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Potassium Fertilization Improves Growth, Yield, and Quality of Kinnow Mandarin under North Western Zone of India

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SS and JS conceptualized the study and wrote the methodology. Author SS conducted the investigation. Authors SS, JS and NDS were involved in data curation and contributed to the writing and preparation of the original draft of the manuscript. They also participated in reviewing and editing the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Potassium is known for enhancing crop productivity, due to its active involvement in maintaining cation-anion balance, osmoregulation, photosynthesis, cytoplasmic pH regulation, proteins and starch synthesis, enzyme activation in plant system. Despite the recognized importance of potassium in citrus production, region-specific dose optimization for Kinnow mandarin in Punjab's semi-arid soils remains largely unexplored, remained the main reason for poor fruit quality and yield

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due to adoption of sub-optimal levels of potassium application in kinnow. The present study was conducted to optimize potassium fertilizer dose in Kinnow mandarin for better fruit quality and production in Semi-arid zone of Punjab, India. The experiment was conducted during the year 2022 to 2024 using randomized block design with three replications, consisted of seven treatments of K_2O fertilizer (0.0, 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 kg/plant) applied in the month of December-January besides the recommended doses of fertilizers. The pooled data of 3 years revealed that fruit weight, size, juice content, soluble solids content, carotenoids and sugars content were improved substantially with K fertilizer than the control. Fruit weight, length and diameter increased by 13.4, 21.6 and 24.1%, respectively in the plants applied with 0.6 kg K_2O plant^{-1} over the control, whereas higher dose of K_2O application enhanced granulation that resulted in lower recovery of juice content. The plants applied with lower K levels produced fruits of smaller size, thin peel and poor consumers' acceptability. Correlation studies indicated that fruit size, weight and peel thickness were directly related with leaf and soil K content. These findings provide the region-specific recommendation for optimal potassium fertilization in Kinnow mandarin, supporting improved fruit yield, quality, and farmer profitability in Punjab's semi-arid region.

Keywords: Kinnow; soil K; fruit quality; leaf K content.

1. INTRODUCTION

Kinnow (*Citrus nobilis* Loureiro × *Citrus deliciosa* Tenora) is growing in arid to semi-arid zones of Punjab, Rajasthan, Haryana, Uttar Pradesh, lower hills of Himachal Pradesh and Union Territory of Jammu and Kashmir. The optimum dose of fertilizers in citrus crops are recommended on the basis of long-term experiments, cultivars and site specific, ionic combinations, spacing, intercultural practices etc (Lindsay & Norvell, 1978). It is observed that citrus growers are applying fertilizers impulsively that substantially reduced fruit yield related parameters, quality attributes and peel colour (Singh et al*.,* 2023). Potassium (K) performs a crucial role in enhancing crop productivity, because of its involvement in maintaining cation-anion balance, osmoregulation, photosynthesis, cytoplasmic pH regulation, proteins and starch synthesis, enzyme activation (Wang and Wu, 2013). Studies confirmed that the application of potassium fertilizer in different citrus cultivars substantially enhanced fruit yield (Alva et al*.,* 2006) and peel colour, juice flavour, fruit weight, peel thickness, juice volume and quality (Ashraf et al*.,* 2013).

According to an estimate, one tonne of Kinnow fruits annually removes significantly 2.40 kg of N, 0.27 kg of P_2O_5, and 1.97 kg of K_2O from the soil. It is estimated that about 64.4 kg N, 7.24 kg P_2O_5, and 52.9 kg K_2O contents were removed annually by Kinnow fruits to realize the productivity of 26.83 MT/ha (Dhatt et al. 1992 and Anonymous 2023). Similarly, available K content of higher and lower yielding Kinnow orchards growing in aridisol soils of Punjab ranged from 103.2-121.4 kg/ha with average value of 114.5 kg/ha and 51.0-103.2 kg/ha with average value of 73.52 kg/ha, respectively (Khokhar et al., 2012).

