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Synergistic Effects of Applying Potassium Nitrate Spray with Putrescine on Productivity and Fruit Quality of Mango Trees cv. Ewais

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Abstract: The current investigation represents of the synergistic effects of application of potassium nitrate (KNO_3) in combination with putrescine (Put) on flowering, productivity, and fruit quality on Ewais mango (*Mangifera indica* L.) trees during the seasons 2021/2022 and 2022/2023. The selected trees were sprayed at three different stages, including flower bud differentiation, full bloom, and beginning of the fruit set, with one of the following treatments: control, 2% KNO_3, 4% KNO_3, 50 ppm Put, 75 ppm Put, 2% KNO_3 + 50 ppm Put, 2% KNO_3 + 75 ppm Put, 4% KNO_3 + 50 ppm Put, 4% KNO_3 + 75 ppm Put. Results showed that all treatments were successful in improving the productivity of mango trees by increasing flowering terminal shoots, fruit set, fruit retention, number of fruits/tree, yield, and fruit yield increment while reducing the percentage of fruit drop, as well as improving the quality of mango fruits cv. Ewais by increasing fruit length, fruit diameter, TSS, total sugars, V.C, and total phenol and carotenoid content, but at the same time, diminishing the total acidity, as compared with control. Based on this research, the application of 4% KNO_3 in conjunction with 75 ppm Putrescine has shown the most prominent advances in enhancing Ewais tree productivity and fruit quality. The investigation successfully highlighted the synergistic effect of using KNO_3 and putrescine to improve mango fruit yield and quality.

Keywords: chemical characteristics; fruit drop; fruit set; physical characteristics; *Mangifera indica*; yield

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1. Introduction

The Mango (*Mangifera indica* L.), one of the 73 genera of the family Anacardiaceae in the order Sapindales, is one of the world's most important tropical and subtropical fruits, as well as one of the most valued fruits [1–3]. It may be consumed fresh or as juice, or may be added in some food industries due to its high nutritional value and health benefits, due to its nutritional and phytochemical compounds [4,5]. Mango components can be grouped into macronutrients: carbohydrates (i.e., pectins and cellulose), proteins, amino acids (i.e., lysine, leucine, cysteine, valine, arginine, phenylalanine, and methionine), lipids (i.e., omega-3 and omega-6 fatty acids), fatty acids, and organic acids, as well as micronutrients: vitamins (A, B6, B9, C and K), minerals (macroelements, i.e., Ca, P, K, Mg and microelements, i.e., Fe, Zn, Mn, Cu), besides phytochemicals: phenolic and polyphenolic pigments (i.e., carotenoids), and volatile constituents [5,6]. So, it occupies the status of the king of fruits, due to its delicacy, attractive appearance, fragrance, nutritive values, and delicious taste [7].

Low productivity of mango is most often attributed to factors related to nutrition and fruiting, which leads to failure of floral induction, irregular flowering, low fruit set, low fruit retention, and irregular bearing, leading to low yield and fruits of poor quality and short availability period, all of which are also the main problems in mango production [8,9]. Thus, it is envisaged that synergistic yield and fruit quality of mango trees can be achieved by applying nutrients and growth regulators that are capable of altering the flowering and fruiting patterns of the mango varieties [9–11], thus ensuring increased and regular productivity. Hence, the improvements in crop productivity in modern agricultural systems are increasingly dependent on manipulation of the physiological activities of the crop by nutrients, i.e., foliar application of potassium salts [12] and growth regulators, i.e., polyamines [13].

