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ORIGINAL ARTICLE / ORIGINALBEITRAG

Supplementation of Potassium and Phosphorus Nutrients to Young Trees Reduced Rind Thickness and Improved Sweetness in 'Kinnow' Mandarin Fruit

Mahmood Ul Hasan[1] · Aman Ullah Malik[1] · Basharat Ali Saleem[2] · Raheel Anwar[1] · Samina Khalid[3] · Ahmad Sattar Khan[1] · Maryam Nasir[4]

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Abstract
Young 'Kinnow' mandarin orchards have inferior fruit quality in terms of thick rind, less juice and low eating quality. The present research experiment was aimed at evaluating the effect of phosphorus (P) and potassium (K) nutrients on rind and fruit quality at different harvesting times. Young trees (6 years old) were supplied with fertilizers containing P (P_2O_5 = 552 g and 828 g) and K (K_2O = 600 g and 900 g) nutrients at the fruit set stage. For yield and physical quality assessment, fruits were harvested at commercial maturity (second harvest). Trees showed maximum yield in terms of fruit number and weight subjected to K_2O (600 g). Rind thickness was promisingly reduced by soil amendment of K_2O- 600 g followed by K_2O-900 g as compared to control trees. Biochemical, phytochemical and sensory attributes were assessed at three times of harvest. Soluble solids content and sugar acid ratio of fruit were positively increased in K-treated trees followed by those subjected to P nutrient and gradually increased as harvesting time was prolonged. Among phytochemicals, K_2O- 600 g showed higher DPPH (2,2-diphenyl-1-picrylhydrazyl) activity and P_2O_5- 552 g application increased the total phenolics content of fruit, but declined at third harvest. Sensory properties (taste, flavor, aroma and texture) were improved in all treatments except control. Conclusively, the results revealed that the optimum range of fertilizers containing K and P nutrients can increase the productivity of young trees and improve the fruit quality of 'Kinnow' mandarin.

Keywords Fruit quality · Productivity · Harvesting time · Sensory attributes · Phytochemicals

Introduction

Citrus is one of the most prominently cultivated fruit groups in the world after grapes. It belongs to the family Rutaceae, which is primarily famous for the genus *Citrus*, because of worldwide consumption and commercial importance. Nevertheless, the family Rutaceae contains approximately 160 genera and 1900 species grown around the globe with significant variation in morphology and phytochemical profile. Fruit species in the Rutaceae family contain a wide array of phytochemicals, particularly secondary compounds including, flavonoids, volatile oils, limonoids, and alkaloids (Groppo et al. 2008; Sevindik et al. 2021a). Presently, global production of citrus is 124.24 million tonnes, with an export trade volume of 15.91 million tonnes. Pakistan ranks 14th in the list of citrus-producing countries of the world (FAOSTAT 2017). In Pakistan, citrus ranks first with respect to annual production (2.18 million tonnes) as well as the cultivated area (186.91 thousand ha) among fruits grown in the country (GOP 2017). 'Kinnow' mandarin is the leading citrus cultivar of Pakistan which contributes to more than 60% of the country's citrus fruit basket (Altaf and Khan 2009). It has gained popularity among growers and traders due to its better adaptation to the local agroecological conditions, good yield, and high export revenue

Data availability The authors declare that the data supporting the findings of this study are available within the article.

✉ Aman Ullah Malik
malikaman1@uaf.edu.pk

[1] Postharvest Research and Training Centre, Institute of Horticultural Sciences, University of Agriculture, 38040 Faisalabad, Pakistan

[2] Department of Agriculture Lahore, Horticulture Extension Wing, Punjab, Pakistan

[3] Department of Environmental Sciences, COMSATS University Islamabad, Vehari Campus, Punjab, Pakistan

[4] Horticultural Research Institute, Ayub Agricultural Research Institute, Faisalabad, Pakistan

(300,000 metric tons, worth >USD 180 million) (Khalid 2013; Annoymous 2014).

Citrus fruits are usually consumed as fresh and in processed forms worldwide, due to their rich source of health-promoting compounds including ascorbic acid, flavonoids, carotenoids, and synephrines, and multiple minerals and components of dietary fiber imperatively help in strengthening the immune system and preventing the risk of different chronic diseases (Lu et al. 2021; Khan et al. 2022). Apart from the nutritional profile of fruit, essential oils extracted from citrus peels have great antibacterial and antifungal activities and could be alternatives of synthetically produced antimicrobial agents (Sevindik et al. 2021b). Consumer's choice for acceptance of fresh produce mainly depends upon the cosmetic look such as peel color, surface texture, peel and pulp ratio, and size of fruit (Khalid 2013; Malik et al. 2021). 'Kinnow' fruit quality is depicted through physical (external) and internal attributes including juice content, vitamin C, soluble solids content (SSC), total acidity (TA), and sugar acid (TSS:TA) ratio (Ahmad et al. 2006). Exporters are usually reluctant to buy fruit of young 'Kinnow' orchards due to their thicker rind, low juice content, and inferior internal quality (Khalid et al. 2012a).

