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Spraying macro and micro fertilizers affects positively fruit yield and quality of 'Page' mandarin

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Abstract: In the current work, the effects of foliar application of two commercial fertilizers [CalfalB (containing calcium and boron) and Rice (containing macro- and micronutrients)] on leaf minerals, chlorophyll content, yield, and fruit quality, as well as some phytochemical characteristics of mandarins 'Page' was investigated for two consecutive years. The solutions were applied three times: mid-June and two more sprays at intervals of 18 days. Based on the results, leaves of fertilized mandarin plants with Rice and CalfalB accumulated higher N, P K, Ca, Mg, Zn, Mn, and Fe concentrations than unfertilized plants. Application of fertilizers, especially Rice, increased significantly the content of chlorophyll a ($p < 0.001$) and total chlorophyll ($p = 0.0013$) in the leaves. Trees fertilized with Rice showed a higher percentage of fruit yield, juice, pulp, and rind. Moreover, mandarins treated with fertilizers, especially Rice, had a higher level of TSS (total soluble solids), TSS/TA (titratable acidity), color parameters of the rind [L^* (lightness), a^* (redness), and b^* (yellowness)], vitamin C, phenol compounds, carotenoid, and antioxidant activity. The results of our research work showed that an application of fertilizers containing macro- and microelements by spraying can considerably improve fruit yield and quality of the mandarin 'Page', especially in areas with poor soils.

Key words: Iran, mandarin, spraying fertilizers, foliar fertilization, fruit yield and quality, biochemical attributes of the fruita

Škropljenje z makro in mikro hranili vpliva pozitivno na pridelek in kakovost mandarin 'Page'

Izvleček: V raziskavi so bili v dveh zaporednih rastnih sezonah preučevani učinki dveh foliarnih komercialnih gnojil, CalfalB-a (vsebuje kalcij in bor) in Rice-a (vsebuje makro in mikro hranila), na vsebnost hranil v listih in klorofila, na pridelek in kakovost plodov, kot tudi na nekatere fitokemične lastnosti mandarin 'Page'. Raztopina s hranili je bila nanešena trikrat in sicer v sredini junija in nato še v dveh intervalih z razmikom 18 dni. Rezultati so pokazali, da so listi mandarinovca pognojeni z obema gnojilama (Rice ind CalfalB) vsebovali več N, P K, Ca, Mg, Zn, Mn in Fe kot nepognojeni. Uporaba gnojil, še posebej gnojila Rice, je zančilno povečala vsebnost klorofila a ($p < 0.001$) in celokupnega klorofila ($p = 0.0013$) v listih. Z gnojilom Rice pognojeni mandarinovci so imeli večji pridelek plodov kot tudi večji izplen soka, pulpe in olupkov v njih. Mandarine, ki so bile obravnavane z gnojili, še posebej z gnojilom Rice, so imele večjo vsebnost celokupne suhe snovi (TSS), večje razmerje TSS/TA (titratibilna kislost), večje vrednosti barvnih parametrov olupka (L^* - svetlost, a^* - rdečina in b^* - rumenost), večje vsebnosti vitamina C, fenolnih snovi in karotenoidov ter večjo antioksidacijsko aktivnost. Rezultati te raziskave kažejo, da foliarno gnojenje z gnojili, ki vsebujejo makro in mikro elemente znatno izboljša velikost pridelka in kakovost mandarin 'Page', še posebej na območjih z revnimi tlemi.

Ključne besede: Iran, mandarinovec, škropljenje z gnojili, foliarno gnojenje, pridelek plodov in njihova kakovost, biokemični parametri plodov

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1 INTRODUCTION

Citrus is produced in many countries and has the first rank of fruit production in the world (Liaquat et al., 2023). Citrus fruits are rich in vitamins, minerals, fiber, and various antioxidants such as carotenoids, flavonoids, and limuloids, which are beneficial for human health (Zou et al., 2016). Iran is one of the leading countries in citrus production, having different citrus fruits and an annual production of more than 3 million tons (FAOSTAT, 2021). In Iran, 'Page' mandarin is one of the most important citrus cultivars, and its cultivated area is increasing. However, fruit yield and quality of citrus in Iran are low due to different factors, mainly improper nutrition (Hosseini, 2018). Therefore, proper nutrition can be one of the strategies to improve fruit yield and quality of citrus.

Foliar spraying fertilizers, when properly planned and conducted, could be used to increase fruit yield and quality of citrus. Citrus trees respond well to foliar fertilization due to the presence of a great number of stomata on the lower surface of the leaf along with more cuticle pores (facilitating nutrient absorption) (Smoleń, 2012). In general, foliar application of essential nutrients is not practical enough to cover the entire nutritional needs of the plants. However, a significant part of the plant's need for essential elements (mostly micronutrients) could be provided by foliar fertilization (Smoleń, 2012). Foliar nutrition is applied to improve the nutritional status of the plants, to eliminate the deficiency of nutrients, and, as a result, to increase fruit yield and quality (Norozi et al., 2019; Van Dang et al., 2022). Furthermore, compared to soil fertilization, foliar feeding is the fastest way to introduce minerals into the aboveground parts of the plants (Fernández et al., 2013).

