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OPTIMIZATION OF NEW GENERATION POTASSIUM (NG-K) FERTILIZER FOR IMPROVEMENT IN QUANTITY AND QUALITY OF CITRUS (*CITRUS LIMON*)

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SUMMARY

Potassium (K) performs multiple essential functions in the plant, including enzyme activation and osmotic regulation. Citrus fruit quality gains considerable influence from potassium (K) fertilizer rate, application method, and sources used. The conducted field experiment assessed the impact and response of different levels of K applications on the quality and yield parameters of citrus fruit, determining a suitable time, stage, and K fertilizer dose for citrus trees. Comparing traditional K fertilizer, i.e., sulfate of potash (SOP), with new-generation potassium (NG-K) employed the use of foliar and soil (basal) applications. Treatments included (i) T1: Control (0 NPK), (ii) T2: Recommended NP and without K, (iii) T3: 500 g K as sulfate of potash (SOP) (basal), (iv) T4: New generation K (NG-K) fertilizer @1.5% (foliar), and (v) T5: 400 g NG-K fertilizer (basal). Observations revealed that citrus trees responded positively in growth characteristics, including fruit quality and physiological attributes, under both foliar and basal K fertilizer applications of different K sources. Notably, NG-K fertilizer proved a better source of K, whether applied as a basal dose or foliar spray. For growth characteristics like the fresh weight of leaves and fruit mass, obtaining the highest values of 35.2 and 172 g, respectively, resulted when applying a basal dose of NG-K. On the other hand, maximum total sugar content (13 mg L^{-1}) and juice content (40%) occurred under foliar-applied NG-K. Foliar application of K fertilizer proved to be more effective for better growth and fruit quality parameters than the basal application of SOP.

Keywords: Citrus, growth characteristics, potassium, fertilizer, formulation

Key findings: K fertilizer application improved the citrus fruits' quality and quantity attributes irrespective of source, dose, and application method. However, among K fertilizer sources, new-generation K fertilizers proved superior over commercial K sources (SOP). Regarding the application method, the foliar application gave better results and effectively improved the quality and growth attributes of the citrus fruits.

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INTRODUCTION

Citrus (*Citrus limon*) is the most-grown fruit tree in approximately 150 countries around the globe. Among the fruit trees of *the Rosacea* family, citrus is highly valuable due to its health benefits, unique taste, and production rate. Worldwide, China, the USA, and Brazil are the significant shareholders of citrus production, with 16%, 14%, and 11%, respectively, which make up two-thirds of the world's total citrus production (Nawaz *et al*., 2018). Citrus fruits are of great economic importance, as they contribute nearly an annual 7 to 8 billion USD globally. Pakistan is growing citrus on an area of 206 to 269 hectares, producing 2.36 million tons and ranking 12th in citrus production on a global scale. The demand for citrus has significantly increased in the past two decades due to its high use in fruit juice manufacturing and baking industries on a large scale. Out of the total production of citrus fruits, 70% is mandarin—a rich source of vitamin C (Alva *et al*., 2006; Liu *et al*., 2012; Liu *et al*., 2014; Siddique and Garnevska, 2017).

Nutrient deficiency is widespread in Pakistan due to intensive cropping patterns and poor soil management. Calcareous soils report a low value of K in the leaf. Under K deficiency, the rate of photosynthesis drops sharply, reducing carbohydrate synthesis and causing a slower fruiting process. In addition, an increase in fruit creasing, splitting, plugging, and ultimately fruit drop may transpire. Moreover, K deficiency resulted in reduced fruit yield and quality. Researchers related that a leaf K concentration of 0.5%–0.8% caused reduced fruit size and yield. Inversely, high-quality fruit and fruit yield displayed with a leaf K value of 1.2% or greater. In case of fruit plants do not respond to soil K fertilizer application, a substitute method is foliar K spray using potassium nitrate (KNO_3) or mono-potassium phosphate and (KH_2PO_4) (Zekri and Obreza, 2003; Fatonah *et al*., 2018).

The essential macronutrients (NPK) are crucial for citrus' excellent quality and yield. Among primary macronutrients, insufficient use of K in the country is responsible for stunted growth and late maturity. Pakistani citrus fruits and their products have a high demand in the international market. Still, only 8% of the total citrus production gets exported due to poor quality resulting from improper nutrient management. Increasing citrus exports immensely, especially mandarin, can result in a focus on fertilizer application and management practices (Yaseen and Ahmad, 2010).

Potassium at 60 kg K_2O ha^{-1} applied as SOP has provided to improve fruit weight, size, fruit $plant^{-1}$, and yield of different fruit plants. Potassium fertilizer application improves citrus fruit quality characteristics (Ahmad *et al*., 2014; Quaggio *et al*., 2006). Moreover, the application of K at this rate gave the slightest disease incidence compared with other K levels. Consequently, a correct K dose is vital for the maximum output of fruit crops (Ahmad *et al*., 2014). K is one of the chief nutrients for citrus' proper growth and production as it increases fruit size, vigor, and taste. The increasing prices of K fertilizer, especially in resource-limited countries like Pakistan, make it too expensive for small-scale farmers. Hence, research for a better technique to improve the efficiency of K in plants needs action. One such practice was to use foliar K fertilizer directly on plant leaves.