Various fertilizers are used as plant nutrition sources in citrus growing regions primarily for improving yield and quality. Macro- and micronutrients are essential for plant growth and quality production (Ashkevari et al. 2013). Rind quality is also affected by the use of different fertilizers especially phosphorus (P) and potassium (K). P is one of the key macronutrients that have an imperative role in the growth and development of plants and significantly increases yield, size of fruit, acidity percentage, and available juice content and slightly decreases peel thickness (Orphanos et al. 1986; Goepfert et al. 1987; Mann and Sandhu 1988; Embleton et al. 1978). With reference to fruit quality, it has been reported that the use of K as nutrient improved fruit size, color, and total acidity in citrus (Tiwari 2005; Alva et al. 2006; Nasir et al. 2016). K-based foliar sprays also enhanced the yield, sugars, and vitamin C content in sweet orange and mandarin cultivars (Lester et al. 2010). There are some reports that fertilizer containing K content increases the rind thickness in various citrus cultivars; 'Cadoux' clementine, oranges, grapefruit, and 'Kinnow' mandarin (Smith 1963; Obreza et al. 2008; Hamza et al. 2015). An inverse relationship was reported in lemons; increase in K containing fertilizer, decrease rind thickness, and improve juice volume of fruit (Embleton and Jones 1966).

Apart from fertilizer application, harvesting time also affects physiochemical properties of mandarin cultivars ('Kinnow' and 'Futrell's Early'); the maximum size of 'Kinnow' was recorded in the last week of December and quality parameter TSS increased with time from Mid-December up until February (Iqbal et al. 2012). 'Kinnow' quality in terms of ascorbic acid, TSS, acidity, and carotenoids varied with harvesting time in young trees (Thakre et al. 2015). Although, different studies are available on nutritional management on different aspects with varying citrus species, an integrated study on the effect of P and K on fruit yield, rind thickness, biochemical quality, and non-enzymatic antioxidants (ascorbic acid, DPPH scavenging activity, and total phenolic contents) under different harvesting times is still lacking. Thus, the present study aimed to determine the effect of K and P fertilizers on rind quality and the correlation between harvesting dates and biochemical properties in young trees of 'Kinnow' mandarin.

Materials and Methods

Plant Material

The research study was carried out in the Experimental Fruit Orchard, Postgraduate Agriculture Research Station (31.388, 73.00), Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan, during the period 2017–2018. Young 'Kinnow' mandarin plants (6-years old) budded on rough lemon (*Citrus jambhiri* L.) and spaced at 6 m × 6 m distance were selected. The selected plants were healthy and grown under uniform cultural conditions including judicious weeding, irrigation, and integrated pest and disease management.

Treatments

A total of 20 uniform trees were subjected to five treatments of K and P containing fertilizers with different doses. The treatments were T_1 = Control, T_2 = diammonium phosphate (DAP) (1200 g) containing 552 g P_2O_5, T3 = DAP (1800 g) containing P_2O_5 828 g, T_4 = sulfate of potash (SOP) (1200 g) containing 600 g K_2O and T5 = SOP (1800 g) containing 900 g K_2O applied to plants at the time of fruit setting. While constant dose of urea (600 g) containing 272 g of nitrogen (N) was applied in three splits to plants including control. However, due to the availability of N (18%) from DAP fertilizer, the dose of urea was adjusted accordingly. The field experiment was designed according to randomized complete block design (RCBD), replicated four times with individual tree taken as single replication. Leaf nutrient (N, P, and K) analysis was carried out during the last week of August. Physical parameters of study (fruit yield per plant, peel thickness, weight of fruit, peel, rag, juice, seed and peel:pulp ratio) were recorded at harvest time (January 10, 2018). However, biochemical (TSS, total acidity percentage, ascorbic acid, pH, TSS:TA ratio), phytochemical attributes (total phenolic contents and total antioxidants) and organoleptic evaluation (taste, texture, flavor, and aroma) were done at three different harvesting times (December 20, 2017; January 10, 2018; January 31, 2018). After harvest, physiochemical and organoleptic analysis of 'Kinnow' fruits was performed at the Postharvest Research and Training Center (PRTC), University of Agriculture Faisalabad (UAF) for physiochemical analysis. Total phenolics and antioxidants were determined at the Biochemistry Lab, Department of Biochemistry, UAF.