The roles of macronutrients in improving the quantitative and qualitative characteristics of citrus fruits have been proven (Srivastava, 2012; Reetika et al., 2018; Van Dang et al., 2022). Nitrogen, as a critical element for citrus, has more effect on the plant growth and on fruit yield and quality than any other nutrient (Liu et al., 2010). Phosphorus plays a vital role in enzyme activation, photosynthesis processes, cell division, metabolism, and sugars movement. Potassium has significant effects on cellular osmotic, stomatal opening and closing, electrochemical processes, enzyme activity, cell division, protein synthesis, sugars synthesis and translocation, and acid metabolism of fruit juice in citrus (Alva et al., 2006; Van Dang et al., 2022). Calcium has a significant effect on the improvement of fruit yield and quality of mandarin (Zaman et al., 2019). Magnesium plays a vital role in the production of chlorophyll, the absorption of phosphorus in the metabolism of carbohydrates, and its deficiency reduces the fruit yield and quality of citrus (Van Dang et al., 2022).

Sufficient supply of micronutrients leads to good fruit yield and quality of citrus (Bastakoti et al., 2022). Lack of use or limited use leads to a deficiency in these nutrients. Micronutrients can easily applied on leaves because they are needed in small amounts. Applying micronutrients by spraying reduces fruit drop and improves fruit yield and quality of citrus (Hosseini, 2019; Khalid et al., 2021; Bastakoti et al., 2022).

Although the role of foliar fertilization in citrus has been widely studied worldwide (Gerendás & Führs, 2013; Hosseini, 2019; Bastakoti et al., 2022; Van Dang et al., 2022), research on the effect of foliar fertilizing on nutritional status, fruit yield and quality of mandarin trees is scarce. In this study, for the first time, the impact of spraying two commercial fertilizers: CalfalB (containing calcium and boron) and Rice (containing macro- and micronutrients) on leaf nutrient contents, quality, yield, and phytochemical parameters of the fruit of 'Page' mandarin were investigated.

2 MATERIALS AND METHODS

2.1 SITE DESCRIPTION

A commercial 'Page' mandarin orchard located in Mazandaran province, Iran (latitude. 36° 50′; longitude. 53° 0′ E; altitude. 52 m above sea level) was used for nutritional treatments. The climatic conditions of the site of trials during the period of experiments are presented in Table 1. Studied plants were 10 years old and were planted in sandy a clay loam soil, which is presented in Table 2, and the distance of plantation is 2 meters on the row and 3 meters between the rows.

2.2 TREATMENTS AND EXPERIMENTAL DESIGN

A completely randomized block design with three nutrient treatments and six replications (trees) in each treatment was used in the experiment. The nutrient treatments included two commercial fertilizers: CalfalB (containing calcium and boron) and Rice (containing macro- and micronutrients). Distilled water was sprayed as the control. Table 3 shows the characteristics and concentrations of the fertilizers used. Fertilizers were purchased from a commercial company (Shahin Faraz Arian, Teheran, Iran; website: Falconagri.ir). The fertilizers were sprayed three times: mid-June and two more times at 18-day intervals. The fertilizers were sprayed in two years (2022-2023); however, the effect of fertilizers on

Table 1: Climatic conditions during the experiment period of the trials on spraying macro and micro fertilizers on 'Page' mandarin in Mazandaran province area, Iran

Months	Mean high temperature (°C)	Mean low temperature (°C)	Mean humidity (%)	Mean rainfall (mm)	Mean sunshine (h)
January	9.8	5.8	71	31.1	5.21
February	22.3	-1	72	89.2	4.28
March	14.6	10.2	70	47.8	3.31
April	39.2	5.4	70	15.7	3.91
May	35.6	11.8	78	63.4	6.16
June	37.2	12.2	67	4	9.15
July	36.2	19.2	66	7.6	6.80
August	36	21.5	74	50.7	9.10
September	25.4	25.2	66	159.4	5.76
October	37	14	76	101	4.43
November	18.6	13.2	76	51.9	4.94
December	27	2.5	80	59.6	3.42

Table 2: The content of minerals in the soil and physico chemical properties of the soil of the experimental orchard of 'Page' mandarin in Mazandaran province area, Iran

Parameters	Depth (cm)	
	0–30	30–60
Clay (%)	37	42
Silt (%)	24	23
Sand (%)	39	35
Soil texture	Clay loam	Clay
pH	7.03	7.21
Electrical conductivity (EC) (ds m^{-1})	0.53	0.56
Organic matter (OM) (%)	3.62	1.12
Organic Carbon (OC) (%)	2.11	0.65
N (%)	0.22	0.25
P (ppm)	92.9	5.8
K (ppm)	277	119
Fe (ppm)	4.3	14.02
Mn (ppm)	12.04	36.12
Zn (ppm)	1.00	9.18
Cu (ppm)	0.68	2.30

fruit yield and quality was not significant in the first year, and only the results of the second year are presented.