The problem of K fixation in soil may reduce via the foliar K application method (Farooqi *et al*., 2012; Ali and Samraiz, 2016). There are various benefits of a foliar application, including a cheap application method, better target-oriented, higher use efficiency of fertilizers, right time availability of nutrients for plants, and ultimately better grain yield than conventional fertilizer application method (Nemeata-Alla and Helmy, 2022). Applying fertilizers at the exact time can enhance the citrus yield to a great extent. The average yield of citrus is 9.2 t ha^{-1}, which is very low compared with other countries. Its improvement can fast progress through the proper K fertilizer application (Sarrwy *et al*., 2012). Thus, dose optimization of fertilizers is the best way to overcome poor soil conditions and attain the highest yield. The need to identify an alternate K fertilizer source and optimum dose to improve citrus yield and quality characteristics is urgent. The conducted experiment had the following objectives: (i) to identify the suitable time and stage of K fertilizer application for citrus trees; (ii) to determine the impact and response of different K applications on the yield and quality parameters of citrus, and (iii) to check the relevant K requirement for citrus.

MATERIALS AND METHODS

A field experiment conducted at the research area of Citrus Research Institute, Sargodha, Punjab, Pakistan, in 2020–2021 assessed the impact and response of different levels of K applications on yield and quality-related parameters of citrus fruit, determining a suitable time, stage, and K fertilizer dose for citrus trees.

Growth conditions

Agro-climate of the experimental site was sub-tropical (32.08° N latitude, 72.67° E longitude) of Central Punjab, Pakistan. The physicochemical properties of the soil used in the presented experiment appear in Table 1.

Treatments

Employing a randomized complete block design (RCBD) carried out in the recent research trial with five treatments replicated three times. Treatments included T1-Control (No NPK); T2-Recommended level of N and P (without K: K0); T3- 500 g K as sulfate of potash (SOP) (basal); T4-New Generation (NG) K fertilizer 1.5% (foliar), and T5-400 g NG-K fertilizer (basal).

Fruit harvesting and plant analysis

At the end of January 2021, harvesting fruits from all the treated citrus trees ensued, recording the data related to growth and yield attributes. Analysis of citrus leaf samples was for K concentrations.

Determination of total chlorophyll contents, potassium ion (K^+), and total sugar contents

The total chlorophyll contents determination used the method of Arnon (1949). The leaf sample (1 g) was cut into small pieces with scissors and homogenized using 80% acetone (v/v). The leaf samples were centrifuged for 15 min at 3000 rpm, with the volume up to 25 mL, using acetone (80%). An apparent mixture used for measuring optical density (OD) consisted of 645 nm and 663 nm against a blank in a spectrophotometer (Shimadzu double beam; UV 240). The formulas used for the measurement of total chlorophyll content in citrus leaves were as follows:

$$\text{Total chlorophyll content } (\mu g\ mL^{-1}) = (20.2 \times \text{OD with 645 nm}) + (8.02 \times \text{OD with 663 nm})$$

Sample preparation and potassium ion (K^+)

Oven-dried leaf samples underwent grinding using a grinder machine. Ground samples got stored in polyethylene bags for further analysis. The measurement of mineral nutrients used the fine-ground powdered specimens for the ashing (dry) process (Chapman and Pratt, 1961) to recover mineral contents. Dry ground leaf samples (1 g for each treatment), placed in a porcelain crucible, proceeded ashing in the furnace at 550 °C continuously for 6 h, with the ash wetted afterward with distilled water (five drops).

Table 1. Soil physicochemical properties.

Soil properties	Values of soil analysis		References
	Pre-sowing	Post-harvest	
Sand (%)	53.5		Moodie *et al*. (1959)
Silt (%)	21		
Clay (%)	25.5		
Soil textural class	Sandy clay loam		
Saturation percentage	29.20 ± 1.20	30.73 ± 1.15	Handbook 60 of U.S Salinity Laboratory Staff (1954)
pH	8.12 ± 0.03	8.13 ± 0.05	Handbook 60 of U.S Salinity Laboratory Staff (1954)
ECe (dS m^{-1})	1.28 ± 0.08	1.3 ± 0.05	Jackson (1967)
Soil organic matter (%)	0.65 ± 0.1	0.80 ± 0.12	Walkley and Black (1934)
Total soil N (mg kg^{-1})	412 ± 9.17	420 ± 8.34	Bremner and Tabatabai (1972)
$NaHCO_3$ extractable P (mg kg^{-1})	7.59 ± 0.12	8.70 ± 0.29	Olsen (1954)
Available K (mg kg^{-1})	184.9 ± 9.23	200 ± 10.31	Handbook 60 of U.S Salinity Laboratory Staff (1954)

Adding 10 mL of sulfuric acid solution (0.36 N) dissolved the ash before allowing it to stand for an hour at room temperature. Then, filtering the samples through Whatman No. 1 filter paper, samples got diluted with water to 50 mL, then stored in airtight plastic bottles. The filtrate was ready for mineral nutrient's determination.

Identifying the potassium content from the leaf used a flame photometer employing the protocol given by Richard (1954). For this purpose, the filtrate dilution continued according to the requirement using distilled water. Making working standards of K took place. Running first standards to obtain a standard curve ensued, then diluted filtrates of K were run to determine the values of unknown samples using a flame photometer (Sherwood, 410).

Total sugar contents

Fruit total sugar content estimations advanced according to the method suggested by Hortwitz (1960). Using a volumetric flask (250 mL), 10 mL of juice taken from the samples gained additional reagents (100 mL of water [distilled], 25 mL of 25% lead acetate solution, and 10 mL of 20% potassium oxalate). The solution was mixed with a stirrer, making the final volume up to the mark using water (distilled), with the mixture left standing for 24 h. The next day, filtering the solution with the appropriate filter paper, 10 mL filtrate got heated via boiling water bath (5 min) with Rochelle salt solution (1 mL) added. After cooling the solution, the recording went on for the absorbance at 510 nm. Final values regarding reducing and non-reducing sugar content estimates used the following formulas:

Total non-reducing sugars' content (%) = a25 a × a(X/Z)

Reducing sugars' content (%) = a6.25 a × a(X/Y)

Non-reducing sugars (%) = 0.95 a × a total sugars (%) - a reducing sugars (%)

Statistical analysis

All collected data underwent statistical analysis, with Statistics 8.1 used for the analysis of variance (ANOVA). Comparing treatment means used the least significance difference (LSD) test at the significance level of 0.05 (Steel *et al*., 1997).

