Effect of P-K fertilizer rate and fruit canopy position on fruit quality and vitamins of Mangifera indica cv. 'Kent'

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Abstract

Mango production in Kenya is hindered by poor fruit quality and imbalanced fertilizer application, hence the need to investigate the long-term effects of different fertilizer regimes on nutrient cycling, and overall mango orchard sustainability. This study aimed to determine the effects of phosphorus (P) and potassium (K) fertilizers, as well as fruit canopy position, on the nutritional content and morphological characteristics of 'Kent' mango fruits. Seven treatments, P1kg, K1kg, P2kg, K2kg, PK1kg, PK2kg, and control, were repeated five times, resulting in 35 test trees of the "Kent" cultivar, aged 7-8 years. The results indicated that increasing P application significantly boosted β-carotene levels ($p \leq 0.05$), while ascorbic acid levels were reduced. However, both β-carotene and α-tocopherol levels were higher in control trees compared to fertilized trees, regardless of the fertilizer type or rate. A weak negative correlation between ascorbic acid and α-tocopherol was observed ($r=-0.48$, $P \leq 0.05$), suggesting a potential trade-off between these two antioxidants. Additionally, fruit weight was strongly correlated with skin weight, stone thickness, and seed thickness. Fruits from within the canopy generally exhibited higher levels of antioxidants than those exposed to direct sunlight. The study provides valuable insights into the influence of P and K fertilizers and canopy position on mango fruit quality. However, further research is needed to optimize fertilizer management practices for sustainable mango production in Kenya

Keywords: Ascorbic Acid; B-Carotene; A-Tocopherol; Mango Fruit Quality; Nutritional Content; Pulp

Introduction

Mango is a widely cultivated fruit crop in Kenya, and it is the third-largest horticultural crop and ranks second only to bananas in terms of monetary value (HCD 2020). Since 2010, Kenya has produced an average of 650,000 metric tons of mangoes annually, with a gross output value of USD 84.4 million (HCD, 2020; Onyango et al., 2023). Mango is mainly grown in Kenya's eastern, central, western, and coastal areas. Smallholder farmers account for 80% of total production, with the remainder split between medium- and large-scale producers (Onyango et al. 2023).

Mango fruit can improve food security and generate income in Kenya if production can be increased through efficient fertilizers (Griesbach 2003). However, imbalanced fertilizers have contributed to low fruit yield, low retention, and poor fruit quality (Sarker et al. 2013). Previous studies have suggested that the application of phosphorus (P) and potassium (K) fertilizers may result in a remarkable improvement in fruit quality, in terms of an increased number of fruits per tree, as well as improved vitamin content (Satapathy and Banik 2002). Furthermore, combinations of P and K have emerged as cations with the most potent effects on fruit quality, an attribute that determines marketability and consumer preference for mangoes (Lester et al. 2010).

Adopting rational nutrient management, high-yielding cultivars, and proper P and K fertilizers often improve mango fruit quality (Griesbach 2003). Early ripening and the formation of seeds and fruits require mineral phosphorus (P) (Garhwal et al. 2014). When absorbed, phosphorus affects mango tree fruiting rates, harvest, yield, and fruit size (Xiuchong et al. 2001). Additionally, reduced peel thickness due to P application has been reported by Obreza et al. (2008). Potassium (K) fertilizer application, on the other hand, is known to improve total sugars and fruit colouration (Sardans and Peñuelas 2015). In addition, increased fruit size/thickness due to K fertilization has been reported (Dou et al. 2005). A challenge is that most farmers in poor African countries often do not apply P and K fertilizers because of their high costs (Sardans and Peñuelas 2015). In addition to economic discrepancies in Africa, P and K are critical limiting factors for high-quality fruit production (Sardans and Peñuelas 2015).

Fertilizer rates and tree canopies can influence the vitamin content of mango fruit (Ndimba et al., 2020; Almeida et al., 2019). For example, Ndimba et al. (2020) reported that excessive fertilizer application reduced the ascorbic acid content in mango fruit. In contrast, fruits from the upper tree canopy had higher beta-carotene content than those from the lower tree canopy (Almeida et al., 2019); variations in vitamin contents among fruits within tree canopies have been reported (Olale et al. 2017, 2019).

Applying fertilizers in mango cultivation is common; however, its impact on the fruit's β-carotene, ascorbic acid, and α-tocopherol content is not fully understood. Furthermore, there is insufficient scientific evidence regarding the influence of different P and K application rates on mango nutritional contents such as ascorbic acid, β-carotene, and tocopherol. Similarly, our literature search revealed limited reports regarding the influence of different P and K application rates on morphological characteristics.