2.3 THE CONTENT OF MINERALS IN THE LEAVES

To measure the concentration of N, P, K, Ca, Mg, Zn, Mn, and Fe in the leaves, mandarin leaves were collected in early September. The samples of leaves were dried in the oven, and after being powdered, 0.2 g was used to determine the concentration of the minerals in the leaves. Kjeldahl method was used to determine N concentration. A spectrophotometer was used to determine the P concentration. K concentration was determined by Flame photometrically. An atomic absorption spectrophotometer (Varian, 220) was used to measure the concentrations of Ca, Mg, Zn, Mn, and Fe.

2.4 CHLOROPHYLL CONTENT IN THE LEAF

According to Lichtenthaler (1987), the chlorophyll content in leaves collected in early September was de-

Table 3: Active ingredient of compounds used in the study

Commercial name	Active Ingredient (w/w) %	Doses of foliar application (%)
CalfalB	Ca 8 %; B 0.5 %	0.3
Rice	N 15 %; P_2O_5 15 %; K_2O 30 %; MgO 1 %; Mn 1.1 %, Fe 0.1 %, Zn 0.52 %, B 0.25 %, Cu 0.21 %	0.5

termined. Chlorophyll concentrations were measured at wavelengths of 646.8 and 663.2 nm, and readings were recorded as mg g^{-1} FM (Fresh Mass) of the leaf.

2.5 FRUIT YIELD AND QUALITY

In early December, the fruits of each tree (replication) were picked and weighed to determine the yield (kg per tree). Fruit length and diameter, and skin thickness were determined by using a digital Vernier caliper. To determine the fruit size, the fruit was placed in a beaker filled with water, and the amount of overflowing water was considered equal to the fruit size (volume) (cm^3).

The percentage of fruit juice was calculated using the equation [A/B] x 100, where A and B are respectively the juice mass and the fruit mass. The percentage of fruit rind was determined using the equation [C/B] x 100, where C and B are respectively the rind mass and the fruit mass.

The firmness of the mandarin fruits was measured using a penetrometer (STEP SYSTEM, Germany), and results were recorded as kg cm^{-2}.

2.6 TOTAL SOLUBLE SOLIDS (TSS), TITRATABLE ACIDITY (TA) AND TSS/TA RATIO

A digital refractometer (Atago, PAL-1, Japan) was used to measure the total soluble solids (TSS) concentration of the fruit juice of mandarin, and results were given as % (Brix). By titration with 0.1 N NaOH up to a pH of 8.1, 1 ml of diluted juice in 25 ml distilled water, titratable acidity (TA) was determined, and results were given as a percentage of citric acid. The TSS/TA ratio was calculated by dividing TSS by TA.

2.7 THE FRUIT COLOR

The color parameters of the fruit rind [L^* (lightness), a^* (redness), and b^* (yellowness)] of 'Page' mandarins were measured using a colorimeter (CR 400-Minolta, Japan). The color was measured at three points of the fruit surface of each replicate, and the mean values were given.

2.8 BIOCHEMICAL ATTRIBUTES OF THE FRUITS

Vitamin C of the fruit juice was determined by oxidizing ascorbic acid with 2, 6-dichloro phenol-indo-phenol, and the results were determined in mg 100 ml^{-1} juice (Nielsen, 2017).

The Folin–Ciocalteau method was used to determine the content of total phenol in mandarin juice (Singleton and Rossi, 1965). Total phenol was measured at 520 nm spectrophotometrically (Cary Win UV 100, Varian, Australia). Total phenol values were determined by applying a calibration curve drawn for the gallic acid standard solution, and the results were determined in mg gallic acid ml^{-1} juice.

The content of carotenoid in the fruits was determined according to Lichtenthaler (1987). The carotenoid concentration in the fruit was measured using a Cary WinUV 100 spectrophotometer (Varian, Australia) at 470 nm, and results were determined in mg·g^{-1} FM.

The total antioxidant activity of the fruit juice was assessed based on the radical scavenging ability in reacting with DPPH (2, 2-diphenyl-1- picrylhydrazyl) according to Brand-Williams et al. (1995). Briefly, 100 µl of mandarin juice, 10 ml of methanol, and 1900 µl of DPPH solution (Sigma-Aldrich, USA) were mixed and stirred for 30 min. Then, at 517 nm against a blank (methanol), the absorbance was measured using a Cary WinUV 100 spectrophotometer (Varian, Australia). The percentage of antioxidant activity as the inhibition percentage of free radical DPPH was estimated using the following formula:

Total antioxidant activity (%) = [(blank absorbance – extract absorbance / blank absorbance] × 100

2.9 STATISTICAL ANALYSIS OF DATA

The data were analyzed using the GLM procedure of SAS (Statistical Analysis System) software (Version 9.1). Significant differences were assessed using Duncan's multiple range test at $p \leq 0.05$. To evaluate significant differences, Duncan's multiple range test at $p \leq 0.05$ was used.