Among mineral nutrients, potassium element plays a great role in plants, being involved in multiple physiological and biochemical processes vital to plant growth, yield, fruit enlargement, quality, and stress, and improving fruit quality parameters i.e., total soluble solids, total sugars, and coloration [14]. Moreover, potassium is indispensable to plant life and plays an imperative role in the activation of many enzymes, the photosynthesis process, and the subsequent carbohydrate translocation and metabolism process, which eventually increases the crop yield [15,16]. In addition, application of potassium regulates many physiological processes such as translocation of solutes, transpiration, respiration, and photosynthesis, and activates nitrate reductase (NR) and starch synthetase, and these two enzymes create a balance by producing protein and carbohydrates, respectively [7,17]. It also impacts the mechanism of stomatal opening and closing by affecting cell water potential and turgor, photosynthesis, assimilation, transport, and enzyme activation, which have direct impact on crop productivity and fruit quality [12,18]. Among the different sources of potassium fertilizers, potassium nitrate is used for trees grown in tropical and subtropical regions, to induce seasonal flowering and to synchronize flowering in mango, as well as to stimulate flowering of trees that had remained vegetative well beyond normal bearing ages. It also affects the number of panicles per tree and the date of flowering, and stimulates breaking of the biennial bearing habits of trees [14,19,20]. KNO_3 stimulates an increased percentage of flowering shoots and the number of panicles and vegetative shoots/auxiliary branches, and increases yields and reduces alternate bearing [21–23]. The effective spray concentrations range from 1 to 10% KNO_3, with the optimal concentration varying with the age of the tree and its climatic conditions [23–25]. It is also affected by various factors, such as cultivars, production conditions, stage of development, dosing range, physiological maturity of the plants, yield of the previous harvest, and age of the shoots [11,26]. To succeed in stimulating flowering, the nitrate salt must be applied after the resting stems of mango have reached sufficient age, to overcome any inhibitory influence they may have on the flowering response [25], as previous anecdotal observations indicated that Haden and Tommy Atkins mango stems need to be at least 4 to 5 months old to reproductively respond to nitrate compounds [27].

Polyamines are low-molecular-weight aliphatic nitrogenous bases containing two or more amino groups that have been proposed to be a new category of plant growth regulators or secondary hormonal messengers [28]. They are implicated in a wide range of plant physiological processes such as morphogenesis, flower differentiation and initiation, pollen viability, root growth, somatic embryogenesis, anti-senescence, and responses to several (mainly abiotic) stresses [29–31]. Previous studies showed that endogenous polyamine is important for pollen germination and pollen tube growth, enhanced pollen tube ovule penetration [32,33], increased viability of ovule and prolonged pollination period, and inhibition of enzymes involved in ripening or inhibition of ethylene synthesis [28,34].

Among polyamines (PAs), putrescine (Put) is a positively charged aliphatic amine that regulates various aspects of the plant growth and development, and modulates various cellular processes such as membrane stabilization, senescence, cell division, morphogenesis, stress tolerance, and flowering and fruit development by influencing biosynthesis of cellular enzymes [35–37]. It plays a part in chlorophyll retardation, plant pigment biosynthesis stimulation, and thylakoid membrane stabilization [38]. It also enhances the uptake of potassium, calcium, and magnesium and regulates intracellular levels of sodium [39,40]. It participates in the biological processes of mango trees, such as plant growth, flowering, and increasing fruit set, fruit development, and fruit ripening, increasing yield and improving fruit quality [13,41,42].

Putrescine application significantly suppresses ethylene production during fruit ripening. This may be due to inhibition of activities of ACC synthase [28,43], or biosynthesis between polyamines and ethylene [44,45]. External application of putrescine, when applied at full bloom, showed increased fruit set, higher fruit retention, increased fruit sizes and yield, and increased quality parameters of mango fruits such as pulp (%), TSS (%) and carotene content, preserved chlorophyll in the fruit skin, reduction of fruit firmness, and sugar content [42,46,47], In addition, putrescine treatments reduced respiration rate, ethylene production, TSS, and TSS:TA, while TA and ascorbic acid content showed the reverse trend and maintained higher fruit firmness during ripening and cold storage, and increased the shelf life of fruit during post-harvest storage [45,48].