In this study, we examined the effect of different rates of phosphorous and potassium fertilizers on ascorbic acid, β-carotene, α-tocopherol, and morphological characteristics, i.e., fruit weight (g), fruit length (cm), pulp weight (g), flesh weight (g), skin thickness (mm), skin weight (g), stone length (mm), stone thickness (mm), seed weight (g), seed length (cm), seed thickness (mm), the proportion of fruit pulp (%), skin proportion of fruit (%), the stone proportion of fruit (%) and seed/stone proportions (%). In addition, we examined the effect of fruit canopy position on vitamins and morphological characteristics due to different fertilizer rates.

Materials and Methods

Study Area and Soil Analysis

A field experiment was conducted in 2019 at the KALRO-Kandara orchard located in Kiambu County, Kenya (Figure 1). The orchard primarily consisted of 'Kent' mango cultivars. Kiambu County is classified as an upper midland (UM) agroecological zone with moderate agricultural potential (Jaetzold et al. 2007). Soil samples were collected from the vicinity of each experimental tree at a depth of 0-45 cm (n = 70). The samples were air-dried, ground to a fine powder, and passed through a 2-mm sieve. Subsequently, soil samples were analyzed at JKUAT, Kenya, using standard wet chemistry techniques to determine the concentrations of extractable P, K, Ca, Na, Mg, Mn, Fe, Cu, and Zn. A Thermo iCAP 6000 series Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) was employed for the analysis. The detailed soil analysis results are presented in Table S1.

Figure 1

Experimental Setup and Sampling

The experiment involved 35 'Kent' mango trees, aged 7-8 years, planted at a spacing of 10 m × 10 m. Seven treatments were applied: a control (no fertilizer), and various combinations of triple superphosphate and potassium sulfate at different application rates. Fertilizer application was carried out at the beginning of the flowering stage. For each treatment, 20 fruits were harvested, with 10 fruits collected from the outer canopy (sun-exposed) and 10 from the inner canopy (shaded).

The harvested fruits were subjected to various measurements, including weight, length, pulp weight, flesh weight, skin thickness, stone dimensions, seed weight, and proportions of pulp, skin, and stone. To determine pulp and juice weight, fruits were washed, weighed, sliced horizontally, and the pulp and juice were extracted and filtered. The experiment used Kent mango cultivars planted with a spacing of 10 m × 10 m. The experiment had 35 test trees; each 7-8 years old. The treatments consisted of different amounts of triple superphosphate and potassium sulphate. These amounts were 1 kg, 2 kg, and 0.5 kg of each fertilizer, used individually or in combination.

The control treatment was free from the use of any fertilizer. The experiment consisted of five replicates for each treatment, with the treatments performed at the beginning of the flowering stage. **Fruit sampling**: Twenty fruits were collected from each tree, with ten being exposed to the sun and the other ten located within the tree crown.

Fruit Morphological Measurements

In the laboratory, the fruits were subjected to washing, weighing, and measuring their length and width. Subsequently, they were sliced horizontally, and further examinations of the pulp color were conducted. The pulp and juice were removed and filtered through a 20-mesh sieve while gently swirling until no more liquid drained.

Measurements were taken for 20 fruits including fruit weight (g), fruit length (cm), pulp weight (g), flesh weight (g), skin thickness (mm), skin weight (g), stone length (mm), stone thickness (mm), seed weight (g), seed length (cm), seed thickness, proportion of fruit pulp (%), skin proportion of fruit (%), stone proportion of fruit (%), and seed/stone proportions (%).

Fruit Pulp Treatments

The fruits were peeled at a uniformly distributed position in the equatorial area and sliced into little pieces using a sterile knife. The pulp of these fruits was blended and subjected to freeze-drying while considering the tree canopy position from where the fruit was sampled (outer/inner canopy).

L-Ascorbic Acid

The analysis of ascorbic acid was done using a modified method, as reported by Hernández et al. (2006) and Olale et al. (2017). Approximately 1 gram (with an accuracy of ±0.0001 grams) of freeze-dried mango pulp was added to 10 milliliters of a 0.8% solution of meta-phosphoric acid and then crushed using a mortar and pestle. The samples were passed through Millipore filters (13 mm, 0.45 µm) and then subjected to centrifugation at 10,000 rpm for 10 minutes.

The supernatants were stored at low temperatures and then introduced into the High-Performance Liquid Chromatography (HPLC) system using a single C18 column. The elution process involved using a constant solvent composition of 70:20:10. The flow rate was set at 0.8 mL per minute, and a volume of 10.0 µl was injected. Calibration curves were created for L-ascorbic acid using four known concentrations. The correlation coefficient (R^2) for the curve was 0.9642, and the equation of the line was $y = 313531x-12164$

β-carotene

The β-carotene extraction was done using the methodology described by Rodriguez-Amaya and Kimura (2004). The HPLC analysis was performed using a monomeric C18 column (3 µm, 4.6 × 150 mm) with a mobile phase consisting of isopropanol, acetonitrile, and methanol.

