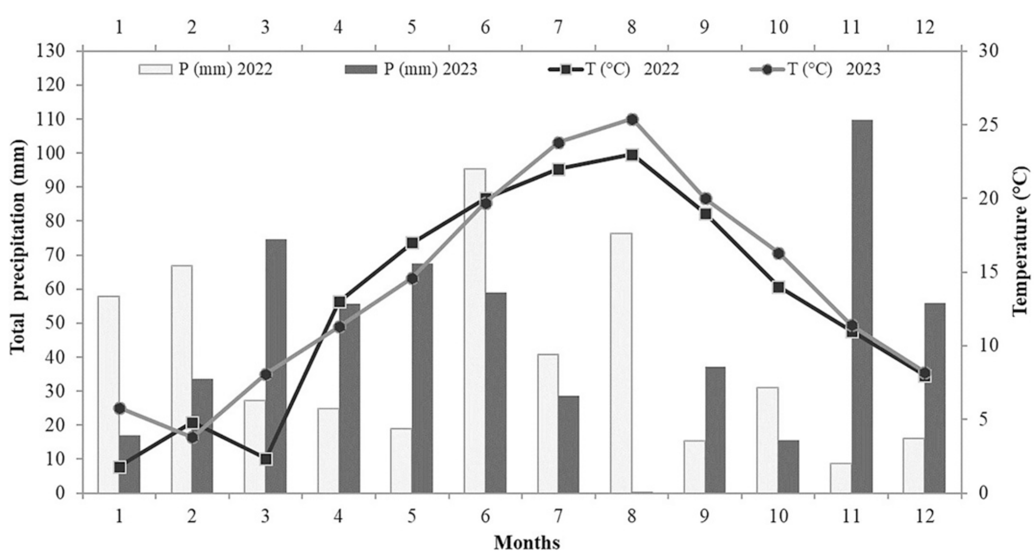

Fig. 1. The monthly average temperature and total precipitation for the years 2022 and 2023. P = precipitation; T = temperature.

Table 1. Effect of selenium application on herbal and biochemical properties.

		Cluster wt (g)					Cluster width (mm)					Cluster ht (mm)			
		Treatments (mg·kg^{-1})					Treatments (mg·kg^{-1})					Treatments (mg·kg^{-1})			
		Control	4	8	Mean		Control	4	8	Mean		Control	4	8	Mean
Variety	Jostaberry	6.96^{b}	6.26^{c}	7.65^{a}	6.96^{A}	Jostaberry	34.26	31.32	34.05	33.21^{A}	Jostaberry	47.52	46.06	50.71	48.09^{B}
	Red Lake	2.61^{e}	3.77^{d}	3.49^{d}	3.29^{B}	Red Lake	20.13	22.53	20.55	21.07^{B}	Red Lake	51.08	54.74	53.69	53.17^{A}
	Mean	4.79^{B}	5.01^{A}	5.57^{A}		Mean	27.19	26.93	27.30		Mean	49.30	50.40	52.20	
Year	2022				6.53^{A}	2022				29.37^{A}	2022				52.36
	2023				3.72^{B}	2023				24.91^{B}	2023				48.91
		100-berry-weight (g)					Berry width (mm)					Berry height (mm)			
		Treatments (mg·kg^{-1})					Treatments (mg·kg^{-1})					Treatments (mg·kg^{-1})			
		Control	4	8	Mean		Control	4	8	Mean		Control	4	8	Mean
Variety	Jostaberry	218.18^{b}	249.70^{a}	258.90^{a}	242.26^{A}	Jostaberry	14.87^{b}	15.47^{a}	15.47^{a}	15.27^{B}	Jostaberry	15.32^{b}	15.98^{a}	15.50^{ab}	15.60^{A}
	Red Lake	33.55^{c}	37.60^{c}	42.10^{c}	37.75^{B}	Red Lake	9.30^{c}	7.02^{e}	7.84^{d}	8.06^{A}	Red Lake	8.46^{c}	6.62^{d}	6.98^{d}	7.35^{B}
	Mean	125.86^{B}	143.65^{A}	150.50^{A}		Mean	12.08^{A}	11.25^{C}	11.66^{B}		Mean	11.89^{A}	11.30^{B}	11.24^{B}	
Year	2022				164.31^{A}	2022				12.82^{B}	2022				12.81^{A}
	2023				115.69^{B}	2023				10.50^{A}	2023				10.14^{B}
		TSS (°Brix)					Titratable acidity (g/L)					pH			
		Treatments (mg·kg^{-1})					Treatments (mg·kg^{-1})					Treatments (mg·kg^{-1})			
		Control	4	8	Mean		Control	4	8	Mean		Control	4	8	Mean
Variety	Jostaberry	15.70^{a}	15.75^{a}	14.90^{b}	15.45^{A}	Jostaberry	1.49^{bc}	1.80^{a}	1.47^{bc}	1.59^{A}	Jostaberry	2.82	2.79	2.77	2.79^{A}
	Red Lake	10.87^{c}	9.45^{d}	10.15^{cd}	10.16^{B}	Red Lake	1.65^{ab}	1.29^{c}	1.47^{bc}	1.47^{B}	Red Lake	2.56	2.57	2.63	2.59^{B}
	Mean	13.28^{A}	12.60^{B}	12.53^{B}		Mean	1.57	1.55	1.47		Mean	2.69	2.68	2.70	
Year	2022				12.81	2022				1.57^{A}	2022				2.78^{A}
	2023				12.80	2023				1.48^{B}	2023				2.60^{B}