Considering those facts, the present investigation is an attempt to determine whether potassium nitrate (KNO_3) spray can act synergistically with putrescine to stimulate flowering, crop abundance, and high crop quality of mango trees cv. Ewais, as compared to the current production practices.

2. Materials and Methods

2.1. Plant Materials and the Experimental Location

The present study was conducted on 10-year-old organic Ewais mango trees (*Mangifera indica* L.) budded on Sukkary rootstock, in a private orchard in the Idko city, EL-Beheira, Egypt (GPS co-ordinates: 31°20′00.0″ N, 30°25′05.9″ E), for two seasons in 2021/2022 and 2022/2023. The selected trees were planted at 6 × 4 m apart and grown under a drip irrigation system every two weeks in a sandy soil. Trees were fertilized in the two successive seasons with organic manure in November, and calcium super phosphate (15% P_2O_5) during February, both at a rate of 60 m^3, 300 kg per hectare,. Organic manure used was composed of 22% organic C, 44% organic matter, 1.24% N, 0.36%, P_2O_5, 1.40% K_2O, 0.68% CaO, 0.36% MgO, 44 ppm Cu, 4500 ppm Fe, 450 ppm Mn, and 125 ppm Zn, while it had a C:N ratio of 11:1 and a moisture content of 11.4 db, as average across seasons. Chelated Zn (21.0% Zn) and Mn (13.0% Mn), each at 75 kg, and 5 kg chelated Fe (4.6% Fe) per hectare were added annually with calcium super phosphate. During the growing season of both years, ammonium nitrate (33.5% N), potassium sulphate (48% K_2O), and magnesium sulphate heptahydrate (15.9% MgO, 47.8% $MgSO_4$) were added in three doses: at the beginning of March, May, and late June at a rate of 500, 350, and 100 kg per hectare, respectively. In addition, all the uniformly selected trees were nearly similar in vigor, size, and productivity, as well as under regular horticultural practices including pruning as well as pest and disease control. Experimental soil was collected at a depth of 0–90 cm, and the physicochemical properties were analyzed and are presented in Table 1. According to the International Union of Soil Sciences (IUSS), the soil classification of the soil used on this study is Entisols.

Table 1. Physical and chemical analyses of the experimental soil.

Soil Depth (cm)	Soil Fractions			Soil Texture	pH	EC (dS/m)	$CaCO_3$ (%)	OM (%)	Soluble Cations (meq/L)				Soluble Anions (meq/L)		
	Sand (%)	Clay (%)	Silt (%)						Na^+	Ca^{2+}	Mg^{2+}	K^+	HCO_3^-	Cl^-	SO_4^-
0–30	89.3	6.50	4.2	Sand	8.3	1.61	2.20	0.43	10.2	3.25	2.5	0.15	2.9	9.4	3.8
30–60	90.9	4.20	4.90	Sand	8.1	1.78	1.85	0.32	12.4	3.70	2.7	0.2	3.1	10.8	3. 9
60–90	92.7	2.15	5.15	Sand	7.8	1.90	1.50	0.22	12.15	3.50	2.8	0.2	3.2	11.5	4.3
Average	90.96	4.28	4.73	Sand	8.07	2.39	1.85	0.32	11.58	3.48	2.66	0.18	3.07	10.57	4.00

2.2. Experimental Design and Treatments

For the present study, thirty-six trees, as uniform as possible in growth and vigor, were selected and subjected to the following treatments, with 4 replicates per treatment and a single tree for each replicate (i.e., 9 treatments × 4 replicates × 1 tree per replicate = 36 trees). Trees were sprayed using a small spraying motor, until run-off stage, with surfactant agent Tensotec (produced by BC. Fertilize—Oliva, Spain) at 0.01% (v/v) added to the spraying solution to reduce the surface tension and increase the contact angle of sprayed droplets, and each tree was sprayed with 5 L of the spraying solution until run-off. In addition to the control (water spray) (T1), eight treatments were applied, as follows: 2% KNO_3 (T2), 4% KNO_3 (T3), 50 ppm Put (T4), 75 ppm Put (T5), 2% KNO_3 + 50 ppm Put (T6), 2% KNO_3 + 75 ppm Put (T7), 4% KNO_3 + 50 ppm Put (T8), 4% KNO_3 + 75 ppm Put (T9). KNO_3 and Put were sprayed at three different phonological stages including flower bud differentiation (last week of October) (phenological stage 010 of BBCH scale), full bloom (last week of March) (state 615 BBCH) and beginning of fruit set (15 days after full bloom) (state 619 BBCH).