The elution was carried out isocratically at a ratio of 70:20:10. The flow rate was set at 0.8 mL/min, and the injection volume was 5.0 µl. The calibration curves for the β-carotene standard were created by using four known concentrations. The correlation coefficient (R^2) for the curve was 0.9997, and the equation of the line was $y = 15.596x-21.168$.

α-Tocopherol

The method outlined by Chun et al. (2006) was applied with revisions. In brief, freeze-dried mango samples weighing 0.5 g (with an accuracy of ±0.0001g) were placed in a 50mL beaker. Subsequently, 10mL of hexane was added to the beaker, and the combination was subjected to a rotor vortex for 15 minutes.

The samples were passed through Millipore filters (13 mm, 0.45 µm) and then subjected to centrifugation at a speed of 10,000 revolutions per minute for 15 minutes. A 1-milliliter sample was transferred into an Eppendorf tube and subjected to sonication for 15 minutes. The HPLC conditions were set using a C18 column, with isocratic elution at a ratio of 50:30:20. The flow rate was adjusted to 0.8 mL/min, the injection volume was at 10.0 µl, and the mobile phase consisted of a mixture of isopropanol, acetonitrile, and methanol. The correlation coefficient (R^2) for the curve was 0.9687, and the equation of the line was $y = 56359x – 50916$.

Statistical Analysis

The data of all the above-detailed parameters were subjected to factorial analysis of variance (ANOVA). Subsequently, significant means were separated and compared using Tukey's test at a significance level 0.05. All data were tested for treatment effects on the analyzed parameters. Pearson's correlation established the relationship between fertilizer application rate and the chemical/physical parameters analyzed. The statistical analysis was performed using SPSS version 23, 2020, and Past 4.0 (Hammer et al. 2001) software.

Results

Fertilizer Application Dynamics on Β-Carotene, Ascorbic Acid and Α-Tocopherol

Table 1 shows the response of phosphorus and potassium doses on mango fruit morphological characteristics, while Figure 2 presents effects of phosphorus and potassium doses on vitamins. For the fruit pulp's vitamin content, addition of phosphorus to the trees significantly ($p \leq 0.05$) changed the quantities of β-carotene (15.90±1.11 mg/100 g at 1 kg; 15.90±1.11 mg/100 g at 2 kg) as compared to addition of potassium (9.75±0.89 mg/100 g at 1 kg; 5.27±2.22 mg/100 g at 2 kg). However, the ascorbic acid concentrations were significantly lower ($p \leq 0.05$, 0.65±0.01 mg/100 g) than the control (1.31±0.99 mg/100 g) at 1 kg of phosphorus.

The control group, which received no additional phosphorus or potassium, had higher concentrations of β-carotene and α-tocopherol. Similarly, the group that received only 1 kg of potassium had the highest ascorbic acid content. Regardless of the dosage, the amount of β-carotene (16.47±1.12 mg/100 g) and α-tocopherol (4.35±0.05 mg/100 g) from the control trees were much higher ($p \leq 0.05$) than those fertilized with phosphorus, potassium or combination phosphorus and potassium (Figure 2). However, the fruit pulps of trees fertilized with potassium had significantly higher ($p \leq 0.05$) ascorbic acid (4.19±2.56 mg/100 g) than the control (1.31±0.99 mg/100 g).

Table 1

Figure 2

Fertilizer Application Dynamics on Fruit Morphological Characteristics

The type of fertilizer did not significantly affect the morphological characteristics of the fruit ($p \geq 0.05$). However, fruits in the control category outperformed those fertilized with either P, K, or a combination of P and K in terms of fruit length, fruit width, fruit thickness, fruit weight, pulp weight, skin thickness, skin weight, stone weight, seed length, seed width, and seed weight (Table 1).

Fruit fertilized with potassium had significantly higher ($p \leq 0.05$) seed/stone proportion ratios than those fertilized with phosphorus or a combination of phosphorus and potassium. Potassium fertilizer significantly ($p \leq 0.05$, 49.20±5.03 mg/100 g at 1 kg; 51.91±4.68 mg/100 g at 2 kg) increased the means of fruit length/width proportion ratios than those fertilized with 1 kg (1.27±0.10 mg/100 g) or 2 kg (1.20±0.10 mg/100 g) of phosphorus or a combination of phosphorus and potassium (1.20±0.03 mg/100 g at 1 kg; 1.21±007 mg/100 g at 2 kg) (Table 1). However, the mean fruit weight, pulp weight, skin weight, and stone weight were higher for the control than those fertilized with either fertilizer, although the difference was insignificant.

These results suggest that increased phosphorus and K levels in the soil may not significantly affect the concentrations of vitamins and other fruit dimensions. However, it is essential to maintain balanced nutrition and to monitor soil nutrient levels rigorously to achieve optimal fruit quality. Therefore, careful monitoring of soil nutrient levels is necessary to ensure optimal fruit quality.