RESULTS

Citrus growth attributes

Fresh weight of leaves

The fresh weight of leaves is a key criterion in accessing the growth response of crop plants. Data regarding fresh weight (g plant^{-1}) of leaves resulting from varying K sources at different rates and methods of application reflected a substantial (P < 0.05) positive impact on the fresh weight of leaves under basal and foliar application of K as SOP and NG-K fertilization than the control (Figure 1). The least fresh weight (16.26 g) was with the control treatment, and the highest (35.2 g) was under the T5 treatment. When comparing the basal application of SOP (T3) with foliar NG-K fertilizer (T4), increased fresh weight of leaves resulted in T4 treatment. The new generation K fertilizer basal application proved better leaf fresh weight results (35.2 g) than its foliar application (28.95 g).

Dry weight of leaves

Data regarding leaves' dry weight (DW) (g plant^{-1}) showed a considerable (P < 0.05) effect on leaves DW under basal and foliar applications of varying K sources, including SOP and NG-K fertilization, compared with the control (Figure 2). The lowest DW of leaves was with control (5.2 g), whereas the highest DW came under T5 (11.4 g) treatment. When comparing the basal application of SOP (T3) with foliar NG-K fertilizer (T4), DW increases with T4, showing a better response of foliar K over basal K application. New generation K fertilizer basal application provided better leaves DW (11.4 g) over its foliar application (9.1 g).

Fruit weight of fruit

Plant fruit weight (g plant^{-1}) for each citrus tree under different K treatments appears in Figure 3. The statistical interpretation of data regarding fruit weight indicated that a statistically significant (P < 0.05) difference among basal and foliar applications of varying K sources (SOP and NG-K) occurred. A maximum mean fruit weight value of 172 g emerged under T5 (Basal NG-K at 400 g), whereas a minimum mean score of 150 g fruit weight was under the control treatment. Among two different K sources (SOP and NG-K), NG-K fertilizer as a foliar treatment proved

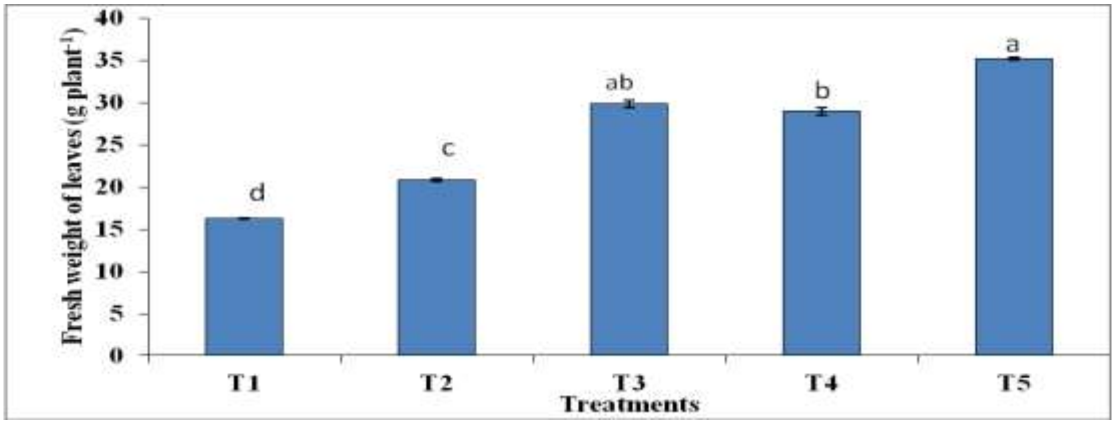

Figure 1. Fresh weight of citrus leaves under foliar and basal applications of K fertilizers (SOP and NG-K)
Where T1 = Control (0 NPK), T2 = Recommended NP and without K, T3 = 500 g K as sulfate of potash (SOP) (Basal), T4 = New generation K (NGK) Fertilizer at 1.5% (Foliar), and T5 = 400 g NGK Fertilizer (Basal)