The Kinnow plants shows deficiency of K content has a tendency to produce fruits of smaller size and inferior quality due to prolific bearer that eventually realizes lower market price (Merwin & Peech, 1950). The literature review also highlighted the need for a comprehensive integrated nutrient management strategy to keep orchard at optimum productivity level (Puri, 1949). In Kinnow mandarin, fruit quality and sustainable production related to the application of K_2O fertilizer has not been fully exploited under semi-arid region of Punjab (Olsen et al., 1954). Therefore, the present study has been planned to elucidate the effect of K fertilizers on the fruit yield related properties of Kinnow mandarin.

2. MATERIALS AND METHODS

The experiment was conducted for successive three years at Punjab Agricultural University, Krishi Vigyan Kendra, Bathinda, Punjab (North-western region of India). Uniform and vigorous Kinnow mandarin plants budded on *Citrus jambhiri* rootstock spaced at 6 m × 6 m with a planting density of 110/acre^{-1} were used for the experimentation. The experiment was started on 12-year-old plants during the year 2022 and data for the years 2022 to 2024 has been presented in the study. The site is located in semi-arid regions at (Latitude: 30.1883^0; Longitude: 74.9523^0), and an elevation of 201 m above *msl*. The site receives about 518 mm annual rainfall where more than 70 percent rainfall occurs during the months of July-September. The experiment was laid out using randomized complete block design, where seven treatments with three replicates were employed. Each treatment consisted of five uniformly grown, 12-year-old Kinnow trees, spaced at 6 × 6 m. The different doses of potassium were applied during December i.e. 0.0 (control), 0.20, 0.40, 0.60, 0.80, 1.00 and 1.20 kg plant^{-1} year^{-1} (Muriate of potash; 60% K as K_2O) and treatments titled as T_1, T_2, T_3, T_4, T_5, T_6 and T_7, respectively. The recommended doses of farmyard manure, inorganic fertilizers, and plant protection measures were applied as per recommendations of Punjab Agricultural University, Ludhiana for cultivation of fruit crops (Anonymous, 2018).

The composite soil samples were collected from soil layers at 0-15 cm and 15-30 cm depth with the help of post hole auger. The collected soil samples were analyzed for various physico-chemical properties of soil (Supplementary data). Soil texture (International pipette method), pH (pH meter), Electrical conductivity (conductivity meter), Soil organic carbon (SOC) (%) (Walkley and Black, 1934 wet digestion method) and available soil macro and micro nutrients by the method followed by Singh et al., (2022). About 60 leaves during August were collected from all the directions around the plant. Leaves were washed with running water under the tap followed by with deionized water to remove any contaminant deposited over the leaf surface. The samples were air-dried in the shade, and then dried in the hot air oven. The fruits were washed thoroughly. The peel was collected from randomly selected fruits and dried in the hot air oven from each treatment. The oven dried samples were ground in the stainless-steel bladed grinder to get a fine powder. A known weight of ground peel and leaf samples were digested using di acid (mixture of concentrated sulphuric acid and perchloric acid in the ratio of 4:1) as per the procedure followed by Singh et al., (2022). The K content of the digested leaf and peel samples was analyzed using flame photometer.

The fruits were harvested in the Ist fortnight of January successively during the three experimental years. Fruit length, diameter, and peel thickness were measured using digital vernier's caliper (Mitutoyo, Japan). Soluble solids content (SSC) was determined using a digital hand refractometer (Atago, Japan). After harvesting, average fruit weight of a sample size of twenty fruits was measured with the help of electronic weighing balance. Juice titratable acidity was expressed as citric acid (%) by titrating fruit juice against 0.1 N NaOH. The fruit juice was extracted using hand juicer and expressed in per cent. The juice extracted was analyzed for ascorbic acid, carotenoids, reducing, non-reducing and total sugars (%) (AOAC 2005). The total number of fruits was counted to estimate fruit yield from each tree by multiplication with average fruit weight.

The data generated from the experiment was subjected to analysis of variance (pooled data for three years), where the year was considered as an independent variable. The data was analyzed using PROC ANOVA using SAS 9.1 (SAS Institute, CA), where means were compared using Duncan Multiple Range Test (DMRT) when F-test was found significant. The correlation analysis was performed using PROC CORR using SAS 9.1.