Relationships Between Vitamins and Morphological Characteristics

In order to ascertain the degree of association between morphological traits and vitamins, a correlation analysis was conducted (Figure 3). The correlation matrix showed a weak significant negative correlation between ascorbic acid and α-tocopherol ($r=-0.48$, $P\leq0.05$) and a weak significant negative correlation between ascorbic acid and fruit length ($r=-0.47$, $P\leq0.05$). These results indicate that mango fruits with high ascorbic acid content likely have significantly lower quantities of α-tocopherol and shorter fruit lengths. In contrast, a significantly weak negative correlation between β-carotene and stone thickness ($r=-0.45$, $P\leq0.05$) suggests that fruits with larger stone thickness contain low levels of β-carotene (Figure 3).

A strong positive correlation was observed between fruit weight and skin weight ($r=0.97$, $P\leq0.05$), between fruit weight and stone thickness ($r=0.76$, $P\leq0.05$), and between fruit weight and seed thickness ($r=0.82$, $P\leq0.05$). A strong negative correlation existed between pulp weight and seed thickness ($r=-0.81$, $P\leq0.05$), indicating that an increase in fruit seed thickness decreased fruit pulp weight (Figure 3, Table S2).

Figure 3

Principal Component Analysis Between Vitamins, Morphological Characteristics, and Fertilizers

Principal component analysis (PCA) was used to determine significant variables in the dataset (Figure 4). Several factors were correlated because they shared the same physicochemical characteristics or were related to the fertilizer type. According to the PCA results, the first two components explained approximately 72% of the observed variation (Figure 4, Table S2).

The first principal component analysis (PCA 1) revealed that β-carotene (mg/100g), α-tocopherols (mg/100g), fruit length (cm), fruit weight (g), pulp weight (g), skin thickness (mm), stone length (cm), stone weight(g), seed length (cm), seed thickness (mm), seed weight (g), absence of fertilizer (control) and application of 1kg phosphorous accounted for 46.22% of the total variation in fruit characteristics. In contrast, the second PCA 2 revealed that ascorbic acid (mg/100 g), stone thickness (cm), seed length (cm), seed thickness (cm), seed weight (g), and application of 1 kg and 2 kg Phosphorous+ K contributed 25.4% of the total variation in fruit characteristics (Figure 4).

Figure 4

Effect of Fruit Canopy Position on Vitamins and Fruit Morphological Characteristics

The results for the variations in ascorbic acid, β-carotene, α-tocopherol, and morphological characteristics of fruit grown at two positions, sun-exposed and within the crown, are shown in Table 2. The highest vitamin recorded within the tree crown was β-carotene (08.34±8.30 mg/100 g), while the least was ascorbic acid (01.59±1.92 mg/100 g). Similarly, in sun-exposed fruits, the highest vitamin was recorded by β-carotene (08.14±1.04 mg/100 g), and the lowest vitamin concentration was 01.20±1.91 mg/100 g by ascorbic acid.

The fruit position, either within the crown or sun-exposed, did not significantly differ in ascorbic acid, α-tocopherol, and β-carotene, even after applying various P.K. fertilizers. However, generally, the ascorbic acid, β-carotene, and α-tocopherol contents of the fruits harvested from the tree crown were higher than those harvested from the sun-exposed canopy (Table 2). Regarding morphological characteristics, the parameters measured, including fruit length (t(55)=-0.482, p= 0.632), fruit width (t(55)=-0.423, p= 0.674), and fruit weight (t(55)=-0.497, p= 0.621), as well as stone weight (t(55)=-0.681, p= 0.499), and seed weight (t(54)=-1.099, p= 0.277) in the sun-exposed canopy, were not significantly ($p \geq 0.05$) higher than the corresponding fruits harvested within the canopy (Table 2). Although not significant ($p \geq 0.05$), the heavy fruit weight recorded was within the tree crown (409.14±102.75g), as compared to 394.26±122.12g for sun-exposed fruits.

Discussion

Effect of P and K Fertilization on Mango Fruit Quality

The study investigated the effects of phosphorus (P) and potassium (K) fertilization on the nutritional quality of 'Kent' mango fruit. Contrary to expectations, increasing P and K application rates did not significantly enhance ascorbic acid, β-carotene, or α-tocopherol content. These findings diverge from previous research by Quaggio et al. (2006) and Sarker and Rahim (2012), which reported positive correlations between K fertilization and ascorbic acid content in various fruit crops. The non-significant effect of P and K on β-carotene concentration agrees with previous studies. However, historical research has suggested that increased soil K content can lead to reduced carotene levels and increased ascorbic acid content. This effect is hypothesized to be linked to the influence of fertilizers on photosynthetic processes and chlorophyll content (Gull et al. 2012; Massri and Labban 2014). P and K fertilization did not significantly affect α-tocopherol levels, the synergistic relationship between antioxidants like ascorbic acid, tocopherols, and carotenoids suggests that optimizing nutrient management could potentially enhance overall fruit quality.