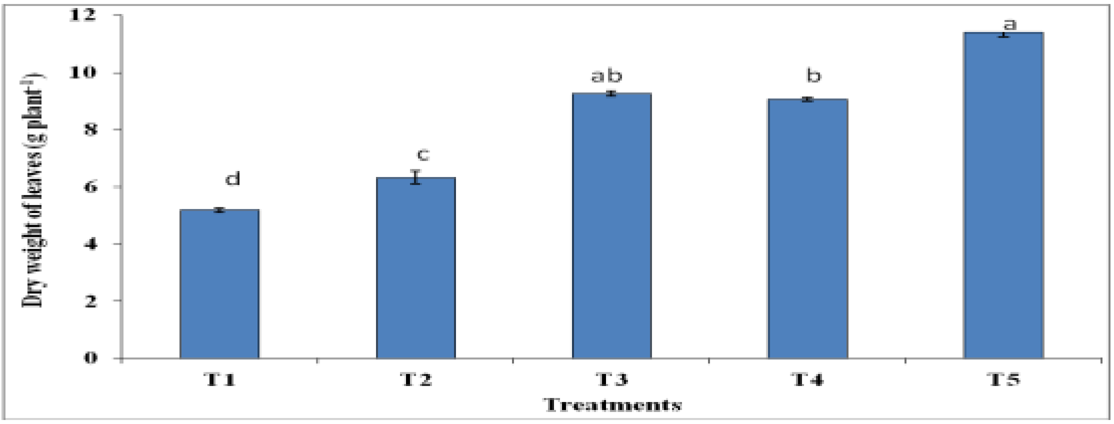

Figure 2. Dry weight of citrus leaves under foliar and basal applications of K fertilizers (SOP and NG-K)
Where T1 = Control (0 NPK), T2 = Recommended NP and without K, T3 = 500 g K as sulfate of potash (SOP) (Basal), T4 = New generation K (NGK) Fertilizer at 1.5% (Foliar), and T5 = 400 g NGK Fertilizer (Basal)

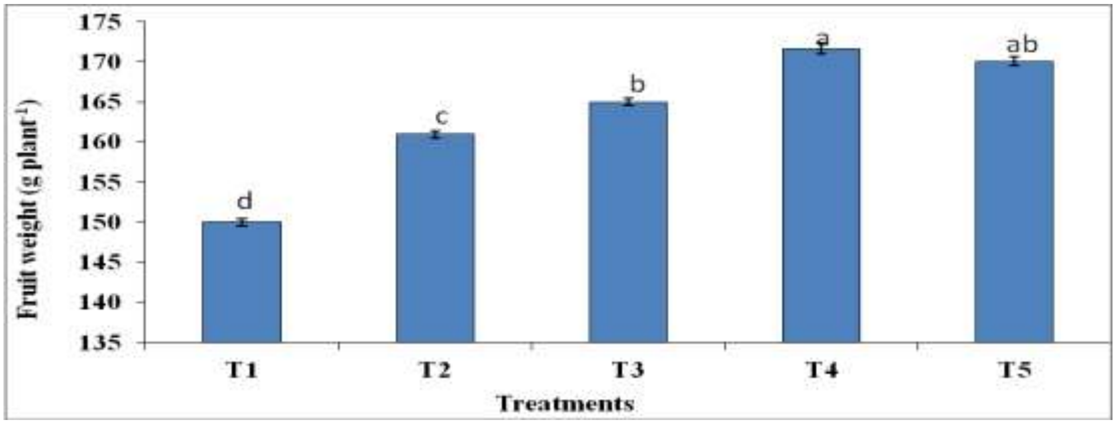

Figure 3. Fruit weight of citrus under foliar and basal applications of K fertilizers (SOP and NG-K)
Where T1 = Control (0 NPK), T2 = Recommended NP and without K, T3 = 500 g K as sulfate of potash (SOP) (Basal), T4 = New generation K (NGK) Fertilizer at 1.5% (Foliar), and T5 = 400 g NGK Fertilizer (Basal)

more effective in terms of the fruit weight of the citrus tree, giving an increase of 46.6% of the fruit weight over SOP application. However, when comparing foliar and basal NG-K fertilizers, 172 g fruit weight surfaced under foliar NG-K (T4) and 170 g fruit weight with basal NG-K chemical fertilizer.

Relative water content

The statistical interpretation of data regarding relative water content (%) indicated that a difference among basal and foliar applications of different K sources (SOP and NG-K) was statistically significant ($P < 0.05$) (Figure 4). A maximum means relative water content value of 82%, observed under T5 (Basal NG-K at 400 g), displayed against a minimum mean value of 68% under the control treatment. Among two different K sources (SOP and NG-K), NG-K fertilizer as a foliar treatment (78%) proved more effective regarding relative water content over SOP application (75%). However, when comparing foliar and basal NG-K fertilizers, 78% relative water content was lesser under foliar NG-K (T4) than 82% under basal NG-K chemical fertilizer.

Citrus fruit quality attributes

Fruit juice

Citrus fruit quality attributes data regarding fruit juice for each citrus tree under different K treatments exist in Figure 5. Data from fruit juice indicated statistically significant differences among basal and foliar applications of SOP and NG-K. A maximum mean fruit juice value of 49% resulted in T4 (foliar NG-K at 400 g), with a minimum mean value of 40% fruit juice recorded with the control treatment. Among SOP and NG-K sources of K, NG-K fertilizer as a foliar treatment proved more effective regarding fruit juice of citrus tree that increased by 6.5% fruit juice compared with SOP source of K. However, when comparing foliar and basal NG-K fertilizer, 49% fruit juice appeared under foliar NG-K (T4) treatment and 47% fruit juice with basal NG-K chemical fertilizer treatment.

Total sugar contents

Data plotted about total sugar content (a primary citrus fruit quality attribute for citrus trees) under different K treatments is in Figure 6. A statistically significant ($P < 0.05$) difference among basal and foliar applications of SOP and NG-K appeared. A maximum mean total sugar content value of 13 mg L^{-1} occurred under T4 (foliar NG-K at 400 g). On the other hand, the minimum mean value of 9 mg L^{-1} total sugar content was with the control treatment. Comparing two different K sources, NG-K fertilizer as a foliar treatment was more effective for the total sugar content of citrus fruit juice and a 30% increase in total sugar content came out in the NG-K source of K compared with SOP source of K. A comparison between foliar and basal NG-K fertilizer treatments showed 13 mg L^{-1} total sugar content for both foliar NG-K (T4) application and basal NG-K chemical fertilizer treatment.