3. RESULTS AND DISCUSSION

The physico-chemical analysis of soil depicts that loamy soil has normal pH and electrical conductivity; and favorable for the cultivation of Kinnow crop. Soil organic carbon (SOC) (%) content was medium, high in available P content and has sufficient Zn, Mn, Fe and Cu content. The soil was adequate in available K content (<157.7 kg/ha). The calcium carbonate content of soil was < 5 % that is considered favourable for the successful cultivation of citrus crop (Supplementary data).

The pooled data for the three years presented in Table 1 show that the application of K fertilizer along with recommended doses of FPM, N and P fertilizers significantly improved size and quality of Kinnow fruits. Fruit weight, length and diameter were increased by 13.4, 21.6 and 24.1%, respectively in the plants applied with 0.6 kg K_2O plant^{-1} over the control. However, fruit size and weight showed the decreasing trend at higher K fertilizer doses compared to the plants applied with K_2O @ 0.6 kg plant^{-1} (T_4). Minimum fruit weight of 142.7g and size (5.27 × 6.25cm) was observed in the control (T_7). Average fruit weight was ranged from 142.7g to 161.9g, being maximum in T_4 and minimum in T_1; whereas, T_4 and T_5 were statistically at par with each but significantly higher than the rest of treatments including the control (T_1). Fruit weight and diameter was increased in the plants treated with K_2O at 0.2 to 0.6 kg; thereafter, it values showed a decreasing trend for both the parameters from T_5 to T_7 treatments but had significantly higher values than the control. Being an essential macro nutrient, K^+ ion is involved for enzymes activation, protein synthesis, ion homoeostasis, regulates opening and closing of stomata and stability between mono and divalent cations, provides resistance against abiotic and biotic stresses (Liu et al., 2000), translocation and accumulation of photosynthates from source to sink (Braun et al., 2014). The results are supported with the findings of Quaggio et al*.,* (2006) who reported that K fertilizers improved fruit size, quality and yield parameters. Increment in fruit weight and size of Kinnow fruits may be attributed to the enhancement of photosynthesis and translocation of photosynthates. Ashraf et al*.,* (2013) also observed significantly increased fruit size, weight, yield and peel thickness in the citrus plants treated with potassium fertilizers growing under soils with low K content.

Peel thickness significantly increased with higher doses of K fertilizers (Table 1) and values were ranged from 0.31 cm in T_2 to 0.49 cm T_7, wherein, treatments: T_1, T_2, and T_3 were statistically at par with each other but values were significantly the lowest than the rest of treatments. In general, peel thickness was increased by 3.2% to 34.7% with the application of potash fertilizers in comparison to the control. The results are in confirmation with the findings of Ashraf et al., (2010) who observed that K fertilizers considerably increased peel thickness and is also considered good indicator to protect fruit pulp and juice from drying during storage.

The increment in dose of K fertilizers significantly enhanced fruit juice per cent up to 0.8 Kg K_2O with the values of 42.7, 44.3, 47.6 and 45.1 % in T_2, T_3, T_4 and T_5, respectively as compared to the control (40.2%). At higher doses of K_2O fertilizer (1.0 and 1.2 kg plant^{-1}) with the values of 39.7 and 38.9 %, respectively for juice content was reduced significantly over the untreated plants. Higher availability of K content effectually improved juice content up to the doses of 0.2 to 0.6 K_2O plant^{-1}. However, doses of 1.0 to 1.2 kg K_2O plant^{-1} significantly enhanced granulation which resulting in lower recovery of juice content. Lester et al*.,* (2010) also reported improvement in fruit quality with application of potassium. The application of potassium was found effective in enhancing juice content, as confirmed by Yener et al*.* (2021) and Kumar et al. (2022) who also observed substantial juice volume increases with supply of optimal dose of potassium, even under soils with rich supply of potassium.