It is important to note that several factors, including genetic variability, environmental conditions, and post-harvest handling practices, can influence fruit quality. In addition, soil moisture deficits can limit soil K transport and plant uptake, causing K deficiency (Lester et al. 2010). The conflicting results regarding the effect of P.K. fertilizer application can only be explained by differences in modes of fertilization, whether via the soil or foliar, and differences in sources of P and K fertilizers. Therefore, the impact of P and K fertilization on mango fruit composition may vary depending on specific growing conditions and cultivar characteristics.

Morphological Characteristics of Mango Fruit

An increase in the combined phosphorus and potassium fertilizer rate increased only the seed proportion from stone and no other characteristics (Tables 1 and 2). These results are consistent with those reported by Sarker and Rahim (2013). They noted significant differences in fruit weight, stone pulp ratio, peel pulp ratio, and shelf life due to potassium application but no significant variations in fruit length, breadth, thickness, and edible portion.

According to de Mello Prado (2010), P released by the fertilizer is expected to accumulate in the plant stem tissues and then be released into other plant organs. Because mango plants are biannual, a low yield follows a high yield in the subsequent year, which often complicates fertilization (de Mello Prado 2010). However, according to Nascimento et al. (2008), an adequate strategy to fertilize mango plants should consider the different phases of plant development since each phase presents different nutrient demand levels. Additionally, mango trees fertilized with phosphorus at 2 kg had a significantly higher mean stone proportion of the fruit than those with phosphorus at 1 kg.

Influence of Fruit Canopy Position on Mango Fruit Quality

Light intensity during fruit development is a significant factor influencing ascorbic acid synthesis, although light is not strictly necessary for this process (Lee and Kader 2000). In the current study, P and K fertilization did not significantly impact the physical and chemical characteristics of mango fruit, regardless of their position within the canopy. This finding contrasts with previous research by Pandey et al. (2013), which reported that reduced light exposure can lead to smaller fruit size. However, other studies have shown that fruits within the canopy can exhibit higher weight and lower stone weight compared to sun-exposed fruits(Olale 2024; Olale et al. 2017, 2019).

These findings concur with our general trend that fruits within the tree crown were heavier than sun-exposed fruits, although this difference was not statistically significant. The impact of canopy position on ascorbic acid content can vary depending on climatic conditions and cultivar characteristics. While some studies have reported higher ascorbic acid levels in sun-exposed fruits, others have found no significant differences.

Conclusion

According to our results, most mango physical and chemical quality parameters were not significantly influenced by the K and P application. This indicates that increased levels of K and P in soils may not significantly affect the concentrations of mango fruit vitamins. Furthermore, fruits within the tree crown had higher levels of ascorbic acid, β-carotene, and α-tocopherol than sun-exposed fruits.

Morphological characteristics measured in the sun-exposed canopy, such as fruit length, width weight, stone weight, and seed weight, were not significantly ($p \geq 0.05$) higher than the similar fruits taken within the canopy.

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Disclosure Statement

No potential conflict of interest was reported by the author.

Supplementary Materials

The supplementary tables on soil chemical parameters (Table S1) and PCA loadings (Table S2) are attached separately.