Total chlorophyll content

Data related to total chlorophyll contents (TCC) (μg g^{-1} cm^{-1}) revealed that basal and foliar applications of K fertilizer with different sources (SOP and NG-K) had shown significant ($P < 0.05$) effects on TCC when compared with the control treatment (Figure 7). The highest mean value of TCC was 26 μg g^{-1} cm^{-1} observed in the T4 treatment, followed by T5 and T3 treatments. The observed least value of 15 μg g^{-1} cm^{-1} of TCC was with the control (T1) treatment.

Mineral contents in soil and plant

Potassium content in leaves

Results about K contents (mg kg^{-1}) in leaves depicted that basal and foliar applications of K fertilizer with different sources (SOP and NG-K) had shown a substantial ($P < 0.05$) effect on K contents in leaves when compared with the control treatment (Figure 8). Potassium concentration in leaves' highest mean value of 0.85 mg K kg^{-1} resulted in the foliar application of K (1.5%) using the NG-K chemical fertilizer (T4 treatment). The basal application of K (500 g per plant) as SOP (T3 treatment) followed showed 0.80 mg K kg^{-1} in leaves of citrus trees. The third effective treatment was the basal application of K as NG-K (400 g per plant), with a value of 0.75 mg K kg^{-1} in leaves. The most negligible value of 0.44 mg K kg^{-1} in leaves was in the control treatment. Generally, T4 showed a 93.18% improvement in K contents in leaves compared with control treatments.

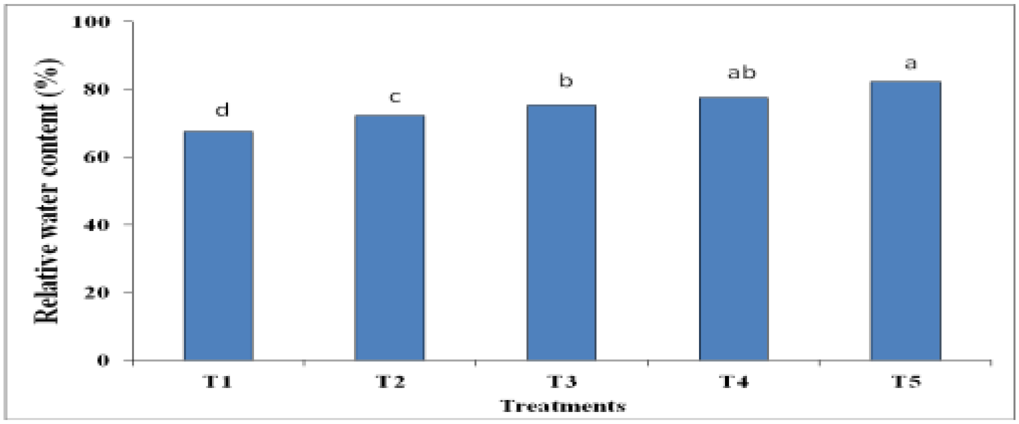

Figure 4. Relative water content in citrus fruit under foliar and basal applications of K fertilizers (SOP and NG-K)
Where T1 = Control (0 NPK), T2 = Recommended NP and without K, T3 = 500 g K as sulfate of potash (SOP) (Basal), T4 = New generation K (NGK) Fertilizer at 1.5% (Foliar), and T5 = 400 g NGK Fertilizer (Basal)

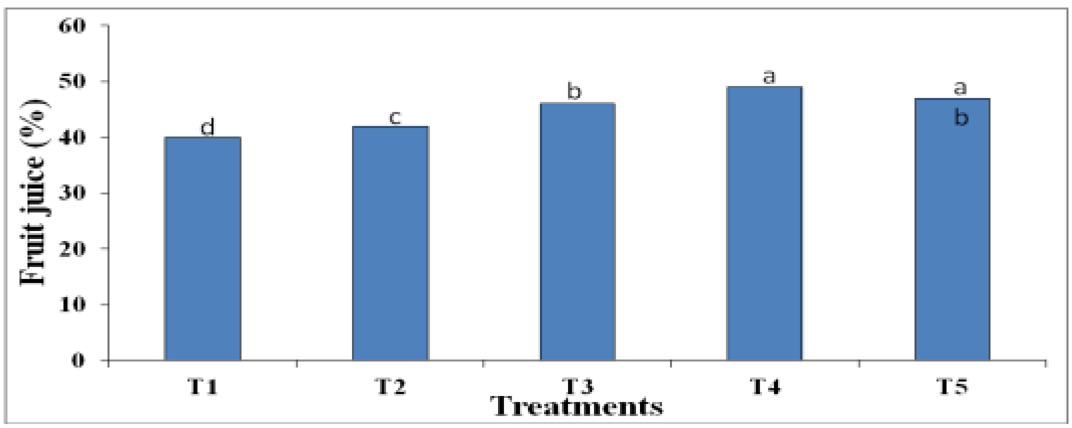

Figure 5. Fruit juice in citrus fruit under foliar and basal applications of K fertilizers (SOP and NG-K)
Where T1 = Control (0 NPK), T2 = Recommended NP and without K, T3 = 500 g K as sulfate of potash (SOP) (Basal), T4 = New generation K (NGK) Fertilizer at 1.5% (Foliar), and T5 = 400 g NGK Fertilizer (Basal)