2.3. Measurements

2.3.1. Productivity

Productivity was evaluated by the determination of terminal shoot flowering of Ewais mango trees, fruit set, fruit retention, fruit drop, yield, and fruit yield increment during this study. To determine terminal shoot flowering under different treatments, 100 terminal shoots, similar in size and health per tree growing in different directions, were marked before applying the treatments for recording the percentage of flowering branches [26]. At flowering time (March), twenty bearing shoots were used to measure the number of initial fruit set and the fruits remaining on the panicle until harvesting to calculate fruit set/panicle count after 15 days of full bloom, while the fruit retention and fruit drop were determined by the equations:

$$\text{Fruit retention } (\%) = \frac{\text{Total number of remained fruit}}{\text{Total number of fruit set}} \times 100 \quad (1)$$

$$\text{Fruit drop } (\%) = 100 - \text{Fruit retention} \quad (2)$$

When fruits reached the fully mature stage, the number of fruits/tree for each replicate was recorded. The total tree yield (kg/tree) was determined by multiplying the average of fruit weight × number of fruits/tree. However, fruit yield increment compared with the control was calculated with the following equation:

$$\text{Fruit yield increment } (\%) = \frac{\text{Fruit yield (kg) at treatment } - \text{ Fruit yield (kg) at control}}{\text{Fruit yield (kg) at control}} \times 100 \quad (3)$$

2.3.2. Fruit Physico-Chemical Properties

Ripe fruits were identified and harvested using a peel color index, visually evaluated on a scale of 1 to 5, when having reached scale 4 (turned 3/4 yellow). A sample of four fruits from each replicate were randomly taken for measuring the fruit physical measurements; fruit weight (g), seed weight (g), and pulp/fruit ratio were calculated. Also, fruit length and fruit width (cm) were measured with a caliper and fruit shape index (length/width) was estimated. In addition, fruit firmness (Newton) was measured by pressure tester using an 8 mm "plunger". Two readings were taken in two opposite sides on the flesh of each fruit after peeling. Newton (N) = kilogram-force (kg f) × 9.807. In addition, for determining fruit chemical characteristics, another sample of four fruits from each replicate were randomly selected. The fruit pulp was squeezed and, in the fruit juice, the percentage of total soluble solids (TSS) was determined using a hand refractometer. Fruit acidity (%), expressed as g citric acid/100 mL juice, was determined by titrating with 0.1 N sodium hydroxide in the presence of phenolphthalein as an indicator according to AOAC [49] (2019), and the

TSS/acidity ratio was calculated. Moreover, fruit total sugar percentage was determined by using the phenol sulfuric acid method outlined by Malik and Singh [50]. The percentages of total and reducing sugars in the juice were also determined according the Lane and Eynon method as described by Egan et al. [51]. In addition, ascorbic acid (vitamin C) was measured by the oxidation of ascorbic acid with 2,6-dichlorophenol indophenol dye, and the results were expressed as mg/100 mL juice according to AOAC [49]. Soluble phenol content was determined as a percentage of the fresh weight of mango pulp (5 g) according to the method described by Swain and Hillis [52]. One gram was taken from the whole fruit pulp and was extracted in 10 mL acetone (85%), and carotenoid content was determined colourimetrically at a wavelength of 440 nm using a spectrophotometer as described by Moran and Porath [53].