Leaf Nutrient Analysis

For the determination of leaf nutrient content, 40 healthy leaves (aged 5–7 months) were clipped along with petioles from non-fruiting branches. Leaves were collected in the month of August, saved in labelled porous bags and brought to PRTC, IHS, UAF for further process. Samples of leaves were washed with tap water, cleaned with detergent to remove surface dirt and then washed again with deionized water. After cleanup, leaves were placed in the shade till moisture was evaporated. Samples were dried in the oven at 65 °C for 48 h and ground in an electric grinder to a fine powder. N was estimated by distillation and titration methods (Khan et al. 2015). For N (%) analysis, micro Kjeldal apparatus was used after the digestion of leaf samples in a fume hood following the procedure adopted by Ullah et al. (2012). For the estimation of P and potassium (K), the method of wet digestion was used as illustrated by Nasir et al. (2016). Tri acid mixture (nitric acid (HNO_3): per chloric acid ($HClO_4$): sulphuric acid (H_2SO_4) with 5:2:1 ratio was prepared just before the start of digestion according to available samples. By using a weighing balance, 1 g of leaf sample was taken in 100 ml of the beaker, 10 ml of tri acid mixture poured in it and covered the beakers with a watch glass to prevent fumes. The beakers having digestion mixtures were allowed to stay for a period of 4 h to complete reactions inside. After the specified period, beakers were placed on a hot plate to heat samples gradually until whole acids transformed into fumes and given colorless material having a volume of 1.5 ml. Beakers were removed from heat, cooled, and made a volume of 100 ml by adding deionized water, and the final mixture was preserved in air-tight bottles. K and P were determined by using a flame photometer (Sherwood Scientific Ltd., Cambridge, UK) and spectrophotometer (GmbH, Geesthacht, Germany), respectively (Razzaq et al. 2013).

Fruit Yield and Quality Analysis

Physical Parameters

Fruit yield per plant was recorded by conventional methods (counting the number of fruits and weighing). For physical fruit quality assessment, 10 fruits from each of the experimental trees were harvested from all sides at shoulder height and brought to the PRTC lab in a plastic basket cushioned with paper. Peel thickness (mm) was measured by using a digital Vernier caliper, selected fruits were weighed to measure the average weight of fruit (g). Similarly, peel, rag, juice, and seed weight (after extraction in beaker) were measured by using available digital electric balance (Setra, BL-4100S). Peel:pulp ratio was calculated by simply dividing peel weight with juice and rag weight collectively of representative fruit (Khalid et al. 2012b).

Biochemical Quality

The determination of biochemical quality analysis regarding internal fruit quality was carried out at three harvesting dates (December 20, 2017; January 10, 2018; January 31, 2018). Total SSC (°Brix) was determined using digital hand 'refractometer' (ATAGO, RX 5000, Tokyo, Japan), TA percentage (TA%) was determined following the technique as adopted by Hasan et al. (2020) through titration of 5 ml of juice with 0.1N NaOH and TSS:TA ratio was calculated by simple division. Ascorbic acid was measured following the method adopted by Ali et al. (2016), by titrating 5 ml of aliquot taken in the beaker after filtration with dye (2,6-dichlorophenolindophenol) and reading expressed in mg per 100 ml of 'Kinnow' juice.

Phytochemicals

The activity of total antioxidants was assessed in the form of DPPH (2,2-diphenyl-1-picrylhy drazyl-radical) as outlined by Ali et al. (2016) using a methanolic solution of DPPH, juice extracts of different concentrations were added and permitted to hold for 30 min at room temperature as the incubation period. After completion of the incubation period, the reading was calculated through the ELISA plate reader at 517 nm of set absorbance. The final readings after calculation were expressed in percent. The total phenolic contents (TPC) were measured using the Folin-Ciocalteu (FC) method as earlier reported by Ainsworth and Gillespie (2007) and TPC was presented as mg GAE 100 g^{-1} FW.

Sensory Evaluation

Fruits from all experimental trees were also evaluated for organoleptic tests through sensory assessment (pulp taste, color, texture, and flavor) using a rating scale of 1–9. Peeled fruits were placed before panelists (postgraduate students) after code labeling on tagged plates. Each panelist was advised to rinse their mouth before the sensory evaluation of the next sample. The whole procedure of organoleptic evaluation was adopted as reported by Ali et al. (2016).

Statistical Analysis

The experimental data were subjected to statistical analysis using computer-operated software STATISTICS 8.1 (Tallahassee, FL, USA) and treatment means were compared ($P \leq 0.05$) through LSD (Least Significant Difference) test, while the overall significance of data was analyzed using ANOVA (analysis of variance).

Results and Discussion

Leaf Nutrients (N, P, and K)

Before conducting this research experiment, the soil samples from similar orchard were taken at three depths (6, 12, and 18 inches) and analyzed for soil nutrient profile depicting the status of macronutrients (N, P and K), pH, EC and organic matter percentage (Supplementary Table 1). Statistically, analysed data regarding N status in leaves represented significant ($P \leq 0.05$) results. N range of 2.59–3.04% in 'Kinnow' mandarin leaves was observed from trees treated with P and K fertilizers along with constant amount of N application (urea 600 g/plant), and the range was found in optimum to the high percentage (Sauls 2008). However, control plants displayed 2.17% leaf N, which was considered as deficient in citrus plants (Sauls 2008). Soil application of K followed by P improved the N status in leaves of 'Kinnow' mandarin as compared to control. Maximum N percentage (3.04%) was found in trees treated with $K_2O = 900$ g followed by $K_2O = 600$ g (2.92%), $P_2O_5 = 828$ g (2.67%), and $P_2O_5 = 552$ g (2.59%), respectively (Fig. 1a). Our results are in line with different reports in which application of K nutrient significantly increased leaf N status and its uptake from the soil in citrus orchards (Wang et al. 2006; Ashraf et al. 2010).