3 RESULTS

3.1 THE CONTENT OF MINERALS IN THE LEAF

Foliar application of Rice and CalfalB fertilizers caused a significant increase in the concentrations of N ($p = 0.0002$), Mn ($p = 0.0010$), and Fe ($p < 0.0001$) in the mandarin leaves. The effect of Rice was statistically more remarkable than that of CalfalB. With Rice spray, the concentration of N, Mn, and Fe was respectively 26.41 %, 159.20 %, and 142.68 % greater than the unfertilized plants (Table 4).

Mandarin trees fertilized with Rice fertilizer showed the highest increase in the concentrations of P, K, and Mg in the leaves (196.00 %, 79.78 %, and 94.73 %, respectively). The effect of Rice was greater than that of CalfalB; nevertheless, there is no significant difference between CalfalB and the control (Table 4).

Compared to unfertilized trees, the Ca concentration of fertilized trees with CalfalB and Rice fertilizers was significantly (p <.0001) increased (12.42–37.85 %), and the effect of CalfalB was statistically more considerable than that of Rice (Table 4).

Plants sprayed with Rice and CalfalB fertilizers accumulated significantly a higher concentration of Zn than unsprayed plants. With the application of Rice and CalfalB, the concentration of Zn was respectively 180.19 % and 212.57 % higher than the control (Table 4).

3.2 THE CONTENT OF CHLOROPHYLL IN THE LEAVES

Spraying Rice and CalfalB fertilizers affect significantly the content of chlorophyll a ($p < 0.0001$) and total chlorophyll ($p = 0.0013$) in the leaves, but had no significant effect ($p = 0.5158$) on the content of chlorophyll b (Fig. 1). The influence of Rice was considerably more significant than that of CalfalB. With Rice application, the contents of chlorophyll a and total chlorophyll were

Table 4: Effect of spraying fertilizers on the content of minerals in the leaves of 'Page' mandarin in Mazandaran province area, Iran

Treatments	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Zn (ppm)	Mn (ppm)	Fe (ppm)
Control	2.12 c	0.25 b	0.94 b	1.77 c	0.19 b	16.06 b	25.10 c	49.08 c
Rice	2.68 a	0.74 a	1.69 a	1.99 b	0.37 a	50.20 a	65.06 a	119.11 a
CalfalB	2.45 b	0.35 b	1.00 b	2.44 a	0.22 b	45.00 a	40.13 b	82.16 b
P-value	0.0002	0.0043	0.0010	<.0001	0.0032	0.0018	0.0010	<.0001
CV (%)	1.70	18.77	7.52	1.21	11.10	12.75	10.33	2.06

Values in columns followed by the same letter are not significantly different at $p \leq 0.05$, Duncan's multiple range test. CalfalB: Ca 8 %, B 0.5 %; Rice: N 15 %, P_2O_5 15 %, K_2O 30 %, MgO 1 %, Mn 1.1 %, Fe 0.1 %, Zn 0.52 %, B 0.25 %, Cu 0.21 %