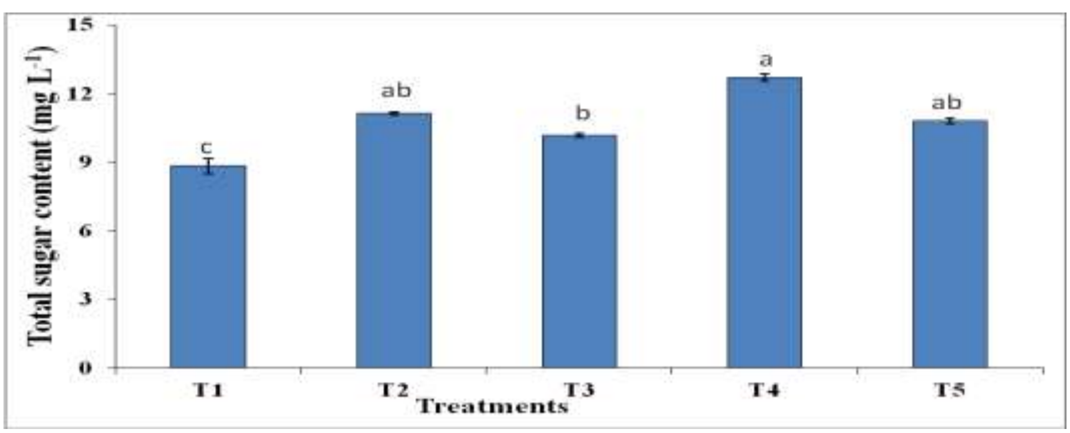

Figure 6. Total sugar content in citrus fruit under foliar and basal applications of K fertilizers (SOP and NG-K)
Where T1 = Control (0 NPK), T2 = Recommended NP and without K, T3 = 500 g K as sulfate of potash (SOP) (Basal), T4 = New generation K (NGK) Fertilizer at 1.5% (Foliar), and T5 = 400 g NGK Fertilizer (Basal)

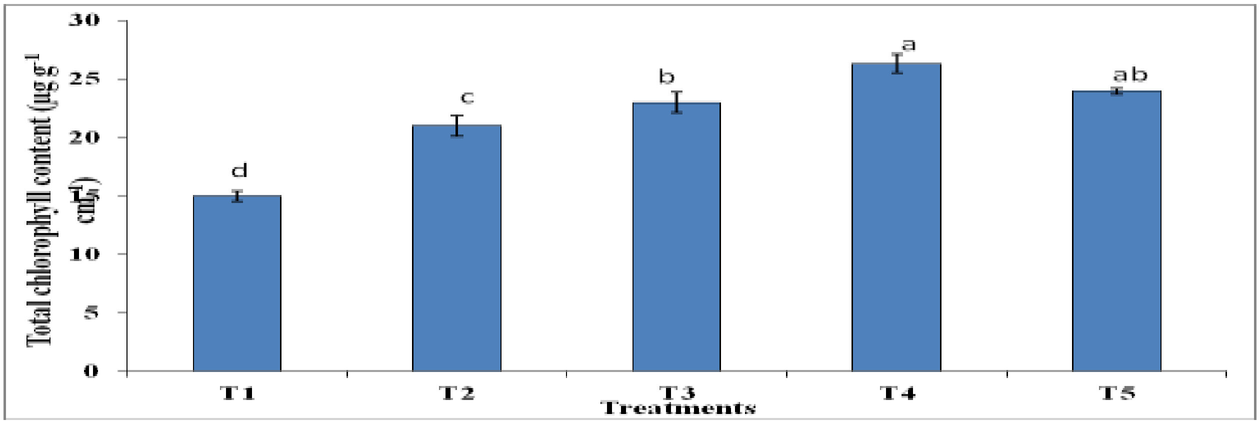

Figure 7. Total chlorophyll content in citrus leaves under foliar and basal applications of K fertilizers (SOP and NG-K)
Where T1 = Control (0 NPK), T2 = Recommended NP and without K, T3 = 500 g K as sulfate of potash (SOP) (Basal), T4 = New generation K (NGK) Fertilizer at 1.5% (Foliar), and T5 = 400 g NGK Fertilizer (Basal)

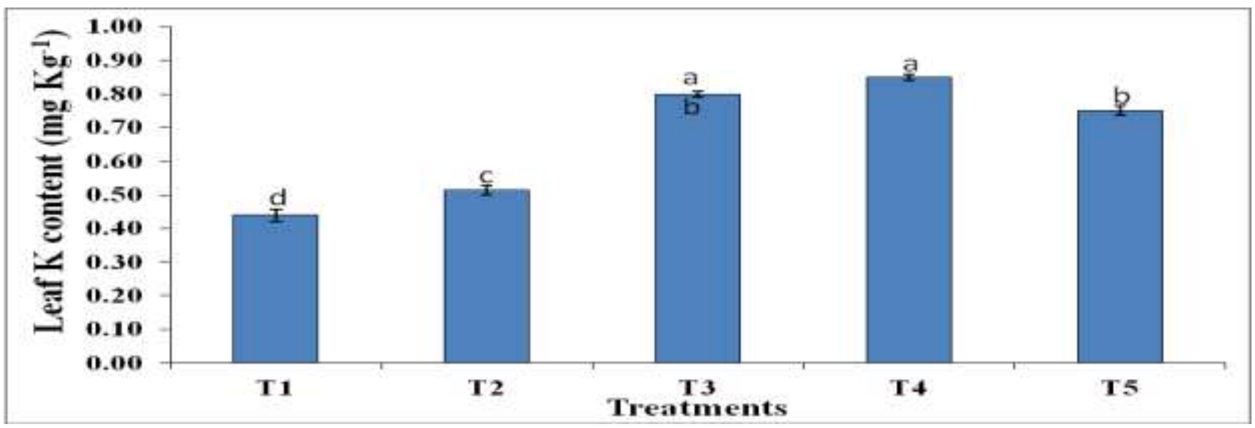

Figure 8. Potassium content of citrus leaves under foliar and basal applications of K fertilizers (SOP and NG-K)
Where T1 = Control (0 NPK), T2 = Recommended NP and without K, T3 = 500 g K as sulfate of potash (SOP) (Basal), T4 = New generation K (NGK) Fertilizer at 1.5% (Foliar), and T5 = 400 g NGK Fertilizer (Basal)