Similarly, the range of P nutrient in leaves of the treated plants was 0.16–0.22% except control (Fig. 1b). Maximum P percentage (0.26 and 0.22%) was recorded in trees subjected to higher doses of P_2O_5 552 g and 272 g followed by plants subjected to K nutrient (0.16 and 0.18%), while control trees showed lower (0.11%) P percentage, which was in the deficient range (Sauls 2008). The present study showed that P nutrient uptake was more triggered in plants treated with P and K as compared to the control. Furthermore, K nutrient status in the leaves represented significant ($P \leq 0.05$) results, and K range was measured between 0.87–1.58% from leaves of treated as well as non-treated plants (Fig. 1c). 'Kinnow' mandarin trees subjected to potash-based fertilizer application had higher K content in their leaves; K_2O with 900 g and 600 g dose per plant depicted maximum K percentage (1.58–1.31%), and

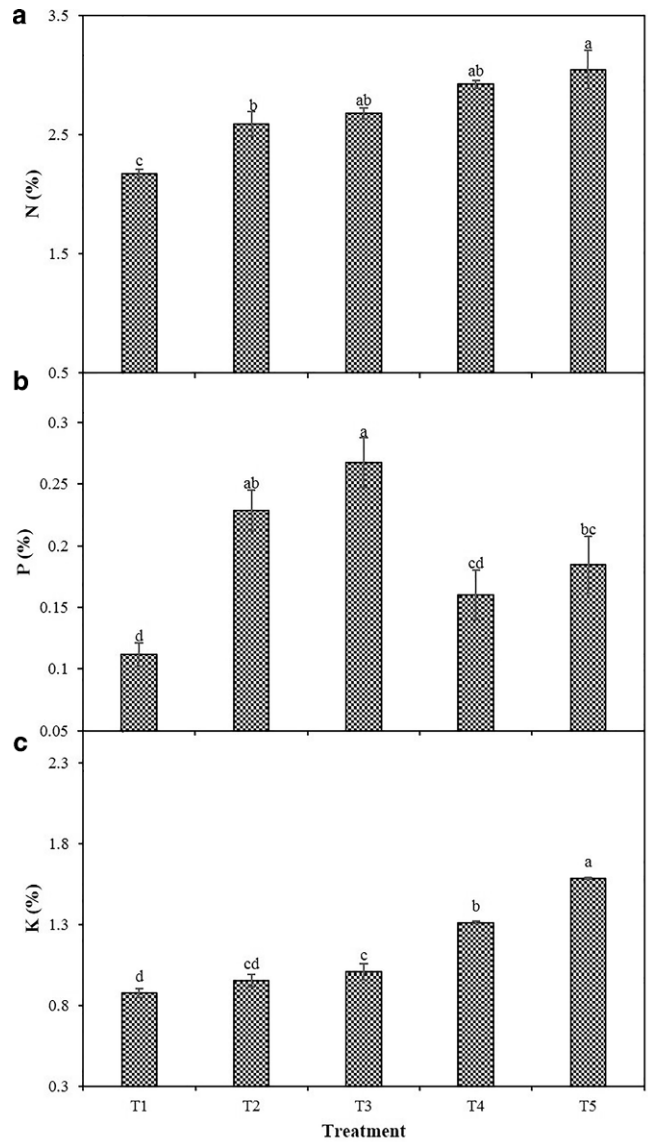

Fig. 1 Effect of fertilizer application (diammonium phosphate and sulfate of potash fertilizers as source nutrients of phosphorus and potassium) on **a** nitrogen (*N*), **b** phosphorus (*P*), and **c** potassium (*K*) contents of 'Kinnow' mandarin leaves. *Vertical bars* represent ± standard error of the means. Treatments = five; *T1* = control, *T2* = P_2O_5 (552 g), *T3* = P_2O_5 (828 g), *T4* = K_2O (600 g), and *T5* = K_2O (900 g). *n* = four replicates

Table 1 Effect of soil application of phosphorus (P_2O_5) and potassium (K_2O) nutrients using respective fertilizers on fruit yield and physical quality parameters of 'Kinnow' mandarin

Treatments	Fruit no./tree	Fruit weight/tree (kg)	Average fruit weight (g)	Average peel weight (%)	Average rag weight (%)	Average juice weight (%)	Peel thickness (mm)	Number of seeds	Seed weight (g)	Peel:pulp ratio
T_1 = Control	54d	6.5a	166.25b	25.57^a	32.47b	29.77a	3.72a	17.50a	2.76a	61.53a
$T_2 = P_2O_5$ (552g)	71.75c	8.625ab	215.25a	24.70^a	36.89a	34.23abc	2.3 cd	17.25a	2.45a	74.17a
$T_3 = P_2O_5$ (828g)	91.22b	10.35ab	212.25ab	26.76a	38.88a	36.46c	2.6b	18.26a	2.79a	63.95a
$T_4 = K_2O$ (600g)	104.5a	16.1a	203.75ab	23.48^a	35.44ab	35.60ab	1.75d	19.75a	2.87a	66.16a
$T_5 = K_2O$ (900g)	100.00ab	13.835ab	209.25a	27.48^a	36.91a	30.85bc	2.02bc	17.27a	2.46a	66.49a
LSD ($P \le 0.05$)	9.7883	1.1721	NS	NS	3.9023	NS	0.2246	NS	NS	NS

Means with different lettering represent significant difference at $P \le 0.05$

NS Means with similar lettering showed non-significant results at $P \le 0.05$

this range was considered optimum for plant growth (Sauls 2008). Ashraf et al. (2010) have reported that the increase of K nutrient in the 'Kinnow' leaves will increase with soil amendment of K-based fertilizer.