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Table Titles

Table 1: Fruit Morphological characteristics after fertilizer application

Morphological characteristics	**Control**	**Phosphorus**		**Potassium**		**Phosphorus + Potassium**	
		1 Kg	**2 Kg**	**1 Kg**	**2 Kg**	**1 Kg**	**2 Kg**
Fruit length	10.74±1.52^a	11.74±1.46^a	09.46±2.38^a	09.86±1.13^a	10.36±1.18^a	10.37±0.66^a	10.46±0.75^a
Fruit weight	441.92±130.35^a	481.79±106.70^a	338.03±200.13^a	339.21±79.1^a	393.13±112.98^a	394.44±58.39^a	405.61±54.71^a
Pulp weight	320.84±95.08^a	343.27±79.59^a	246.58±151.61^a	244.28±58.69^a	288.40±84.95^a	285.89±42.12^a	294.43±41.81^a
Skin thickness	00.21±0.02^a	00.20±0.01^a	00.19±0.04^a	00.21±0.01^a	00.19±0.02^a	00.20±0.01^a	00.20±0.02^a
Skin weight	77.85±21.64^a	89.96±25.19^a	57.00±29.29^a	61.75±14.48^a	65.11±17.46^a	67.72±9.78^a	66.09±10.01^a
Stone length	09.11±1.37^a	10.07±1.14^a	08.14±2.02^a	08.48±1.16^a	08.49±1.31^a	08.93±0.61^a	08.79±0.75^a
Stone thickness	01.63±0.32^a	01.56±0.42^a	01.57±0.35^a	01.68±0.29^a	01.69±0.21^a	01.76±0.22^a	01.84±0.09^a
Stone weight	36.15±11.59^a	36.38±10.15^a	30.43±18.52^a	27.88±6.02^a	31.48±10.86^a	34.33±6.09^a	35.74±6.76^a
Seed length	05.77±0.81^a	05.44±1.09^a	05.31±1.37^a	05.19±0.69^a	05.67±0.88^a	05.65±0.52^a	05.64±1.0^a
Seed thickness	01.39±0.2^a	01.36±0.12^a	01.34±0.35^a	01.38±0.12^a	01.44±0.19^a	01.42±0.15^a	01.55±0.17^a
Seed weight	19.29±6.24^a	16.19±6.87^a	16.99±10.21^a	14.50±4.36^a	17.31±6.41^a	17.97±3.59^a	18.86±6.63^a
Proportion of fruit pulp (%)	72.24±1.69^a	71.23±5.31^a	70.97±3.24^a	71.76±1.07^a	73.38±1.44^a	72.30±1.75^a	73.01±1.59^a
Skin proportion of fruit (%)	17.94±1.19^a	19.02±3.82^a	18.42±2.58^a	18.18±0.56^a	16.91±1.34^a	17.42±1.06^a	16.65±1.61^a
Stone proportion of fruit (%)	08.32±0.79^a	07.59±1.31^b	09.25±0.94^a	08.28±0.26^a	08.01±0.94^a	08.70±0.61^a	08.76±0.71^a
Seed/stone proportions (%)	98.51±0.64^a	48.71±7.90^b	55.90±3.04^b	98.23±0.62^a	98.31±0.77^a	50.67±4.15^b	57.20±3.17^b
Fruit length/width proportions (%)	50.08±5.71^a	01.27±0.10^b	01.20±0.05^b	49.20±5.03^a	51.91±4.68^a	01.20±0.03^b	01.21±0.07^b

Mean values followed by the same superscript letter in a row are not significantly different according to the LSD test at $p \leq 0.05$. Values are presented in descending order of size.

Table 2: Effect of fruit canopy on vitamins and morphological characteristics of mango fruit

Characteristics	Fruit Position	N	Mean ± SD	F	Sig.	t	df	Sig. (2-tailed)
Ascorbic Acid (mg/100g)	Sun exposed	19	01.20±1.91	1.692	0.203	-0.574	31.00	0.570
	Within crown	14	01.59±1.92			-0.574	28.12	0.571
α-tocopherol (mg/100g)	Sun exposed	19	02.11±1.64	0.710	0.406	-0.618	31.00	0.541
	Within crown	14	02.64±3.30			-0.562	17.74	0.581
β-carotene (mg/100g)	Sun exposed	18	08.14±1.04	0.273	0.605	-0.037	29.00	0.971
	Within crown	13	08.34±8.30			-0.041	25.34	0.967
Fruit length (cm)	Sun exposed	29	10.35±1.50	0.688	0.410	-0.482	55.00	0.632
	Within crown	28	10.53±1.24			-0.484	53.79	0.631
Fruit width (mm)	Sun exposed	29	08.56±1.01	0.758	0.388	-0.423	55.00	0.674
	Within crown	28	08.66±0.76			-0.425	51.98	0.673
Fruit thickness (mm)	Sun exposed	28	07.33±0.59	0.341	0.562	0.253	5.004	0.802
	Within crown	28	07.29±0.67			0.253	53.22	0.802
Fruit weight (g)	Sun exposed	29	394.26±122.12	0.192	0.663	-0.497	55.00	0.621
	Within crown	28	409.14±102.75			-0.498	54.01	0.620
Pulp weight (g)	Sun exposed	29	286.27±92.16	0.752	0.39	-0.448	55.00	0.656
	Within crown	28	296.20±73.57			-0.450	53.15	0.654
Skin thickness (g)	Sun exposed	28	00.20±0.02	0.120	0.731	0.192	54.00	0.848
	Within crown	28	00.20±0.02			0.192	52.43	0.848
Skin weight (g)	Sun exposed	29	68.17±19.56	0.110	0.742	-0.492	55.00	0.625
	Within crown	28	70.76±20.11			-0.491	54.78	0.625
Stone length (cm)	Sun exposed	29	08.75±1.37	1.464	0.231	-0.665	55.00	0.509
	Within crown	28	08.97±1.12			-0.667	53.63	0.508
Stone width (mm)	Sun exposed	29	04.64±0.47	0.180	0.673	-0.840	55.00	0.405
	Within crown	28	04.74±0.43			-0.841	54.86	0.404
Stone thickness (mm)	Sun exposed	29	01.67±0.31	0.261	0.612	-0.525	55.00	0.602