Potassium contents in shoot

Potassium contents (mg kg^{-1}) in shoots revealed that basal and foliar application of K fertilizer applied as SOP and NG-K had shown a substantial ($P < 0.05$) effect on K contents in the shoot when compared with the control treatment (Figure 9). Potassium concentration in the shoot had the highest mean value of 0.86 mg K kg^{-1} resulting from the foliar application of K (1.5%) of the NG-K chemical fertilizer (T4 treatment), with 0.82 mg K kg^{-1} in the shoot of citrus trees following using the basal application of K (400 g per plant) as NG-K (T4 treatment). The next effective treatment was the basal application of K as SOP (500 g per plant), displaying 0.69 mg K kg^{-1} in shoots. The lowest value observed of 0.48 mg K kg^{-1} was in the shoots under the control treatment. Overall, T4 treatments showed a 79.16% increase in shoot K content compared with the control. An increment in K content in leaves with the application of K fertilizer can refer to better availability of K contents in soil for uptake by plant roots.

Potassium contents in soil

Potassium contents (mg kg^{-1} soil) in soil indicated that basal and foliar application of K fertilizer with SOP and NG-K had shown a significant ($P < 0.05$) effect on soil K content when compared with control treatments (Figure 10). Potassium concentrations in soil

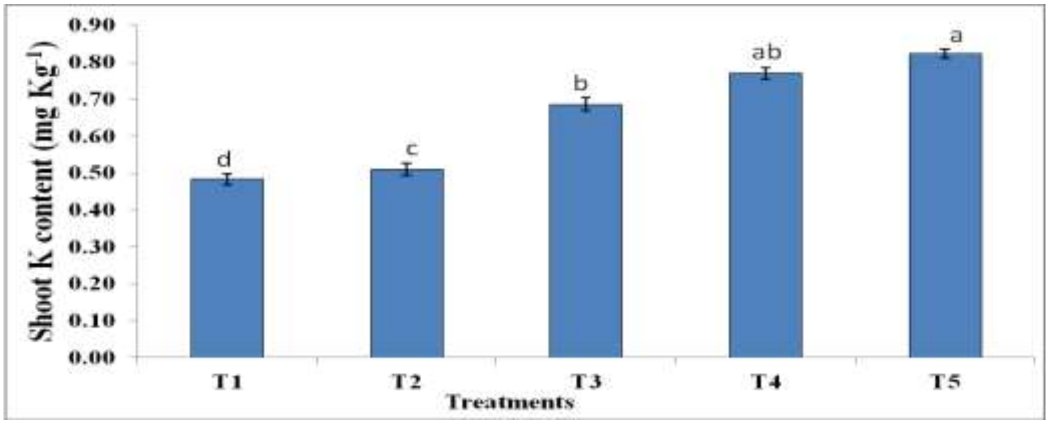

Figure 9. Potassium content in citrus shoot under foliar and basal applications of K fertilizers (SOP and NG-K)
Where T1 = Control (0 NPK), T2 = Recommended NP and without K, T3 = 500 g K as sulfate of potash (SOP) (Basal), T4 = New generation K (NGK) Fertilizer at 1.5% (Foliar), and T5 s= 400 g NGK Fertilizer (Basal)

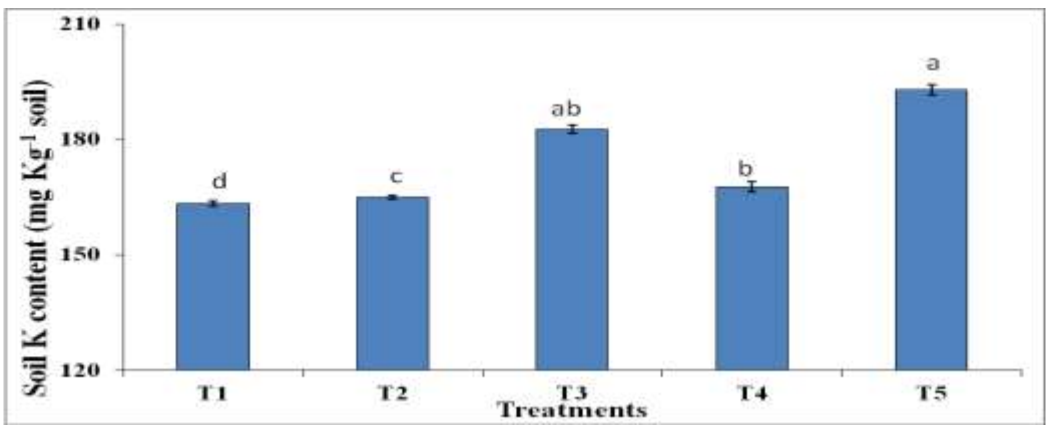

Figure 10. Potassium content in soil under foliar and basal applications of K fertilizers (SOP and NG-K)
Where T1 = Control (0 NPK), T2 = Recommended NP and without K, T3 = 500 g K as sulfate of potash (SOP) (Basal), T4 = New generation K (NGK) Fertilizer at 1.5% (Foliar), and T5 = 400 g NGK Fertilizer (Basal)

showed the highest mean value of 193 mg K kg^{-1} soil with the basal application of K (400 g per plant) using NG-K chemical fertilizer (T5 treatment). The basal application of K (500 g per plant) as SOP (T3 treatment) as second best showed 183 mg K kg^{-1} soil, followed by the foliar application of K (400 g per plant) as NG-K (T4 treatment) giving a value of 168 mg K kg^{-1} soil. The slightest value of 163 mg K kg^{-1} in the soil emerged with the control (T1) treatment. On average, T5 treatments showed an 18.40% increase in soil K content compared with the control treatment. Notably, foliar application of K (T4 treatment) had non-significant results compared with the control treatment regarding soil k content.