Fruit Yield and Quality Analysis

Physical Parameters

Fruit yield (weight and number) per plant was significantly improved in plants subjected to K_2O (600 g per plant) and found to be the optimum dose yielding maximum fruit number (104) and fruit weight (16.1 kg) per tree, respectively, compared to control (Table 1). The previous studies confirmed that fruit yield in terms of fruit number and weight increased with the proper nutrient application, especially K and P supplementation (Srivastava and Singh 2006; Ashraf et al. 2010). In addition, soil pH also plays a significant role in the overall yield of citrus orchards as earlier studied by Ghagare et al. (2017) for 'Nagpur' mandarin in which soil pH of 7.12–7.74 was reported, which was considered as optimum for micronutrient uptake except zinc. Average peel weight (g) and peel:pulp ratio displayed non-significant ($P \le 0.05$) results in treated as well as non-treated plants (control). However, maximum peel weight percentage (27.48%) and peel:pulp ratio (66.49) was observed in T_5 (K_2O- 900 g). Apart from yield, a significant increase in average fruit weight (215.25 g) was observed in plants subjected to T_2 (P_2O_5- 552 g) followed by T_3 (P_2O_5- 828 g), T_4 (K_2O- 600 g) and T_5 (K_2O- 900 g) in contrast with control (166.25 g). The results for average juice weight were found non-significant; however, K- and P-treated plants showed higher juice volume as compared to the control (Table 1). Results of the non-significant juice weight percentage were contrary to the findings of Ashraf et al. (2013) who reported that fertilizer containing macronutrients increased juice volume. Rag weight percentage was also least significantly affected by the application of P and K nutrients, maximum average rag (38.88%) was recorded in fruits harvested from trees treated with higher P_2O_5 (828 g), while lower rag percentage (32.47%) was exhibited by non-treated trees. Furthermore, the number of seeds and seed weight of fruits were also not affected by nutrient application (Table 1).

Peel quality is a critical factor representing the cosmetic quality of 'Kinnow' mandarin fruit and affecting consumers' choice in the market and exporters' willingness at farmgate (Khalid et al. 2012b; Malik et al. 2021; Hasan et al. 2021). Rind quality, especially thickness, is significantly affected by the use of various fertilizers. Our present study exhibited significant results regarding peel thickness of 'Kinnow' fruit. There was a reduction observed in peel thickness of fruits in plants subjected to K_2O. The minimum peel thickness (1.75 mm and 2.02 mm) of 'Kinnow' fruit was recorded in plants treated with K_2O (600g) followed by (900g), and the maximum was viewed in control (3.72 mm) (Table 1). The results of present study confirmed the findings of Embleton and Jones (1966) who reported a positive effect of potassium on the rind quality of lemons. Khalid (2012) also reported in its nutritional trial that K_2O application at the rate of 250g/plant in young 'Kinnow' mandarin was not found effective to reduce peel thickness contrary to our findings that a K_2O- 600g application significantly reduced its thickness.

Biochemical Quality

Fruit quality attributes, especially internal biochemical compounds, are highly dependent on the nutrients applied and harvesting time (Khan et al. 2015; Iqbal et al. 2012).