Number of fruits was substantially the higher in the plants applied with 0.6 kg K_2O plant^{-1} which was statistically at par with treatment of 0.8 kg K_2O plant^{-1} and followed a significant quadratic trend line with different rates of K fertilizer (Fig. 1). Higher fruit yield of 89.2 kg plant^{-1} was registered in the plants applied with K_2O (0.6 kg) than untreated control plants. The plants supplied with 0.6 kg K_2O (T_4) substantially improved fruit yield by 17.28 % compared to the control (T_2); however, treatments T_4 and T_5 were not statistically significant with each other. Fruit yield exhibited a polynomial relationship with different rates of K; wherein, the highest fruit yield was registered in T_4 (Fig. 1). Fruit yield was reduced drastically to 83.1 and 79.9 kg plant^{-1} at higher doses of K_2O 1.0 and 1.2 kg fertilizer, respectively compared to plants applied with 0.6 K_2O kg/plant but had significantly higher values than the control. The higher yield under T_4 treatment is due to the cumulative effect of higher fruit weight, size and juice content. Srivastava and Patil (2016) also described that, optimum leaf K content of 1.10 to 1.41 % should be maintained to obtain higher fruit yield for Kinnow mandarin growing under Illitic soils of Indo-gangetic plains. In the present studies, fruit yield ranged from 86.3 to 89.1 kg plant^{-1} where leaf K content of 12.05 to 14.88 mg/g was attained in the plants applied with 0.60 to 0.80 K_2O plant^{-1}. The results are in conformity with the results reported by Kumar et al. (2022), where application of potassium had improved fruit yield under soils rich in available potassium.

The plants depict deficiency symptoms of K nutrient significantly reduced photosynthetic efficiency and translocation of photosynthates. A decline in fruit yield/plant at higher K doses may be due to the effect on the absorption of water, Ca and Mg content which results in limiting the ability of the plants in the conversion of light energy to chemical energy. Ashraf et al*.* (2013) also observed that fruit yield-related parameters were improved with K fertilizer as the results of more fruit retention as evident from the number of harvested fruits/plant (Fig. 2). It is also clear from the present study that lower K content in Kinnow plants and fruits is responsible for lower fruits production with poor quality attributes. Arora et al. (2022) also found that the application of K nutrient in 'Amrapali' mango improved fruit yield in Punjab, India.

Table 1. Effect of K on fruit growth and yield attributes in Kinnow mandarin (pooled mean of three years)

K fertilizer (Kg plant[-1])	Fruit Weight (g)	Fruit length (cm)	Fruit diameter (cm)	Peel thickness (cm)	Juice content (%)
Control	142.7e	5.27c	6.25e	0.32c	40.2c
0.2	149.9d	5.52bc	6.35e	0.31c	42.7bc
0.4	155.6bc	5.72bc	6.81d	0.35c	44.3b
0.6	161.9a	6.72a	8.23a	0.42b	47.6a
0.8	159.2ab	6.24ab	7.55b	0.42b	45.1ab
1.0	156.1bc	6.02ab	7.24c	0.45b	39.7d
1.2	151.8dc	6.07ab	7.09c	0.49a	38.6d
P>F	<0.01	<0.01	<0.01	<0.01	<0.01
C V (%)	1.77	6.66	1.59	5.46	3.45

The different letters (a, b, c, d) in each column of experimental factors show significant differences at probability level (p>F)