2.4. Statistical Analysis

The experimental treatments were organized in a randomized complete block design (RCBD), according to Snedecor and Cochran [54]. Treatment means were separated and compared using least significant difference (LSD) at probability level of 0.05 according to Snedecor and Cochran [54] by one-way analysis of variance (ANOVA). The statistical analysis was performed using XLSTAT statistical package software, Version 2019, 1 [55].

3. Results

3.1. Productivity

The effect on terminal shoot flowering as a result of foliar spray with KNO_3 and/or putrescine at different concentrations is illustrated in Figure 1. Data obtained in the first and second seasons showed that all treatments had prominent effects in improving the terminal shoots flowering over the control. The minimum terminal shoot flowering was observed in the control: 29.43% and 30.18% in the first and second seasons, respectively. However, the maximum percentages of terminal shoots flowering (63.88% and 63.13%) were recorded under the treatment T9 (4% KNO_3 + 75 ppm Put), which was significantly superior to all other treatments, followed by treatment T8 (4% KNO_3 + 50 ppm Put) and T3 (4% KNO_3). Results also showed that higher concentrations markedly increased the percentage of flowering terminal shoots compared with lower ones. Meanwhile, the opposite trend was observed with putrescine.

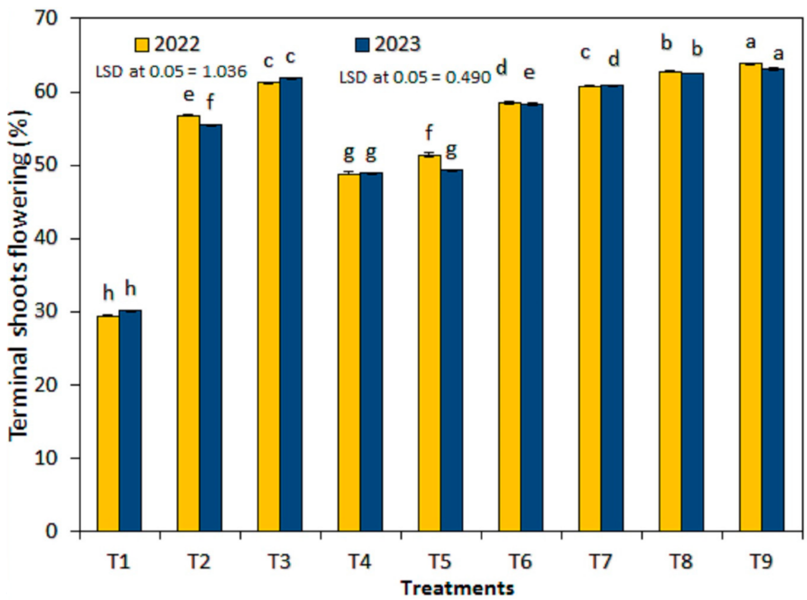

Figure 1. Effect of the sprayed potassium nitrate and putrescine on the number of terminal shoots of Ewais mango trees flowering in the 2022 and 2023 seasons. Different letters indicate significant differences at $p \leq 0.05$.

Data regarding the foliar spray of KNO_3 or putrescine at various concentrations, either alone or in combination, show significantly induced high positive effects on fruit set and fruit retention, as compared with control in both seasons, as shown in Table 2. Results illustrated that the treatment T9 (4% KNO_3 + 75 ppm Put) yielded the best number of fruit set (7.90% and 8.10%) and fruit retention (26.08% and 25.95%) in the first and second seasons, respectively, compared to untreated control. The next best treatments regarding these parameters were T7 (2% KNO_3 + 75 ppm Put) and T5 (75 ppm Put). All treatments with KNO_3 and putrescine succeeded in reducing fruit drop as compared with control in both seasons. The lowest fruit drop was recorded with T9 (4% KNO_3 + 75 ppm Put) as compared with control, which recorded the highest fruit drop. It is apparent from the data that higher concentrations of putrescine significantly improved fruit set, fruit retention, and fruit drop, as compared with lower concentrations, while the opposite trend was noticed with KNO_3. Similarly, all tested treatments exerted a higher number of fruits per tree, as compared with control. Generally, T9 (4% KNO_3 + 75 ppm Put) proved to be the superior treatment (288.50 and 289.10) as compared with control, which recorded the lowest number of fruits (159.50 and 161.0) in both seasons, respectively.