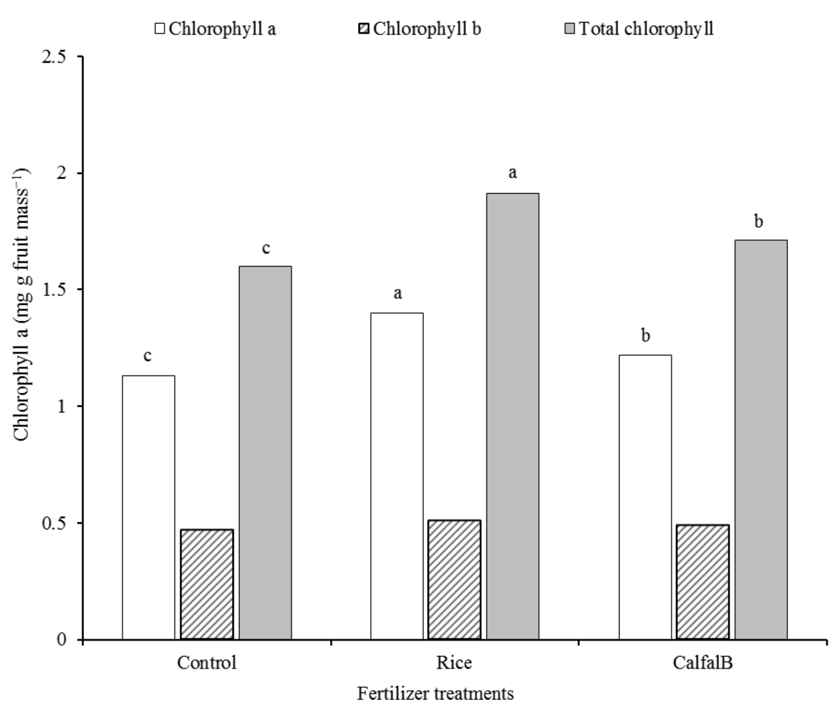

Fig. 1: Effect of spraying fertilizers on the content of chlorophyll in the leaves of 'Page' mandarin in Mazandaran province area, Iran. Different letters at the top of columns indicate significant differences ($p \leq 0.05$) among treatments. CalfalB: Ca 8 %, B 0.5 %; Rice: N 15 %, P_2O_5 15 %, K_2O 30 %, MgO 1 %, Mn 1.1 %, Fe 0.1 %, Zn 0.52 %, B 0.25 %, Cu 0.21 %

respectively 23.891 % and 19.37 % greater than the control (Fig. 1).

3.3 FRUIT YIELD AND QUALITY

The fertilizers affect significantly fruit yield (p = 0.0015), juice percentage (p = 0.0501), pulp percentage (p = 0.0031), and rind percentage (p = 0.0417) of mandarins, whereas there is no significant effect on fruit diameter (p = 0.5457), fruit length (p = 0.9545), fruit size (p = 0.2935), and firmness (p = 0.0909) (Table 5).

Compared to unfertilized plants, the yield of fertilized mandarins with CalfalB and Rice increased by 17.15 % and 45.59 %, respectively. The effect of Rice was considerably higher than that of CalfalB (Table 5).

The highest percentage of juice and rind was achieved with Rice fertilizer. With Rice application, the percentages of juice and rind were respectively 11.441 % and 15.87 % greater than the control (Table 5). Regarding the percentage of juice and rind, there is no significant difference between Rice and CalfalB and also between control and CalfalB (Table 5).

Mandarins fed with fertilizers exhibited a lesser pulp percentage than the control. The effect of Rice fertilizer was considerably superior to that of CalfalB. With Rice application, the fruit pulp percentage was 30.02 % less than the control (Table 5).

3.4 TSS, TA, AND TSS/TA

Spraying Rice and CalfalB fertilizers affect significantly TSS (p = 0.0011) and TSS/TA (p = 0.0500) of mandarins, but had no significant effect (p = 0.6621) on TA (Table 6). Compared to the unfertilized control, the TSS of fruits was 32.67 % and 20.09 % higher for Rice and CalfalB, respectively. The influence of Rice was considerably more significant than that of CalfalB (Table 6).

The highest TSS/TA (10.72) was obtained with the Rice application, which resulted in an increase of 25.67 % compared with the control. However, this influence was not superior to that of CalfalB. In addition, there is no significant difference between CalfalB and control (Table 6).

3.5 FRUIT COLOR

Foliar application of Rice and CalfalB fertilizers affect significantly the rind color parameters (L^*, a^*, and b^*) of the fruits of mandarin (Table 6). The influence of

Table 5: Effect of spraying fertilizers on fruit yield and quality of 'Page' mandarin in Mazandaran province area, Iran

Treatments	yield (kg tree $^{-1}$)	Fruit length (mm)	Fruit diameter (mm)	Fruit size (cm^3)	Fruit juice (%)	Fruit pulp (%)	Fruit rind (%)	Fruit firmness (kg cm^{-2})
Control	58.60 c	58.37	66.98	124.16	47.02 b	30.04 c	22.93 b	10.06
Rice	85.32 a	58.75	67.43	131.66	52.40 a	21.02 a	26.57 a	11.10
CalfalB	68.65 b	58.50	68.20	132.06	48.31 ab	26.20 b	25.48 ab	11.46
P-value	0.0015	0.9545	0.5457	0.2935	0.0501	0.0031	0.0417	0.0909
CV (%)	4.70	2.67	1.88	4.58	4.02	5.20	4.63	5.36

Values in columns followed by the same letter are not significantly different at $p \le 0.05$, Duncan's multiple range test.

Table 6: Effect of spraying fertilizers on TSS, TA, TSS/TA and rind color indices of 'Page' mandarin fruits in Mazandaran province area, Iran

Treatments	TSS (%)	TA (%)	TSS/TA	L^* (lightness)	a^* (redness)	b^* (yellowness)
Control	10.10 c	1.20	8.53 b	35.20 b	3.31 c	18.45 c
Rice	13.40 a	1.25	10.72 a	40.80 a	7.78 a	30.13 a
CalfalB	12.13 b	1.28	9.45 ab	35.93 b	4.76 b	24.32 b
P-value	0.0011	0.6621	0.0500	0.0039	0.0001	<.0001
CV (%)	3.19	8.62	7.77	2.57	5.85	2.31

Values in columns followed by the same letter are not significantly different at $p \le 0.05$, Duncan's multiple range test. CalfalB: Ca 8 %, B 0.5 %; Rice: N 15 %, P_2O_5 15 %, K_2O 30 %, MgO 1 %, Mn 1.1 %, Fe 0.1 %, Zn 0.52 %, B 0.25 %, Cu 0.21 %

Rice was considerably superior to CalfalB. Application of Rice improved the values of *L**, *a**, and *b** by 15.90 %, 135.04 %, and 63.30 % respectively (Table 6).