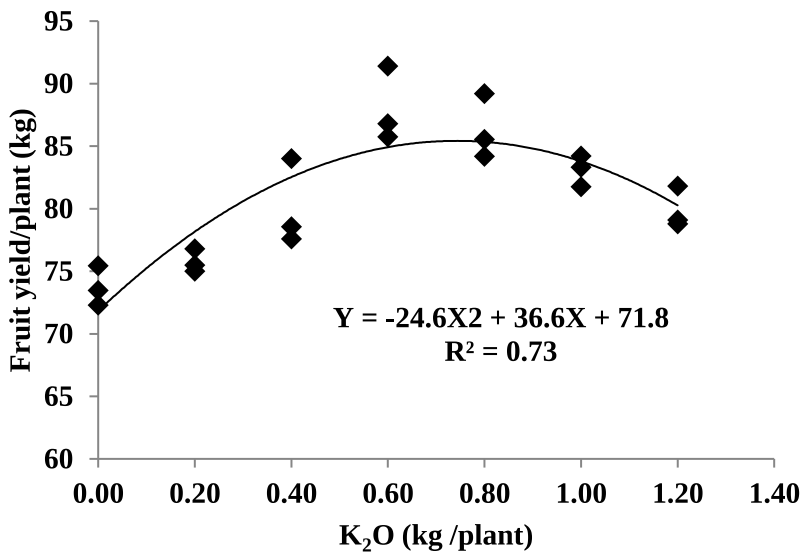

Fig. 1. Effect of K application on fruit yield of Kinnow mandarin

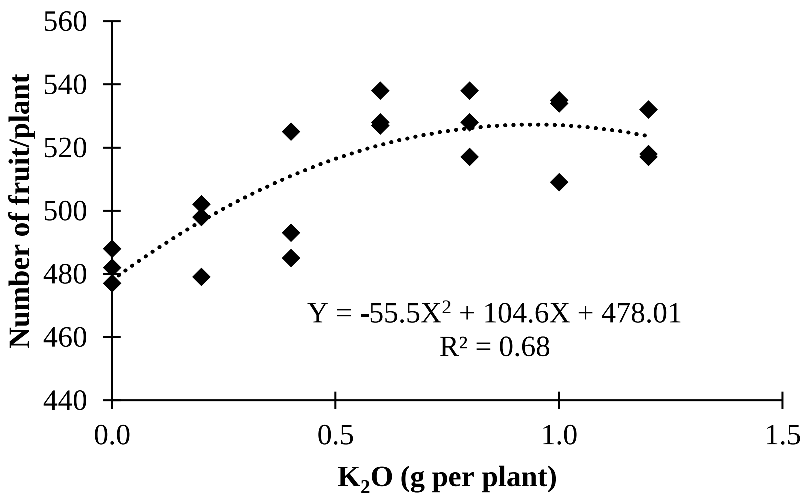

Fig. 2. Effect of K application on fruit production of Kinnow mandarin

Application of K fertilizer in different doses effectively enhanced juice SSC (Table 2) being the highest (11.3 %) in T_4 treatment followed by T_5 (0.8 kg K_2O plant^{-1}). In general, juice SSC content was improved by 13.0% over the plants not applied with K_2O fertilizers. Ashraf et al. (2010) also confirmed that juice SSC was improved with the soil application of K fertilizer. Juice titratable acid content was significantly higher in the plants applied with K_2O fertilizer doses and it ranged from 0.71 % (0.2 kg K_2O plant^{-1}) to 0.80 % (1.2 kg K_2O plant^{-1}) in comparison to 0.67 % in the control. The maturity indices of Kinnow fruit were determined on the basis of SSC/acid and it was noted that the ratio was ranged from 14.14 in the plants treated with K_2O at 0.2 kg/plant to 15.25 in 0.6 kg/plant; however, at higher doses of 1.0 and 1.2 kg/plant, these treatments showed significantly lower values in comparison to the control and the rest of the treatments. Gill et al. (2005) also reported a close relationship between K content and fruit acidity and SSC/acid in the plants treated with K fertilizer than the control. Likewise, juice carotene content was improved by 11.0 to 54.7 % with the application of different doses of potash fertilizers. It was ranged from 1.48 mg/100 g to 2.12 mg/100g being the highest in the plants applied with K_2O at 0.6 kg plant^{-1} in comparison to other treatments including the control with a value of 1.37 mg/100g. The higher juice carotene content may have resulted from the carotenogenesis reaction that is facilitated by the potassium supply in the plant system (Luxmi et al*.,* 2024).