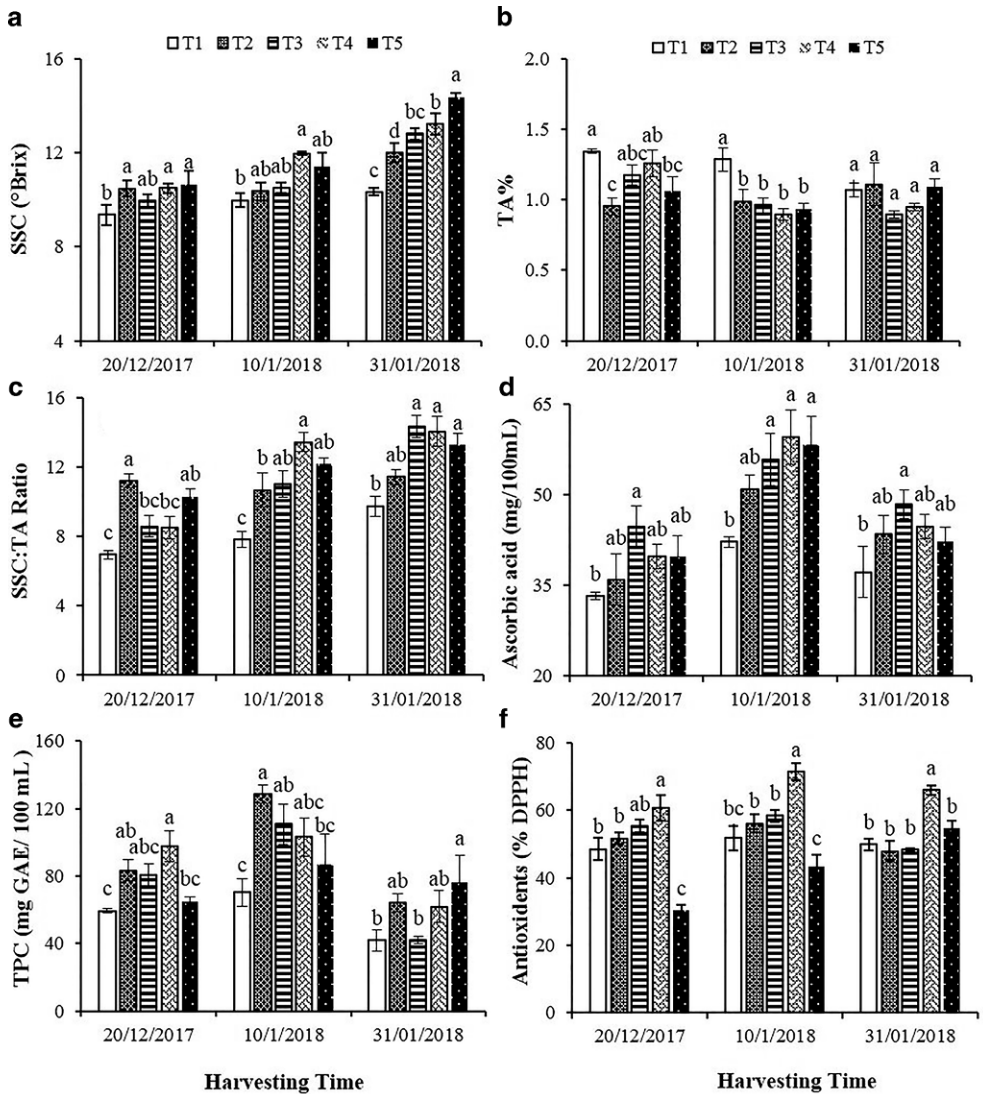

Fig. 2 Effect of fertilizer application (diammonium phosphate and sulfate of potash fertilizers as source nutrients of phosphorus and potassium) on biochemical attributes, i.e., **a** soluble solids content (*SSC*), **b** total acidity (*TA*) %, **c** SSC:TA ratio, **d** ascorbic acid and phytochemicals **e** total phenolic contents, **f** antioxidants in 'Kinnow' mandarin fruit at three harvest stages. *Vertical bars* represent ± standard error of the means. *Treatments* = five; *T1* = control, *T2* = P_2O_5 (552 g), *T3* = P_2O_5 (828 g), *T4* = K_2O (600 g), and *T5* = K_2O (900 g). *n* = four replicates

SSC is mainly depicted as a group of solids (sugars, vitamins, acids, and proteins, etc. with sugars as a major component) available in fruits (Akram 2017). Results of SSC during the first harvest showed the least increase in treated plants as compared to control but were statistically not significant ($P \leq 0.05$). The highest value of SSC (10.65 °Brix) was recorded in K_2O (600g) and the minimum in control (9.35 °Brix). During the second harvest, SSC was observed higher in all respects than in the first harvest with a maximum in T_4 (11.97 °Brix) followed by T_5 (11.4 °Brix) as compared to a minimum (9.97 °Brix) in control. At the third harvest, the trend of SSC was significantly different as compared with previous harvesting times and highly significant results were observed with a maximum value of SSC recorded in T_5 (14.37 °Brix) followed by T_4 (13.22 °Brix) and T_3 (12.8 °Brix), but there was a non-significant difference between the means of T_4 and T_3. Trees subjected to potash nutrients (T_4, T_5) showed a significantly increased level of SSC followed by trees subjected to P nutrient treatments (T_3 and T_2) as compared to control at all harvesting times (Fig. 2a). Results of the present study regarding K and P effect on SSC of 'Kinnow' mandarin fruits are in line with findings of Ashraf et al. (2010); Hamza et al. (2015) and Embleton et al. (1978), respectively. A gradual increase in SSC was observed as the harvesting of citrus fruit was delayed (Thakre et al. 2015). Likewise, the soil application of fertilizers containing nutrients (P and K) significantly minimizes the TA percentage in all treated plants compared with T_1 (control) at the initial two harvesting times. While maximum TA percentage was recorded (first harvest) in control (1.34%) and minimum (0.89%) was in T_4 (second harvest) (Fig. 2b). The decrease in acidity was reported by Kazi et al. (2012) in sweet oranges subjected to compound fertilizer (NPK) and multi-micronutrients. K was also reported for the decrease in acidity of fruit (Ramesh and Kumar 2007). Results of TA percentage at