Table 2. Effect of the sprayed potassium nitrate and putrescine on fruit set, fruit drop, fruit retention, and number of fruit per tree of Ewais mango trees in the 2022 and 2023 seasons.

Treatments	Fruit Set (%)		Fruit Drop (%)		Fruit Retention (%)		Number of Fruit per Tree	
	2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
T1 (control)	3.88i	3.35i	85.68a	85.53a	14.32h	14.48h	159.50i	161.00i
T2	5.15h	5.28h	84.07b	83.73b	15.93g	16.28g	215.75f	218.00f
T3	5.75g	5.86g	81.82c	81.48c	18.18f	18.53f	268.50c	273.50c
T4	6.05f	6.25f	81.28cd	81.03d	18.72ef	18.98e	191.00h	197.75h
T5	7.10c	7.35c	79.12f	78.95f	20.88c	21.05c	204.75g	208.50g
T6	6.38e	6.60e	80.34de	80.18e	19.66de	19.83d	224.75e	225.50e
T7	7.48b	7.80b	75.18g	74.93g	24.82b	25.08b	237.75d	240.25d
T8	6.83d	7.05d	80.10e	79.88e	19.90d	20.13d	284.00b	285.25b
T9	7.90a	8.10a	73.92h	74.05h	26.08a	25.95a	288.50a	289.25a
LSD at $_{0.05}$	0.20	0.23	0.97	0.31	0.97	0.31	3.01	3.57

Values within a column with the same letter(s) are not significantly different by LSD ($p < 0.05$).

Statistical analysis of data presented in Figures 2 and 3 show that yield and yield increment were significantly influenced by all treatments with KNO_3 and putrescine and their combinations. The highest yield (kg/tree) and yield increment (%), (71.69 and 72.02) and (99.36 and 96.86) in the first and second seasons, respectively, were noticed with application of T9 (4% KNO_3 + 75 ppm Put), followed by T8 (4% KNO_3 + 50 ppm Put) and T3 (4% KNO_3).

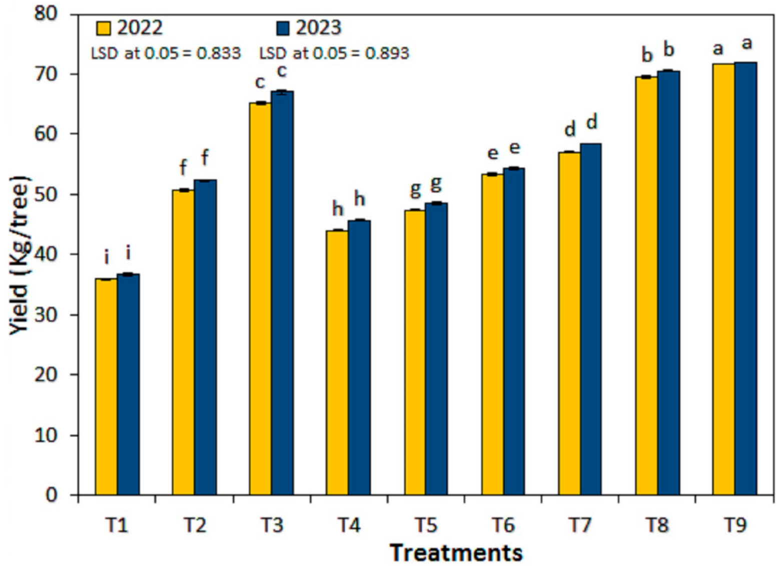

Figure 2. Effect of the sprayed potassium nitrate and putrescine on yield of Ewais mango trees in the 2022 and 2023 seasons. Different letters indicate significant differences at $p \leq 0.05$.