In citrus fruits, sugars are an important parameter of quality measurement and are the main source of energy. The highest reducing and non-reducing sugars (3.78 % and 5.22 %, respectively) was registered in the fruits harvested from the plants treated with 0.6 kg K_2O plant^{-1}. Minimum reducing sugar of 2.80 % was found in the control trees which were statistically at par with 0.2 kg K_2O plant^{-1} and 0.4 kg K_2O plant^{-1} (2.90 % and 3.15 %, respectively) treatments. A minimum non-reducing sugar was observed in the control trees (3.82 %) and the trees treated with 0.2-0.4 kg K_2O plant^{-1} and the values ranged from 4.02 % to 4.21%. It is reported that potassium nutrient activates enzymes responsible for the conversion of polysaccharides into reducing and non sugars which in turn improves SSC of fruits. The perusal of data on leaf and peel K content revealed a linear relationship with K fertilizers. Significantly higher leaf and peel K content to the tune of 17.33 and 7.87 %, respectively was registered in the plants treated with 1.2 kg K_2O plant^{-1} treatment than the control (Table 2). The improvement in K ions uptake in leaf and peel may be due to the involvement of K in metabolic pathways and water relations of the plants (Ashraf et al. 2013). In general, the plants with lower and higher optimum leaf K level in the present study produced fruits of smaller size, lower juice (%), SSC, SSC/acid and sugars content. Hence, optimum leaf K content of 1.2 to 1.5% is be maintained with the application of K fertilizers in orchards showing deficiency of potassium nutrient for the sustainable kinnow production of better fruit quality parameters. The potassium nutrition of citrus enhances the sugar production, also observed in Table 2, whereas, Smeekens et al*.* (2010) reported that that higher sugars regulates and promote carotenoid synthesis and metabolism, leading to colour development and better quality of fruits.

The data on the Pearson's correlation coefficient between fruit yield and quality (Table 3) reveal that fruit weight showed significant positive correlations with fruit length (0.61), fruit diameter (0.82), SSC (0.78), titratable acid (0.60), peel thickness (0.52), juice per cent (0.57), reducing sugars (0.60) and non-reducing sugars (0.81). Leaf K content has a significant positive correlation with SSC (0.58), ascorbic acid (0.53), reducing sugars (0.65) and non-reducing sugars (0.65), which implies that as the leaf K content is directly proportionate to fruit weight, SSC, ascorbic acid and sugars content. The carotene content was positively correlated with the SSC (0.84) reducing sugars (0.60) and non-reducing sugars (0.69). Fruit yield is also directly correlated with fruit size, weight and quality parameters. The results are supported with the findings of Gill et al. (2005) that plants sprayed with K as foliar application significantly improvement in fruit size and weight, fruit yield and biochemical characters of Kinnow mandarin under sub mountane zone of Punjab.

The increment of fruit growth, yield, and quality traits of Kinnow fruit with the application of potash fertilizers at 0.6-0.8 kg K_2O plant^{-1} was observed. Correlations studies between physico-chemical characteristics signify that fruit size, weight, yield and peel thickness are directly related with leaf and soil K content which in turn affect the marketing of fresh fruits and consumers' preference.

Table 2. Effect of K on chemical properties of Kinnow mandarin (pooled mean data of three years)

K_2O (Kg plant^{-1})	SSC (%)	Titratable acidity (%)	SSC: acid ratio	Carotene (mg/100g)	Reducing sugars (%)	Non-Reducing sugars (%)	Leaf K content (mg/g)	Peel K content (mg/g)
Control	10.0c	0.67e	14.89ab	1.37c	2.80c	3.82d	5.26f	6.39d
0.2	10.0c	0.71d	14.14bc	1.52bc	2.90bc	4.02d	6.78e	6.66cd
0.4	10.5b	0.72cd	14.61abc	1.48c	3.15abc	4.21cd	8.61d	6.97bc
0.6	11.3a	0.74bcd	15.25a	2.12a	3.78a	5.22a	12.05c	7.10b
0.8	10.9ab	0.75bc	14.53abc	1.74b	3.62a	4.78b	14.88b	7.55a
1.0	10.7b	0.78ab	13.79cd	1.54bc	3.55a	4.68b	16.57a	7.69a
1.2	10.6b	0.80a	13.26d	1.59bc	3.49ab	4.58bc	17.33a	7.87a
P>F	<0.01	<0.01	<0.01	<0.01	<0.05	<0.01	<0.01	<0.01
C V (%)	2.43	2.81	3.24	7.98	9.74	4.95	5.97	2.84

The different letters (a, b, c, d) in each column of experimental factors show significant differences at probability level (p>F)