	Within crown	28	01.71±0.24			-0.527	52.11	0.600
Stone weight (g)	Sun exposed	29	32.62±11.13	0.219	0.641	-0.681	55.00	0.499
	Within crown	28	34.46±9.09			-0.683	53.54	0.497
Seed length (cm)	Sun exposed	29	05.38±0.96	1.219	0.274	-1.641	55.00	0.107
	Within crown	28	05.75±0.72			-1.649	52.01	0.105
Seed width (mm)	Sun exposed	28	03.22±0.44	1.481	0.229	-0.930	54.00	0.357
	Within crown	28	03.32±0.34			-0.930	50.99	0.357
Seed thickness (mm)	Sun exposed	28	01.40±0.22	1.345	0.251	-0.706	54.00	0.483
	Within crown	28	01.44±0.16			-0.706	48.97	0.483
Seed weight (g)	Sun exposed	28	16.70±6.45	0.374	0.543	-1.099	54.00	0.277
	Within crown	28	18.48±5.62			-1.099	53.01	0.277
Pulp proportion (%)	Sun exposed	29	72.38±2.10	0.183	0.671	0.394	55.00	0.695
	Within crown	28	72.12±2.73			0.392	50.721	0.696
Skin proportion (%)	Sun exposed	29	17.80±1.59	0.330	0.568	0.479	5.005	0.634
	Within crown	28	17.56±2.15			0.477	49.67	0.636
Stone proportion (%)	Sun exposed	29	08.39±1.09	1.457	0.233	-0.337	5.005	0.738
	Within crown	28	08.47±0.67			-0.339	46.99	0.736
Seed proportion from stone (%)	Sun exposed	27	50.68±5.21	0.066	0.799	-1.693	52.00	0.096
	Within crown	27	53.09±5.27			-1.693	51.99	0.096
Fruit length/width proportion (%)	Sun exposed	29	01.21±0.06	0.241	0.625	-0.493	55.00	0.624
	Within crown	28	01.21±0.06			-0.493	54.97	0.624

Figure Captions

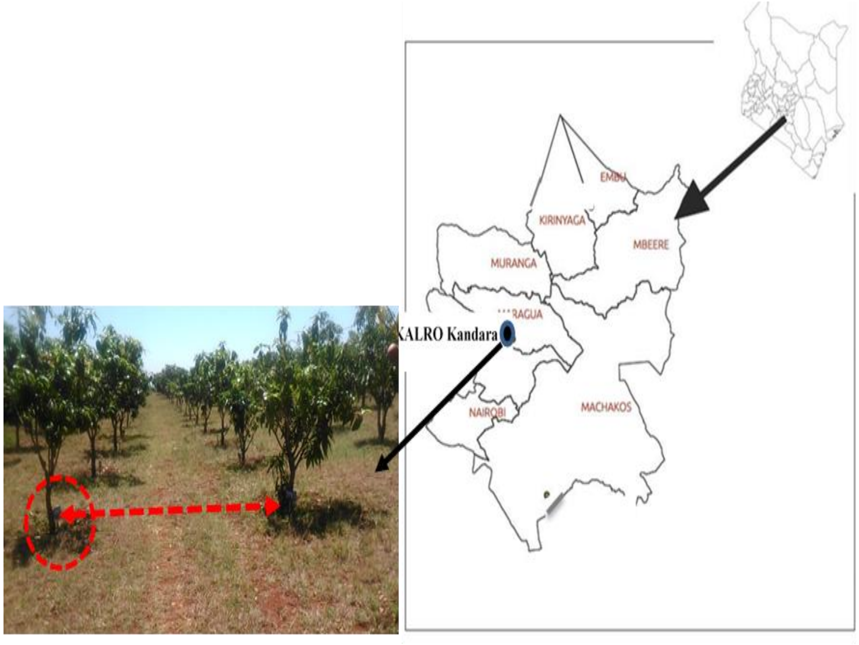

Figure 1: Field experiment at KALRO-Kandara orchard in Kiambu County, Kenya

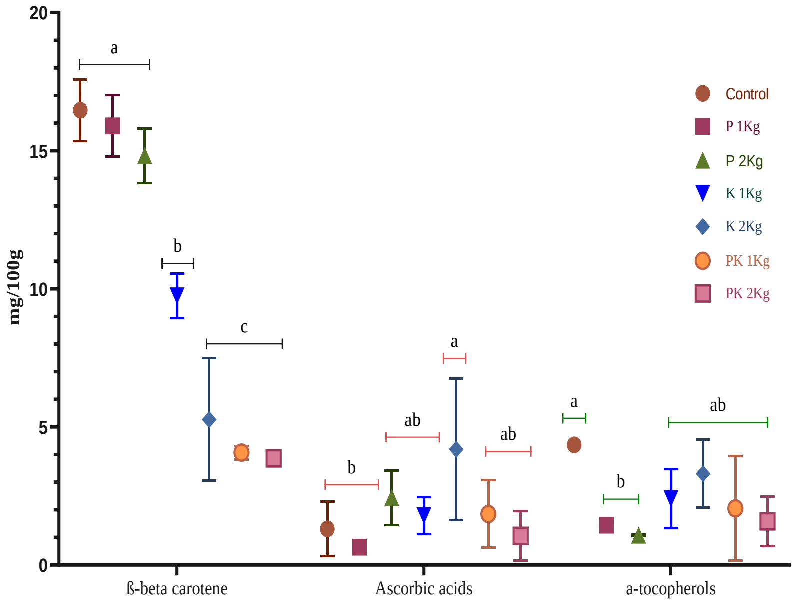

Figure 2: Mean fruit vitamin concentrations after application of different fertilizer rates and types. Mean values followed by the same superscript letter per vitamin are not significantly different according to the LSD test at p ⩽0.05.