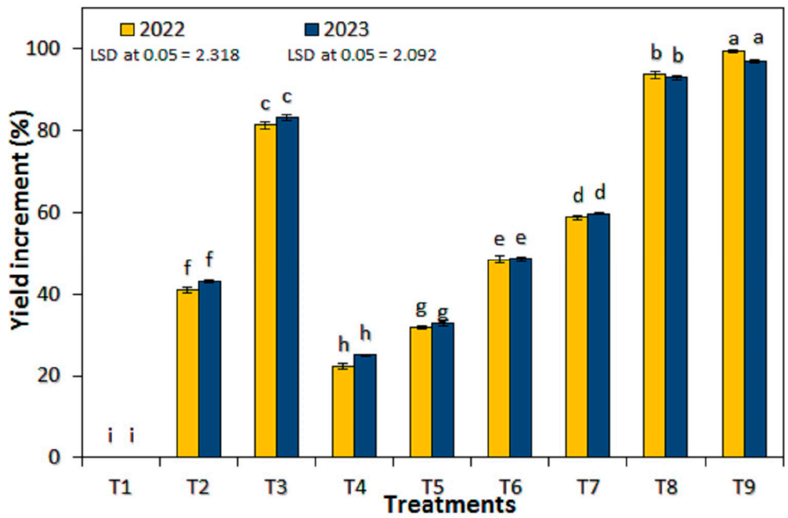

Figure 3. Effect of the sprayed potassium nitrate and putrescine on yield increment of Ewais mango trees in the 2022 and 2023 seasons. Different letters indicate significant differences at $p \leq 0.05$.

3.2. Physical and Chemical Characteristics

It is evident from data presented in Table 3 that all foliar applications with KNO_3, putrescine, or their combinations had a positive effect on improving the fruit physical properties over control. It is clear that the highest fruit weight was recorded under the treatment of T9 (4% KNO_3 + 75 ppm Put), with percent of increase up to 8.5% and 4.7% in the 2022 and 2023 seasons, respectively, as compared with control, followed by T8 (4% KNO_3 + 50 ppm Put) and T3 (4% KNO_3) which were also statistically at par with each other in the first season. Based on the data presented in Table 3, all spraying treatments had a significant effect on seed weight, peel weight, pulp weight, and firmness in both seasons. In this respect, fruits treated with T3 (4% KNO_3), either alone or combined with 75 ppm Put (T9) and 50 ppm Put (T8) in both seasons without significant differences, recorded the lowest values in seed and peel weight, while the opposite trend occurred with the pulp/fruit ratio in 2022 and 2023. Regarding the fruit dimension, data in Table 3 suggest that all treatments with KNO_3 and putrescine had prominent effects on improving fruit length and diameter, as compared with control, in both seasons. The highest fruit dimension (fruit length and diameter) (12.90 cm and 13.13 cm and 8.40 cm and 8.88 cm), respectively, in 2022 and 2023, were recorded under the treatment of T9 (4% KNO_3 + 75 ppm Put), which was significantly superior to all other treatments. Spraying trees with T3 (4% KNO_3), either alone or with 75 ppm Put and 50 ppm Put, considerably increased the shape index in both seasons, as compared with the untreated control trees. The data listed in Table 2 indicated that all fruits treated with T9 (4% KNO_3 +75 ppm Put) recorded the highest firmness (24.90 N and 24.85 N) in 2022 and 2023, respectively, followed by T3 (4% KNO_3) in both seasons. The other tested treatments gave a similar effect, with intermediate values as compared with untreated control fruits.

Table 3. Effect of the sprayed potassium nitrate and putrescine on fruit physical characteristics of Ewais mango fruits in the 2022 and 2023 seasons.