*The different lowercase letters indicate significant differences ($P < 0.05$) variety × treatments interaction. The different capital letters indicate significant differences ($P < 0.05$) in the average of variety, treatments, and year. TSS = total soluble solids.

width, and height), it was observed that the 8 mg·kg^{-1} dose of selenium application stands out. The cluster weight of currant is a crucial determinant of the total production and commercial worth of currant crops. Multiple studies have established the beneficial impacts of using selenium in suitable quantities on both the quantity and quality of crops, including potatoes, peppers, beans, turnips, grapes, tomato, apples, and pears (Aggarwal et al. 2011; Haghighi et al. 2019; Hawrylak-Nowak et al. 2018; Li et al. 2015; Martínez-Damián et al. 2019; Pezzarossa et al. 2012; Sucu and Yağci 2023).

On analyzing the data for the interaction between cluster width and treatments, no significant statistical difference was found. The jostaberry variety exhibited the widest cluster width in the control application, measuring 34.26 mm. On the other hand, the Red Lake variety showed the widest cluster width of 22.53 mm when treated with a selenium dose of 4 mg·kg^{-1}. The cluster length was measured to be 50.71 mm in the jostaberry variety with a treatment of 8 mg·kg^{-1} selenium, and 54.74 mm in the 'Red Lake' variety with a 4 mg·kg^{-1} application. When analyzing the average applied selenium doses, it was shown that a dose of 8 mg·kg^{-1} yielded superior outcomes in terms of cluster width data.

On analyzing the results on 100 berry weight, it was shown that selenium doses were efficacious in both cultivars compared with the control application. There was no significant disparity observed in the doses administered to the Red Lake variety. The optimal outcomes in both cultivars were achieved with the administration of 8 mg·kg^{-1} of selenium. Following examination of the grain width and length values, no significant statistical distinction could be seen between the administrations of 4- and 8-mg·kg^{-1} doses in the jostaberry variety. The jostaberry had a fruit width of 15.47 mm at selenium levels of 4 and 8 mg·kg^{-1}. In addition, at the maximum dose of 4 mg·kg^{-1}, the fruit length measured 15.98 mm. The Red Lake variety showed the highest fruit width (9.30 mm) and length (8.46 mm) when the control application was used. It was shown that selenium doses did not have any impact on fruit width or length.

Nikolic et al. (2006) conducted a study to assess the pomological characteristics of different black currant cultivars. They found that the width of the fruit ranged from 10.99 to 15.42 mm, and the length ranged from 10.96 to 14.70 mm. Okatan et al. (2015) conducted a study to assess the physical qualities of currant, jostaberry, and gooseberry. They found that the fruit width of the Red Lake variety was 8.69 mm and the jostaberry variety was 13.81 mm. The fruit length of the Red Lake variety was 8.39 mm and the jostaberry variety was 14.22 mm. Boran (2023), in an adaptation study on blackcurrant varieties, found that in the average data of 2 years, the berry width was 7.08 to 8.33 mm. It was determined that the berry height varied between 7.41 and 8.59 mm and that the Red Lake variety had the lowest value in both criteria (7.87 mm; 7.41 mm, respectively). The study's findings were found to be consistent with earlier research, and in certain cases, control methods were more prevalent. Although ecological considerations were initially considered to be influential in this case, it was ultimately concluded that the administration of selenium had a beneficial impact on plant traits.