3.6 FRUIT BIOCHEMICAL ATTRIBUTES

Spraying Rice and CalfalB fertilizers improved significantly ($p = 0.0062$) the vitamin C of mandarin fruits. With a spray of Rice and CalfalB, vitamin C in the fruits was respectively 57.86 % and 31.56 % higher than in the unfertilized control. The influence of Rice was noticeably higher than that of CalfalB (Fig. 2).

The content of total phenol and antioxidant activity in the mandarin fruits increased respectively by 60.56 % and 9.87 % with the application of Rice fertilizer. The effect of Rice was superior to that of CalfalB (Figs. 3 and 4).

Fruits of trees sprayed with Rice and CalfalB fertilizers had significantly the higher content of carotenoid than in unsprayed plants. With the application of Rice and CalfalB, the content of carotenoid was respectively 130.76 % and 92.30 % higher than the control (Fig. 5).

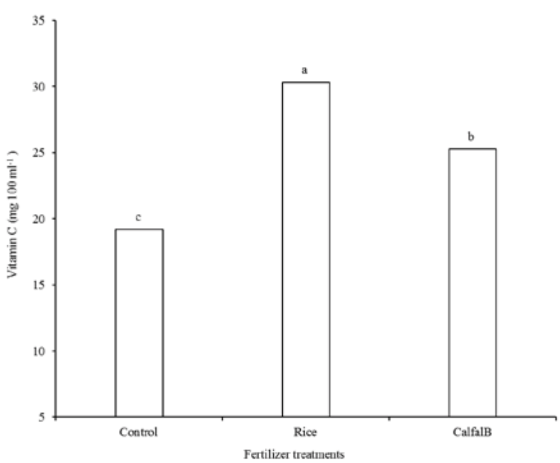

Fig. 2: Effect of spraying fertilizers on the content of vitamin C in the fruits of 'Page' mandarin in Mazandaran province area, Iran. Different letters at the top of columns indicate significant differences ($p \leq 0.05$) among treatments. CalfalB: Ca 8 %, B 0.5 %; Rice: N 15 %, P_2O_5 15 %, K_2O 30 %, MgO 1 %, Mn 1.1 %, Fe 0.1 %, Zn 0.52 %, B 0.25 %, Cu 0.21 %

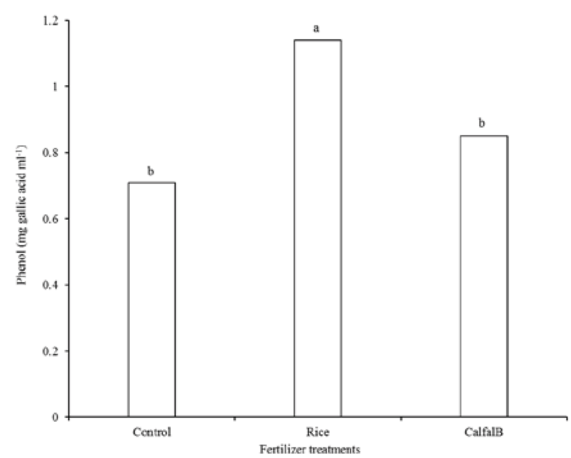

Fig. 3: Effect of spraying fertilizers on the content of total phenol in the fruits of 'Page' mandarin in Mazandaran province area, Iran. Different letters at the top of columns indicate significant differences ($p \leq 0.05$) among treatments. CalfalB: Ca 8 %, B 0.5 %; Rice: N 15 %, P_2O_5 15 %, K_2O 30 %, MgO 1 %, Mn 1.1 %, Fe 0.1 %, Zn 0.52 %, B 0.25 %, Cu 0.21 %

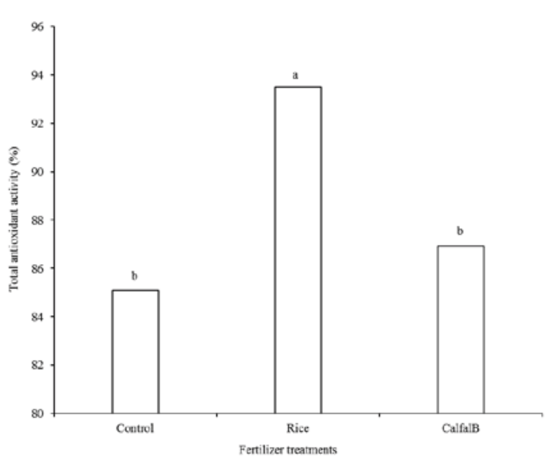

Fig. 4: Effect of spraying fertilizers on the content of antioxidant activity in the fruits of 'Page' mandarin in Mazandaran province area, Iran. Different letters at the top of columns indicate significant differences ($p \leq 0.05$) among treatments. CalfalB: Ca 8 %, B 0.5 %; Rice: N 15 %, P_2O_5 15 %, K_2O 30 %, MgO 1 %, Mn 1.1 %, Fe 0.1 %, Zn 0.52 %, B 0.25 %, Cu 0.21 %