DISCUSSION

Potassium is an essential macro-element for higher crop plants that fundamentally supports biochemical and physiological functions, such as respiration, photosynthesis, oligosaccharide movement and production, signal transduction, and plant cell homeostasis (Lin *et al*., 2004). More than 60 enzymes in plants get activated and controlled by K, which are associated with the production of organic compounds (sugar and proteins) (Oosterhuis *et al.,* 2014). It helps to regulate the transport of CO_2 to plants by stimulating the opening and closing of guard cells. It also increases plant water and sugar use efficiency (Iqbal *et al.,* 2018). For the growth and yield of fruit crops, high rates of K fertilizer (2%–5% of DW) were mandatory (Marschner, 1995). Thus, it is essential to ensure optimum available K supply via the soil or foliar K applications for crops. In addition, K is one of the key macro-nutrients applied to citrus plants that determine the fruit's size and quality (Siddique *et al.,* 2020).

In plants, K^+ ion first uptake via roots apex cells occurred and then moved to leaves via xylem tubes and finally to the fruit body. High and low-affinity K^+ uptake mechanisms are present in plants, including channels or active pumps and carriers on the cell and vacuolar membrane (tonoplast) to transport K from one part of the plant to another (Santa-María *et al*., 1997). Within the vacuole, a specific protein transports K across the tonoplast (Maathuis, 2009). With K starvation conditioned, the vacuole released it, thus maintaining a K^+ homeostasis in the cytosol and sustaining membrane potential, enzymes' activity, and turgor pressure (Nieves-Cordones *et al*., 2014). It supports the cell's turgor pressure vital for the enlargement of the cell. Potassium also maintains osmoregulation and stomata opening and closing (Ali and Samraiz, 2016). In soil, the weathering process (physical and chemical) was responsible for adding minerals, including Ca, Mg, and S, as well as, SO_4^{2-}, and PO_4^{3-}. Consequently, such secondary mineral ions might influence the bioavailability of K^+ in plants. The problem of K fixation in soil may reduce via the foliar K application method, as suggested in the presented study because nutrients applied via foliar application could be more effective (10 to 20 times more) than soil fertilizer practice (Ram and Bose*,* 2000).

Quaggio *et al*. (2002) demonstrated that K source increased the growth parameters of plants, i.e., leaf fresh and dry weight. Study findings were similar to those accessed by Wen *et al*. (2021), who reported that triggered K application improved the leaf fresh weight and area in citrus. This study proved that foliar K application for fruit weight was more effective than their basal application to soil, regardless of different K sources. The presented results agree with earlier findings of Ramful *et al*. (2010) and Quaggio *et al*. (2011) on sweet oranges, who reported that foliar K treatment substantially improved fruit mass. Obtained results proved that basal K application was more effective for relative water content than their foliar application, regardless of different K sources. Recent findings aligned with previous reports on sweet orange fruits (Quaggio *et al*., 2006; Quaggio *et al*., 2011). This study proved that foliar K application for fruit juice was more successful than their basal application to soil, regardless of the different K sources applied. These results about improvement in fruit juice content by foliar NG-K treatment are in line with results reported by Quaggio *et al.* (2006), Ali *et al.* (2011), and Ashraf *et al.* (2015).

The rate and source of extraneously applied K increased total soluble solids and reducing sugars in tomato fruit (Alva *et al.,* 2008). Citrus fruit grown on K-deficient soils showed low total soluble solids and reducing sugars (Lin *et al.,* 2006). The content of reduced sugar in citrus fruit depicted the fruit quality. Wu *et al.* (2021) and Jiao *et al.* (2022) documented an increase in reduced sugar content with increasing potassium concentration. The supplied K affected the reducing-sugar level in fruit. Hence, fruit-reducing sugars manipulation by the K supply can occur. Higher K levels increase fruit weight, size, firmness, or soluble sugar levels in citrus (Lin *et al.,* 2006). Soti *et al*. (2015) and Ashraf *et al*. (2010) also reported that K application increased the total chlorophyll content in leaves.

An increase in K content in leaves with the application of K fertilizer was evident, as these fertilizers provide more available K content in soil for the uptake of K via plant roots. Results are in line with findings reported in earlier studies (Srivastava and Singh, 2006; El-Salhy *et al*., 2010; Desai *et al.,* 2014; Soti *et al.,* 2015; and Salem and Ali*,* 2020), who also confirmed that K fertilizer application improved K contents in different plant parts, particularly in the shoot. Enhanced K content in leaves with K fertilizer application was due to more K uptake by plant roots that can denote more K availability in the medium. Study findings agree with results reported in earlier studies (Ashraf *et al*., 2010; Soti *et al*., 2015; Salem and Ali, 2020) and proved that K fertilizer application improved soil K contents.

CONCLUSIONS

With potassium as a known quality element due to its prominent role in every aspect of the plant growth cycle, the citrus trees displayed significant responses concerning growth characteristics, fruit quality, and related physiological attributes under foliar or basal K fertilizer application with different K sources. New-generation potassium fertilizer proved superior over the conventional source of K (SOP) irrespective of the dose applied. However, the foliar application of K fertilizer proved to be more effective for better growth and fruit quality parameters than the basal application.

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