Woznicki et al. (2015), in their study on the impact of rainfall and chilly climate conditions on yield and fruit quality in black currants, found variations in both cultivar and years as a result of environmental factors.

Furthermore, certain varieties have exhibited a negative association between temperature and fruit weight during the entire growth season. After comparing the average values of all the attributes listed in Table 1 for both years, it was found that the data from the first year (2022) had greater values. After analyzing Fig. 1, it becomes evident that the temperature rose while the precipitation declined during the fruit ripening phase in the second year (2023). It is hypothesized that this phenomenon is responsible for the drop in average data.

Water-soluble solids content, pH level, and titratable acid concentration are crucial elements that impact fruit quality (Eksi Karaagac et al. 2020). On analysis of the quantities of water-soluble dry matter, no significant distinction was observed between the control group and the group treated with 4 mg·kg^{-1} selenium in jostaberry. The highest dose of 4 mg·kg^{-1} resulted in a sugar content of 15.75 °Brix. Statistically, no difference was identified between the control group and the application of 4 mg·kg^{-1} selenium in jostaberry grapes, and the highest Brix value of 15.75 was obtained at the 4 mg·kg^{-1} dose. Studies from the past have shown that the sugar level in black currants is between 13.89 (Contessa et al. 2013) and 18.31 °Brix (Boran 2023), and in red currants it is between 7.4 and 11.92 °Brix (Eksi Karaagac et al. 2020; Pantelidis et al. 2007). No significant statistical difference was seen between the dosage applications in terms of the quantity of titratable acid. On analyzing the interaction between variety and application, it was concluded that the application of the 8 mg·kg^{-1} dose did not result in a significant variation among the different varieties. The highest acidity was determined in the application of 4 mg·kg^{-1} selenium (1.80 g/L) in the jostaberry and in the control (1.65 g/L) application in the Red Lake variety.

After analyzing the pH readings, it was concluded that the application of selenium did not result in a significant statistical difference. The control treatment in the jostaberry had the highest pH value (2.82), whereas the Red Lake variety had a pH value of 2.63 in the 8 mg·kg^{-1} selenium application. Examining earlier research, it was found that the pH range for jostaberry ranged from 3.05 to 3.24, and for red currants, it was between 2.86 and 3.45 (Mikulic-Petkovsek et al. 2015).

Impact of selenium treatment on phytochemical characteristics. Selenium is a micronutrient that has a vital function in the antioxidant defense mechanisms and many physiological processes in plants. Evidence suggests that the utilization of selenium can enhance the antioxidant capacity of plants, as well as improve phytochemical characteristics such as phenolic compounds and vitamin C (Andrejiová et al. 2019; Gul et al. 2017; Zahedi et al. 2019a; Zhu et al. 2017).

The antioxidant activity and total phenolic content of ascorbic acid produced in 2023 are presented in Fig. 2. The application of selenium in jostaberry increased ascorbic acid levels, with the greatest amount seen at a dose of 8 mg·kg^{-1}. The administration of a 4 mg·kg^{-1} dose of selenium resulted in the maximum vitamin C content in red currants, but a drop in vitamin C was found with an 8 mg·kg^{-1} application.

The ascorbic acid concentration of black currants ranged from 52.97 to 2779.30 mg·100 g^{-1} fresh weight (FW) in earlier research (Okatan 2016). Similarly, the ascorbic acid content of red currants ranged from 35.41 to 1,410.60 mg·100 g^{-1} FW (Aneta et al. 2013; Okatan 2016; Pantelidis et al. 2007). Studies have shown that jostaberries contain a significant amount of ascorbic acid, ranging from 42.71 ± 27.97 mg·100 g^{-1} FW (Donno et al. 2018) to 450 mg·100 g^{-1} (Kalugina and Kalugina 2017) and 591 mg·100 g^{-1} (Eksi Karaagac et al. 2020). The specific variety of jostaberries and the conditions in which they are grown are likely factors that influence the variation in ascorbic acid content. Research has established that selenium enhances the concentration of ascorbic acid in several species, including green tea, tomatoes, and table grapes (Puccinelli et al. 2019; Zhu et al. 2018).