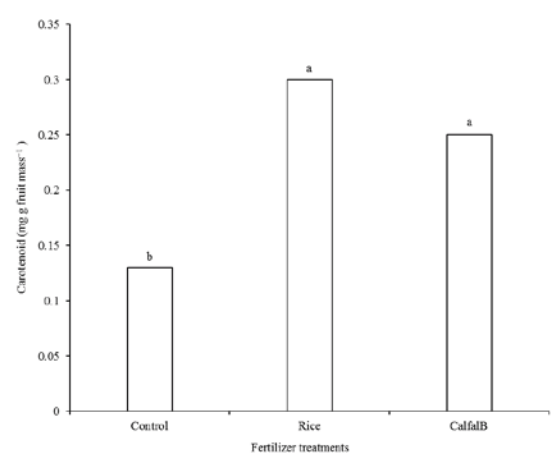

Fig. 5: Effect of spraying fertilizers on the content of carotenoid in the fruits of 'Page' mandarin in Mazandaran province area, Iran. Different letters at the top of columns indicate significant differences ($p \leq 0.05$) among treatments. CalfalB: Ca 8 %, B 0.5 %; Rice: N 15 %, P_2O_5 15 %, K_2O 30 %, MgO 1 %, Mn 1.1 %, Fe 0.1 %, Zn 0.52 %, B 0.25 %, Cu 0.21 %

4 DISCUSSION

Deficiency of essential elements has been one of the main problems in citrus-producing regions of Iran. Compared to the recommended desirable ranges (Menino, 2012; Table 7), the levels of N, K, Ca, Mg, Zn, and Fe in the leaves of unfertilized mandarin trees were lower (Table 7), what shows the deficiency of these minerals. On the other hand, the level of Mn was somewhat similar to the recommended desirable range, and the P concentration was higher than the optimal range (Menino, 2012). However, application of Rice and CalfalB fertilizers by spraying markedly improved leaf levels of N (15.56–26.41 %), P (40–196 %), K (6.38–79.78 %), Ca (12.42–37.85 %), Mg (15.78–94.73 %), Zn (180.19–212.57 %), Mn (59.88–159.20 %), and Fe (67.40–142.68 %) (Tables 4 and 7). Our findings agree with the results published by Hosseini (2018) on lime and Van Dang et al. (2022) on pomelo, who reported that foliar application of fertilizers containing macro- and micronutrients, enhanced the content of minerals in the leaf. Foliar application of fertilizers improves the absorption, movement, and accumulation of mineral elements in the plants (Norozi et al., 2019).

In the current work, due to treatment with fertilizers, especially Rice, chlorophyll a and total chlorophyll increased significantly (Fig. 1). The increase in the content of chlorophyll with foliar application of micronutrients have been described for sweet orange (Nandita et al., 2020), and acid lime (Bastakoti et al., 2022). The increase in the content of chlorophyll because of the application of micronutrients is due to the known roles of micronutrients in the activation of enzymes involved in chlorophyll biosynthesis (Ilyas et al., 2015; Mohammed et al., 2018; Bastakoti et al., 2022). Furthermore, similar findings on the positive effects of macronutrients on the chlorophyll content have been achieved (Oivukkamäki et al., 2023). The positive impact of N and Mg on the content of chlorophyll can be because these elements, as components of a chlorophyll molecule, are necessary for the formation of chlorophyll (Menino, 2012). Moreover, K increases the biosynthesis of chlorophyll and inhibits the decomposition of chlorophyll (Alipour, 2018). The leading cause of reduced chlorophyll content is K deficiency (Ali et al., 2021).

Based on this research, foliar application of fertilizers, especially Rice, improved significantly most traits related to fruit yield and quality of mandarin (Table 5). Using fertilizers containing macro- and micronutrients to improve yield and fruit quality is consistent with Hosseini (2018) for lime, Reetika et al. (2018) for 'Kinnow' mandarin, Bastakoti et al. (2022) for acid lime, and Van Dang et al. (2022) for pomelo. The positive influence of macro- and micronutrients on yield and fruit quality can be ascribed to the effects of these elements on balancing the nutritional status, photosynthetic efficiency, and the transfer of photoassimilate from the source to the sink (Reetika et al., 2018; Cavender et al., 2019; Bastakoti et al., 2022).