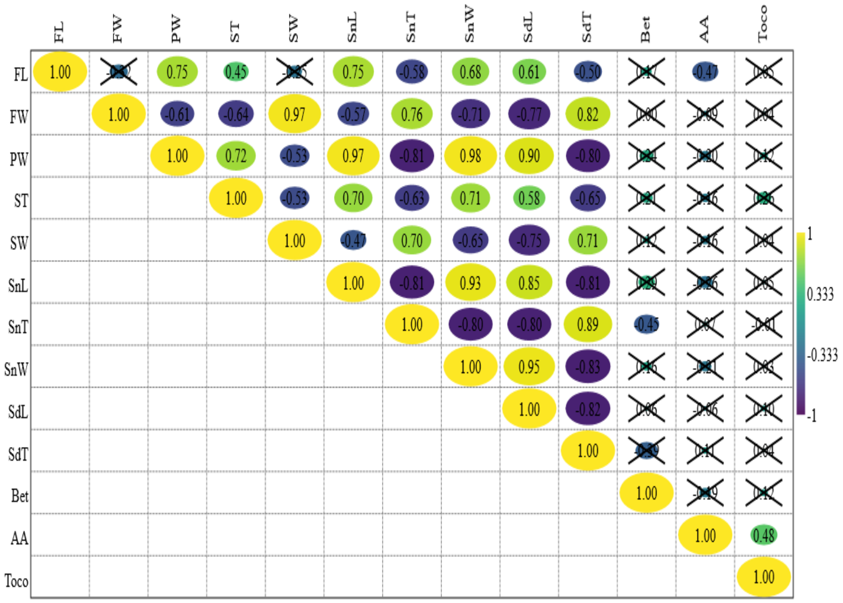

Figure 3: Correlation analyses between the fruit vitamins, pulp, and selected physical characteristics. F.L., fruit length; F.W., fruit weight; P.W., pulp weight; S.K., skin thickness; S.W., skin weight; SnL, stone length; SnT, stone thickness; SnW, stone weight; SdL, seed length; SdT, seed thickness; SdW, seed weight; Bet, β-beta-carotene; A.A., ascorbic acid; Toco, α-tocopherol. Means are significantly different at the p $\leqslant$ 0.05 level, and P>0.05 are crossed.

Figure 3.

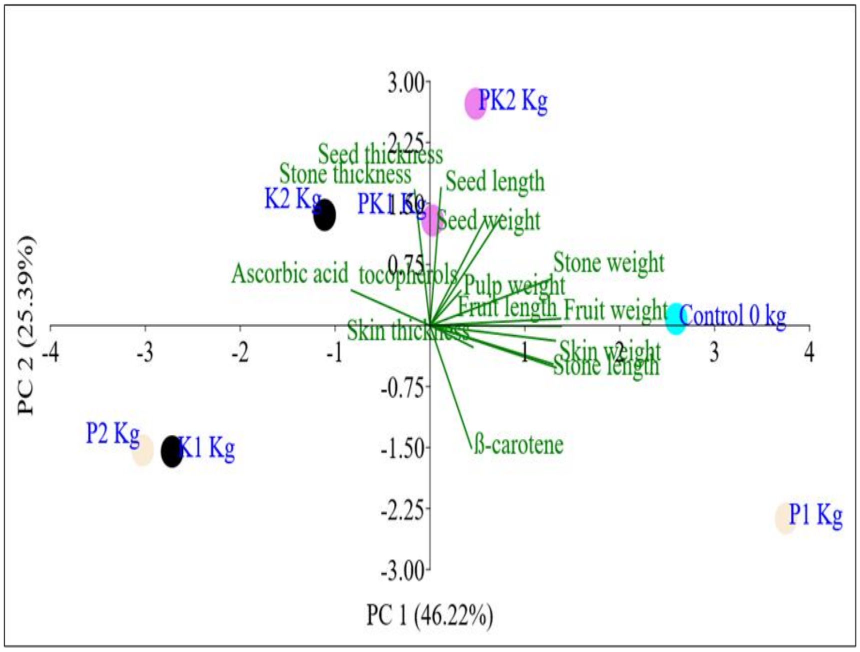

Figure 4: Principal component analysis (PCA) analyses between the fruit vitamins, pulp, and selected physical characteristics