Orsavová et al. (2019), stated that the high ascorbic acid concentration in blackcurrant fruits accounted for their antioxidant activity. The results of our investigation align with the existing literature. On examination of Fig. 2, it becomes evident that the ascorbic content and antioxidant values exhibit a high degree of similarity. There was a rise in the level of antioxidants when selenium dosages were administered to jostaberry. However, in the Red Lake variety, there was an increase at a dosage of 4 mg·kg^{-1} and a decrease at a dosage of 8 mg·kg^{-1}. Selenium possesses crucial antioxidant qualities that are vital for both humans and animals (Ramos et al. 2010). Selenium is regarded as an antioxidant at low levels but as a pro-oxidant in plants at greater levels (Boghdady et al. 2017).

The study found that the jostaberry had the highest total phenol concentration of 8 mg·kg^{-1} (3752.223 mg GAE/100 g FW), whereas the Red Lake variety had a total phenol level of 4 mg·kg^{-1} (3117.167 mg GAE/100 g FW) when selenium was applied. Cristina et al. (2013), revealed that the black currants had a greater total phenol content (ranging from 205.20 to 334.31 mg GAE/100 g FW) compared with the red currants (ranging from 95.21 to 150.0 mg GAE/100 g FW). In Okatan's study (2020), the total phenolic content was found to be 1593.92 mg GAE/100 g FW in jostaberry grapes and 8.45 mg GAE/100 g FW in red currant grapes. Okatan (2020) reported that the difference observed compared with other studies is likely due to ecological factors. This is probably attributed to variations in environmental conditions such as soil properties, climate conditions, cultivation methods, etc., in which the currant varieties are grown. These factors can influence the plant's ability to produce and accumulate phenolic compounds, resulting in different phenolic content (Zdunić et al. 2016).

Impact of selenium application on mineral material composition. To assess the impact of various doses of selenium on jostaberry and red currants, the mineral material content in the peel, pulp, and seed was measured for selenium, iron, potassium, magnesium, calcium, and phosphorus (Fig. 3). According to Kostopoulou et al. (2015), the impact of selenium on the mineral content of plants varies depending on the species and their capacity to store and tolerate selenium.

The Food and Nutrition Board determined a safe and appropriate range for the recommended daily intake of selenium for adult humans in 1980, which is between 50 and 200 µg. The purpose of this range is to provide individuals with a guideline to maintain optimal health while avoiding both deficiency and excess. According to a separate investigation, it has been determined that the acceptable amount of a certain substance in the human body is 40 µg per day. In addition, the recommended range for the concentration of this substance in animal feed is between 100 and 1000 µg/kg (Adams et al. 2002; Broadley et al. 2007). Exceeding these quantities can lead to toxicity (Jung 2006). On analyzing the interaction between variety and dose, based on the average of 2 years (as shown in Fig. 3), it was found that the jostaberry exhibited the greatest selenium concentration of 8 mg·kg^{-1} in both the skin and seed, while the pulp contained 4 mg·kg^{-1}. The selenium levels obtained fall within the boundaries indicated by the researchers and do not reach a level that would pose any toxicity concerns when consumed.

The application of selenium through spraying resulted in the maximum increase in iron content in the peel of both varieties, namely at a dosage of 8 mg·kg^{-1}. On analyzing the seed mineral contents, it was found that applying 8 mg·kg^{-1} of selenium enhanced the iron (Fe) concentration in the jostaberry variety. However, there was no significant difference observed in Red Lake. On analysis of the pulp, it was determined that the highest concentration of Fe was observed in the jostaberry treated with a 4 mg·kg^{-1} dose, whereas the Red Lake variety had the highest Fe concentration in the control group. On examination of the results, it was found that there was no consistent correlation between the increase in dosage and the iron level. Zeidan et al. (2010) highlighted the decrease in iron levels following the use of selenium. Fargašová et al. (2006) discovered that higher amounts of selenium hindered the absorption of metals such as zinc and iron. Longchamp et al. (2016) found that the iron concentration in the roots of maize plants increased when they were exposed to a selenium selenite solution with a concentration of 1 mg·L^{-1}. This