Table 2 Pearson correlation analysis of the relationship between leaf nutrient (phosphorus [P], potassium [K]) and fruit quality attributes of 'Kinnow' mandarin at second time of harvest in trees subjected to P (P_2O_5) and K (K_2O) based fertilizers

	Total antioxidants	K	P	Total phenolics	TA	TSS	TSS:TA ratio	Taste
K	0.0400	–	–	–	–	–	–	–
P	0.0934	–0.7267	–	–	–	–	–	–
Total phenolics	0.4036	–0.2223	0.6402	–	–	–	–	–
TA	–0.3337	–0.6055	–0.0210	–0.6247	–	–	–	–
TSS	0.3969	0.9189	–0.6051	0.0592	–0.7455	–	–	–
TSS:TA ratio	0.4379	0.7797	–0.2688	0.4137	–0.9435	0.9211	–	–
Taste	–0.0045	0.4293	–0.0740	0.6320	–0.7928	0.5276	0.7080	–
Ascorbic acid	0.3005	0.7781	0.4470	0.3833	–0.9572	0.8529	0.9653	0.6576

P phosphorus (%), *K* potassium (%), *TSS* total soluble solids (°Brix), *TA* total acidity (%), *TSS:TA ratio* ripening index

the third harvest of 'Kinnow' were statistically non-significant ($P \leq 0.05$). Results showed that harvesting time also affect the TA% of fruit and confirm the findings of Thakre et al. (2015) studies on 'Kinnow' mandarin, who stated that TA% decreased with the passage of time.

SSC:TA ratio, also known as sugar acid ratio, was found significantly increased in treated plants with P and K fertilizers at three harvesting times as compared with control. The maximum SSC:TA ratio (14.34) was noted in fruits treated with a higher dose of P_2O_5 (828 g)/plant at the time of third harvest (Fig. 2c). Results of SSC:TA ratio in 'Kinnow' mandarin contradicted the findings of Goldweber and Boss (1956) who studied the effect of N, P, and K containing fertilizers on 'Persian' lime and showed non-significant findings for sugar acid ratio of fruit. Application of P and K significantly improved the level of ascorbic acid contents in fruit. Fruits from K treated plants had from 1.38- to 1.41-fold higher ascorbic acid contents followed by P treated plants (1.20 to 1.32-folds) compared with control at the time of second harvest (Fig. 2d). Ascorbic acid content started declining as harvesting time delayed while the contents were maintained in treated ones. From the results, it is inferred that soil amendment of SOP fertilizers can significantly improve the ascorbic acid content of 'Kinnow' juice. Our results are also in line with the findings of Ashraf et al. (2010) and Ashraf et al. (2013) who reported that foliar application of K can improve vitamin C (ascorbic acid) in citrus fruits at commercial maturity. Pearson correlation analysis outlined that K nutrient was positively correlated with SSC, SSC:TA ratio, and ascorbic acid contents and negatively correlated with the acidity of 'Kinnow' mandarin fruit (Table 2).

Phytochemicals

TPC is an integral part of phytochemicals available in fruits with a tremendous effect on consumers' health by preventing chronic diseases (Khan et al. 2022). Application of fertilizers containing P and K macro nutrients significantly ($P \leq 0.05$) increased TPC in fruits of treated plants as compared to control. During the first harvest, trees treated with K_2O (600 g/plant) showed high value of total phenolics (97.72 mg GAE/100 mL) followed by 83.30 mg GAE/100 mL in trees subjected to P (552 g/plant), while minimum values were obtained in the control treatment (59. 47 mg GAE/100 mL). Analysis at the second harvest showed maximum TPC (128.65 mg GAE/100 mL) in T_2 (P_2O_5 552 g) in 'Kinnow' juice while minimum (51.74 mg GAE/100 mL) was recorded in control (Fig. 1e). Pearson correlation analysis revealed that total phenolics were positively improved with an increased dose of P nutrient (Table 2). The present study represented significant results regarding the radicle scavenging activity of 'Kinnow' fruit. At the second harvest, maximum (71.47%) antioxidant activity was determined in fruits where trees were supplied with K_2O (600g) followed by P_2O_5 nutrients, respectively. Moreover, antioxidant activity increased 1.4-fold in K-treated plants than in control (Fig. 2f). Olivos (2012) reported that antioxidant activity in citrus fruits increased as plants treated with a lower amount fertilizer (NPK). However, the combined foliar application of potassium chloride, calcium chloride, and salicylic acid to 'Washington navel' orange trees showed higher preservation of TPC in fruit after 90 days of postharvest storage (Ramezanian et al. 2018). Similarly, the 'Kinnow' trees subjected to the combined application of MLE (moringa leaf extract), potassium, and zinc nutrients significantly increased levels of ascorbic acid, TPC, and antioxidant activities in fruit at commercial harvest (Nasir et al. 2016). With the passage of time, a substantial decrease in phytochemicals (TPC and antioxidant activity) was observed during the present study.