Our findings showed that spraying fertilizers, especially Rice, improved TSS and TSS/TA in mandarin fruits (Table 6). These results are in line with those of Van Dang et al. (2022), who indicated that the use of fertilizers containing macro- and micronutrients increases the TSS in pomelo fruits. The rise in the content of TSS in the fruits by spraying P, K, Mg, and Zn can be due to the increase in enzyme activity involved in carbohydrate synthesis (Gerendás & Führs, 2013; Jiang et al., 2014; Davarpanah et al., 2016; Zhang et al., 2018). Conversely, Van Dang et al. (2022) observed that applying fertilizers containing macro- and micronutrients reduced acidity in pomelo fruits, which is dissimilar to our results (Table 6).

Rind color is a vital fruit characteristic for a fresh market. The rind color of citrus fruits is related to many factors, including maturity, environmental conditions, genotype, and plant nutrition (Menino, 2012). According to our study, the fertilizers in particular Rice improved significantly the rind color parameters of mandarin fruits

Table 7: The content of minerals in the leaves of the unfed and fed 'Page' mandarin trees in Mazandaran province area, Iran, and comparison with suggested optimal ranges

Minerals	Fertilized plants	Unfertilized plants	Optimal ranges (Menino, 2012)
N (%)	2.12	2.44–2.59	2.5–2.7
P (%)	0.25	0.30–0.55	0.12–0.16
K (%)	0.94	1.10–1.38	1.2–1.7
Ca (%)	1.77	1.80–2.35	3.0–4.9
Mg (%)	0.19	0.24–0.35	0.30–0.49
Zn (ppm)	16.06	48.16–58.10	25–100
Mn (ppm)	25.10	45.16–60.00	25–100
Fe (ppm)	49.08	78.10–122.04	60–120

(Table 6). Similarly to these findings, increases in fruit color parameters using chemical fertilizers have been described in pomegranate (Almutairi et al., 2021), and strawberry (Kilic et al., 2021). Reported results on the relationship between mineral nutrients and citrus color parameters are scarce and inconsistent.

Fertilizers play a significant role in the content of vitamin C in citrus fruits (Menino, 2012). The fertilizer treatments, especially Rice, increased the content of vitamin C in mandarin fruits (Fig. 2). Our results agreed with those achieved by Maity et al. (2022), Almutairi et al. (2021) on pomegranate, and Kilic et al. (2021) on strawberry, who stated that the application of fertilizers containing different elements enhanced the content of vitamin C in the fruits. Increases in the content of vitamin C in the fruits have been ascribed to the roles of P, K, Mg, and Zn in the accumulation of greater sugars and phytohormones in the fruits (Menino, 2012; Tanari et al., 2019; Maity et al., 2022).

Phenolic compounds in citrus fruits play an important role in human health (Menino, 2012). In our research work, the content of total phenol in the mandarin fruits substantially improved with the application of Rice fertilizer (Fig. 3). Similarly, Cavender et al. (2019) detected that using fertilizers promoted the content of total phenol in blackberry fruits. Many minerals act as cofactors of many enzymes of the phenolic compound pathway (Treutter, 2010).

Carotenoids protect plants from oxidative damage (Menino, 2012). The results revealed that both fertilizers considerably improved the carotenoid content in mandarin fruits (Fig. 5). Similar to our findings, Balázs et al. (2023) observed that applying fertilizers containing different elements promoted carotenoid content in sweet potatoes. The increases in the carotenoid content in the fruits can be ascribed to the point that mineral elements have roles in the activities of carotenoid biosynthesis enzyme (Bruulsema et al., 2012).

An important parameter in evaluating the quality of fruits is the level of antioxidant activity. Our research study indicated that spraying Rice fertilizer increased considerably the antioxidant activity of mandarin fruits (Fig. 4). Antioxidant activity is affected by fertilizer use (Riahi & Hdider, 2013). Using nutrients and fertilizers to increase the antioxidant activity in the fruits is in line with previous studies (Fanasca et al., 2006; Cavender et al., 2019). Stress management is the most effective strategy for increasing antioxidants (Mukherjee et al., 2020), and improving the plant's nutritional status using fertilizers can reduce plant stress and increase antioxidants. Vitamin C, phenols, and carotenoids contribute to the antioxidant activity of citrus fruits (Zou et al., 2016). Consequently, variations in the concentration of these compounds (vitamin C, phenols, and carotenoids) showed a similar trend with the antioxidant activity of mandarin fruits (Figs. 2, 3, 4, and 5).

5 CONCLUSION

Foliar application of CalfalB and Rice fertilizers, especially Rice, improved fruit yield and quality of mandarin 'Page' due to enhanced leaf minerals, leaf chlorophyll, fruit yield, the percentages of juice , pulp , and rind , TSS, TSS/TA, rind color parameters, vitamin C, phenol compounds, carotenoid, and antioxidant activity in the fruits. Accordingly, applying fertilizers containing macro- and microelements can lead to enhanced quality and quantity of mandarin fruits, especially in regions with poor soils.

6 CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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