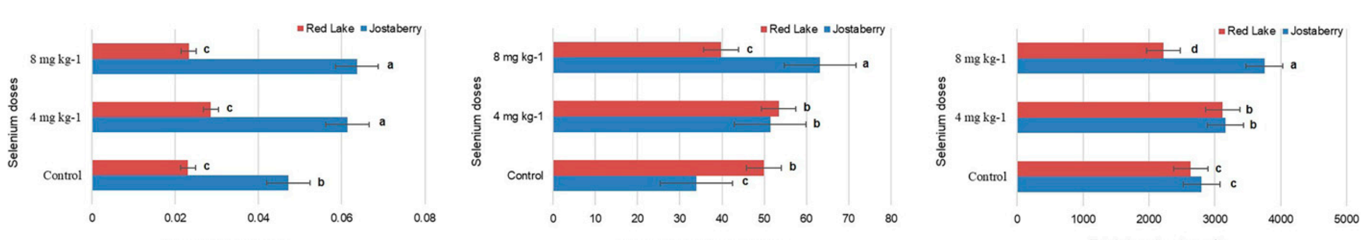

Fig. 2. The impact of different levels of selenium on ascorbic acid, antioxidant activity, and total phenolics. The difference between the averages shown with the same letters is not significant at the $P \leq 0.05$ level.