Table 3. Pearson correlation coefficient matrix

	FW	FL	FD	SSC	TA	SSC:TA	PT	JP	ASC	CRTN	RDS	NRS	LKC	PKC	Yield	NFPP
FW	1															
FL	0.61**	1														
FD	0.82**	0.83**	1													
SSC	0.78**	0.66**	0.87**	1												
TA	0.40	0.49*	0.48*	0.52*	1											
SSC:TA	0.20	0.02	0.21	0.28	-0.67**	1										
PT	0.51*	0.46*	0.62**	0.58**	0.79**	-0.38	1									
JP	0.56**	0.44*	0.54*	0.50*	-0.21	0.65**	-0.18	1								
ASC	0.91**	0.70**	0.82**	0.77**	0.51*	0.07	0.46*	0.60**	1							
CRTN	0.66**	0.65**	0.83**	0.84**	0.31	0.37	0.36	0.58**	0.66**	1						
RS	0.66**	0.58**	0.74**	0.84**	0.63**	0.02	0.65**	0.29	0.64**	0.60**	1					
NRS	0.81**	0.74**	0.90**	0.82**	0.57**	0.06	0.68**	0.48*	0.76**	0.69**	0.76**	1				
LKC	0.51*	0.57**	0.62**	0.58**	0.90**	-0.50*	0.92**	-0.17	0.53*	0.35	0.65**	0.65**	1			
PKC	0.50*	0.44*	0.53*	0.51*	0.81**	-0.46*	0.88**	-0.21	0.51*	0.29	0.59**	0.52*	0.93**	1		
Yield	0.89**	0.63**	0.88**	0.79**	0.45*	0.17	0.60**	0.53*	0.83**	0.66**	0.69**	0.82**	0.58**	0.56**	1	
NFPP	0.68**	0.61**	0.77**	0.67**	0.70**	-0.21	0.73**	0.20	0.69**	0.54*	0.66**	0.70**	0.76**	0.70**	0.87**	1

**Significant correlation at P < 0.05. **Significant correlation at P < 0.0*

Fruit weight (FW), Fruit length (FL), Fruit diameter (FD), Soluble solids content (SSC), Titratable acidity (TA), Soluble solids content/acid ratio (SSC: TA), Peel thickness (PT), Juice content (JP), Ascorbic acid (ASC), Carotene content (CRTN), Reducing sugars (RS), Non-reducing sugars (NRS), Leaf K content (LKC), Peel K content (PKC), Yield (Yield/plant), Number of fruits/plant (NFPP)

Hence, it is suggested that the application of potash fertilizer in January along with recommended doses of FYM and P_2O_5 fertilizers substantially enhances the fruit production, quality and net income of the growers under K deficient sandy loam soils of north India.

4. CONCLUSION

The selection of optimal potassium fertilizer dose resulted in clear improvements in both the yield and quality of Kinnow mandarin grown in Punjab's semi-arid regions. The plants applied with 0.6 to 0.8 kg K_2O each season led to noticeable boosts in fruit weight, size, juice content, and total harvest, with increases reaching 17%. These plants also produced fruits richer in sugars and soluble solids. However, giving more than 0.8 kg K_2O per plant did not bring further benefits and sometimes even diminished fruit quality, therefore 0.6 kg K_2O may be recommended for improved fruit yield and quality of kinnow in the region. The results directly support refined potassium recommendations for sustainable and profitable citrus production in this region.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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SUPPLEMENTRY DATA

Table 1. Physico-chemical properties of experimental site

Soil properties	0-15 cm	15-30 cm	30-60 cm
Soil texture	Sandy loam	Sandy loam	Sandy loam
pH	8.33	8.52	8.84
EC (dS/m)	0.45	0.40	0.35
OC (%)	0.35	0.31	0.28
Available P (mg kg^{-1})	7.91	7.89	7.69
Available K (mg kg-1)	78.9	75.4	71.5
$CaCO_3$ (%)	1.10	2.25	2.30
Av. Zn (ppm)	0.42	0.32	0.30
Av Mn (ppm)	103.4	107.8	108.4
Av Fe (ppm)	1.61	0.91	0.88
Av Cu (ppm)	1.15	0.80	0.71

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