Sensory Evaluation

At first harvest, taste score was found non-significantly different in treated and non-treated fruits and showed that there was no impact of fertilizer on sensory characters, which could be due to more acidity at initial harvest with mini-

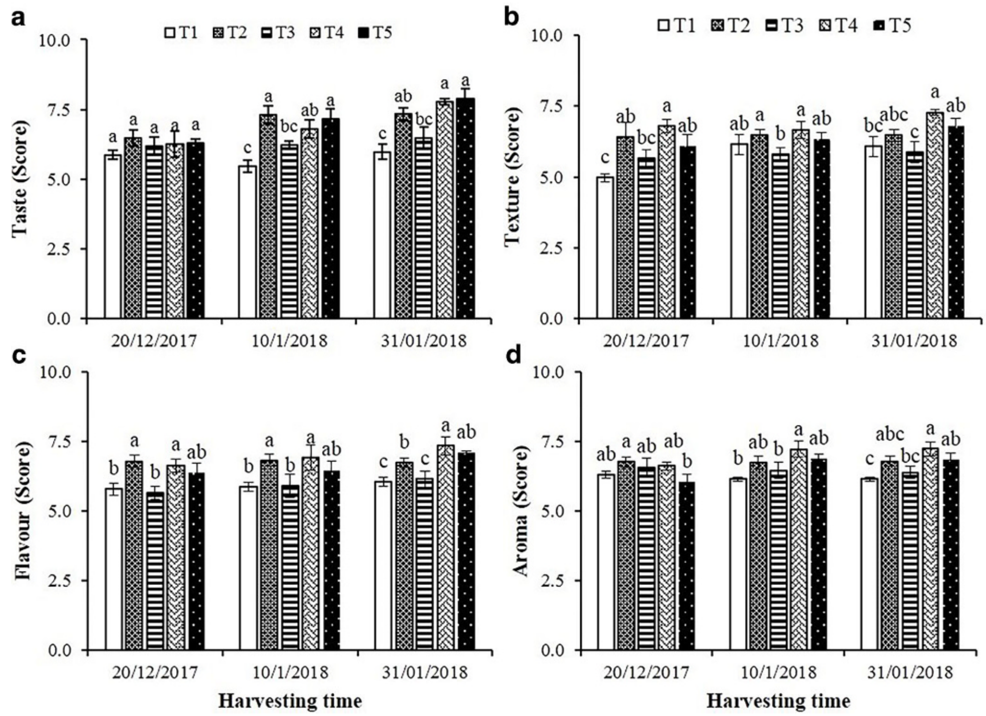

Fig. 3 Effect of fertilizer application (diammonium phosphate and sulfate of potash fertilizers as source nutrients of phosphorus and potassium) on sensory properties including: **a** taste, **b** texture, **c** flavor, and **d** aroma of 'Kinnow' mandarin fruit at three harvest stages. *Vertical bars* represent ± standard error of the means. *Treatments* = five; *T1* = control, *T2* = P_2O_5 (552 g), *T3* = P_2O_5 (828 g), *T4* = K_2O (600 g), and *T5* = K_2O (900 g). *n* = four replicates

mum acceptability to the consumer as reported for 'Valencia' oranges (Bai et al. 2013). Results of the second harvest of 'Kinnow' fruit showed a significant difference in the taste of the fruit, a maximum score (7.3) was recorded for P-treated plants (T_2) followed by K treatment T_5 (7.17) as compared to control (5.47) (Fig. 3a). In the last harvest, there was an increase in sensory properties score observed as correlated with SSC:TA ratio which gradually increased with time. The results of the present study were supported by the findings of Bai et al. (2013). At the third harvest, the taste score of fruit was higher in plants treated with extra doses of K (K_2O), T_5 showed a maximum taste score (7.9) followed by T_4 (7.77) in contrast with the control (5.97). Potash nutrient seems to be a fruit quality (internal and external) improver, proper application of potash can improve the taste and flavor of 'Kinnow' mandarin fruit. P at optimum application also contributes to taste, flavor, aroma as well as a texture shown in our study (Fig. 3a–d).

Conclusions

In conclusion, the optimum application of macronutrients such as P and K in the form of SOP and DAP fertilizers to young 'Kinnow' mandarin trees significantly improved the physical, biochemical as well as phytochemical quality attributes of 'Kinnow' mandarin fruit. Eating quality in terms of sensory attributes such as taste, texture, flavor, and aroma improved in fruit harvested from treated trees. In addition, K_2O (600 g followed by 900 g per plant) reduced rind thickness and effectively increased fruit yield and quality of 'Kinnow' mandarin fruit.

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Author Contribution M.U. Hasan contributed in methodology, formal analysis, data curation, and writing–original draft, writing–review and editing. A.U. Malik, B.A. Saleem, R. Anwar contributed in conceptualization, methodology, visualization, review and editing, funding acquisition, project administration, resources and supervision. S. Khalid, A.S. Khan, and M. Nasir contributed in review and editing, and improved the manuscript.

Conflict of interest M.U. Hasan, A.U. Malik, B.A. Saleem, R. Anwar, S. Khalid, A.S. Khan and M. Nasir declare that they have no competing interests.

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