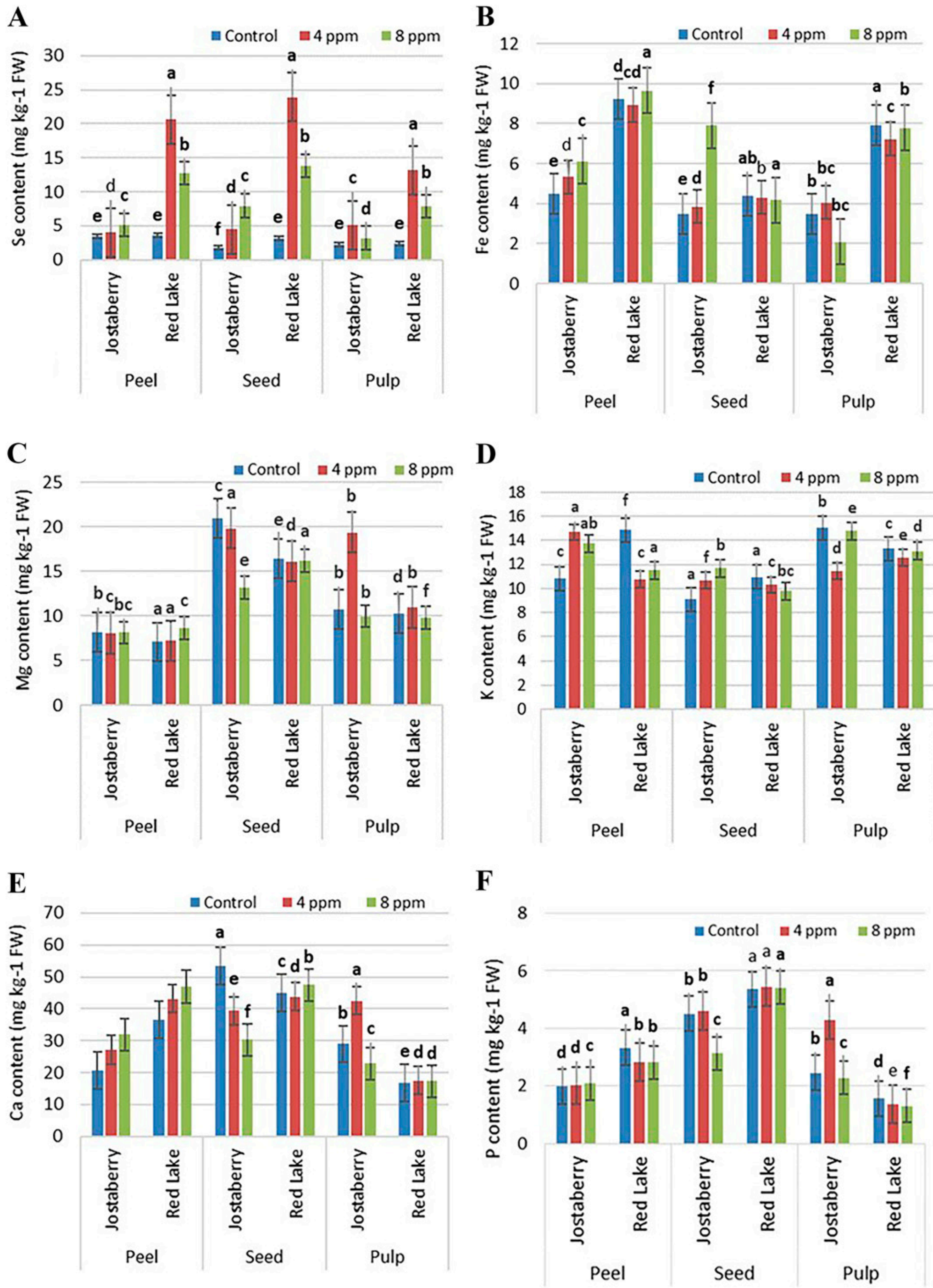

Fig. 3. The effect of selenium (Se) doses on mineral content. (**A**) Se content ($mg \cdot kg^{-1}$); (**B**) iron (Fe) content ($mg \cdot kg^{-1}$); (**C**) magnesium (Mg) content ($mg \cdot kg^{-1}$); (**D**) potassium (K) content ($mg \cdot kg^{-1}$); (**E**) calcium (Ca) content ($mg \cdot kg^{-1}$); and (**F**) phosphorus (P) content ($mg \cdot kg^{-1}$). The difference between the averages shown with the same letters is not significant at the $P \leq 0.05$ level.

increase in iron concentration was observed in both the leaves and stems of the plants when the selenium concentration in the solution was 0.01 $mg \cdot L^{-1}$.

In this investigation, the impact of selenium application on the magnesium content exhibited variation based on the different varieties. The highest concentration of magnesium in the peel was achieved with an 8 $mg \cdot kg^{-1}$ dosage of the Red Lake variety, whereas the seeds and fruit of the jostaberry showed the highest magnesium content with a 4 $mg \cdot kg^{-1}$ dosage. Hawrylak-Nowak (2008) and Pazurkiewicz-Kocot et al. (2008) concluded that the treatment of selenium did not result in any changes in magnesium levels. However, our investigation revealed that a concentration of 4 $mg \cdot kg^{-1}$ in the peel and 8 $mg \cdot kg^{-1}$ in the seed and pulp yielded significant effectiveness.

On analyzing the impact of selenium on potassium (K) levels (Fig. 3), it was found that applying selenium to the peel and seed of the jostaberry variety increased K content. However, the control application in the pulp yielded superior outcomes. It was concluded that the use of selenium did not yield a beneficial impact on the potassium levels in the Red Lake variety.

Following analysis of the calcium content, it was shown that the addition of selenium to the peel of both varieties did not result in a significant change; however, the calcium content showed an increase with higher doses of selenium application. On analyzing the calcium levels in the seed, it was found that the application of selenium did not have any impact on jostaberry. The Red Lake variety had the maximum calcium content at a dosage of 8 $mg \cdot kg^{-1}$. The jostaberry cultivar exhibited the highest calcium level in the pulp when treated with a selenium dosage of 4 $mg \cdot kg^{-1}$.

The impact of selenium application on phosphorus levels was found to be greatest in the control group of the Red Lake variety in the peel. However, the highest values were seen in the Red Lake variety in the seed. No significant difference was detected compared with the control group. On analysis of the pulp content, it was shown that the administration of 4 $mg \cdot kg^{-1}$ selenium resulted in the highest phosphorus level in the jostaberry variety. Selenium is believed to alter the permeability of membranes to certain cations, hence influencing transport in plant cells (Pazurkiewicz-Kocot et al. 2003).

Hawrylak-Nowak (2008) found that the application of selenium in maize plants resulted in elevated levels of calcium and phosphorus at high concentrations; however, there was no impact on the magnesium content at low doses. This study found that the mineral composition of the skin, seed, and fruit of blackcurrants varies. In addition, it was observed that larger doses of selenium can alter the levels of calcium and phosphorus content.

A study on grapes found that the application of selenium increased the potassium and calcium levels in grape berries while reducing the accumulation of heavy metals such as lead, chromium, cadmium, arsenic, and nickel. As a result, selenium was used to enhance the nutritional value of European and American grape species (Rady et al. 2020).

Conclusion

Recent studies have prioritized enhancing the selenium levels in seeds and fruits through the application of selenium via foliage. This study demonstrates that selenium can function as an essential micronutrient during fruit development and that appropriate dosages of this element can enhance the cluster characteristics, and phytochemical and mineral content of jostaberry and red currant (Red Lake) grapes. The results will also provide useful insights for studies aimed at enhancing the quality and nutritional value in the production of other berry fruits through selenium application.

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