Season	Treatments	Fruit Weight (g)	Seed Weight (g)	Peel Weight (g)	Pulp/Fruit (%)	Fruit Length (cm)	Fruit Diameter (cm)	Shape Index	Fruit Firmness (N)
2022	T1 (control)	225.50g	11.10a	17.16a	87.47g	7.93h	6.45g	1.23d	19.55h
	T2	235.00e	10.13d	16.20c	88.80e	9.95f	6.45e	1.32c	23.20e
	T3	242.88b	9.09g	15.28e	89.97b	11.95c	7.51c	1.48a	24.65b
	T4	230.50f	10.75b	16.68b	88.10f	9.66g	8.10f	1.38b	22.20g
	T5	231.75f	10.42c	16.65b	88.32f	9.80gf	7.03f	1.37b	22.50f
	T6	237.50d	9.71e	15.78d	89.27d	10.25e	7.15d	1.32c	23.51d
	T7	240.18c	9.40f	15.68d	89.56c	10.65d	7.75d	1.36b	23.90c
	T8	245.10b	9.02g	15.22e	90.11ab	12.50b	7.83b	1.49a	24.83a
	T9	246.50a	8.96g	15.22e	90.19a	12.90a	8.40a	1.45a	24.90a
	LSD at $_{0.05}$	2.42	0.28	0.35	0.23	0.18	0.15	0.03	0.14
2023	T1 (control)	227.88i	11.50a	17.15a	87.43h	8.13i	6.38g	1.27c	19.65g
	T2	239.90f	10.18d	16.25c	88.98e	10.40f	7.68e	1.36b	23.13d
	T3	245.00c	9.07g	15.30e	90.05b	11.95c	8.25c	1.45a	24.48b
	T4	231.25h	10.85b	16.78b	88.05g	9.70h	7.10f	1.37b	22.15f
	T5	233.00g	10.53c	16.70b	88.31f	9.88g	7.20f	1.37b	22.70e
	T6	241.13e	9.73e	15.80d	89.41d	10.65e	7.80de	1.37b	23.34d
	T7	243.25d	9.39f	15.75d	89.66c	10.95d	7.90d	1.39b	23.85c
	T8	247.38b	9.00g	15.22e	90.21ab	12.35b	8.53b	1.45a	24.63b
	T9	249.00a	8.92g	15.20e	90.32a	13.13a	8.88a	1.48a	24.85a
	LSD at $_{0.05}$	0.22	0.29	0.18	0.21	0.16	0.18	0.03	0.22

Values within a column with the same letter(s) are not significantly different by LSD ($p < 0.05$).

Data presented in Table 4 illustrated that the fruits treated withT9 (4% KNO_3 + 75 ppm Put) markedly increased total soluble solid content TSS (19.10 and 19.25%) in 2022 and 2023, respectively. This is closely followed by T8 (4% KNO_3 + 50 ppm Put), which was, however, at par with T3 (4% KNO_3). The minimum TSS was recoded with control (15.63% and 15.55%) in both seasons. In terms of mango fruit acidity, all treatments with KNO_3 alone or combined with putrescine gave higher reductive effect values of acidity, as compared with control, in both seasons. Briefly, T9 (4% KNO_3 + 75 ppm Put) recorded the lowest value of acidity (0.54% and 0.56%) in both seasons. Conversely, both KNO_3 and Put increased the TSS/acid ratio. Treatment with T9 (4% KNO_3 +75 ppm Put) recorded the highest TSS/acid ratio (35.37 and 34.74) in both seasons. At the same time, the lowest value (12.81 and 12.32) for this trait was recorded in the untreated control (T1) fruits. It is noticed from Table 4 that the total sugar contents in fruits were significantly improved by all foliar treatments, at all concentrations, compared with control. The highest total sugars (14.30% and 14.38%) were found with T9 (4% KNO_3 + 75 ppm Put), with a percentage of increase over control of up to 26.2% and 28.7% in the 2022 and 2023 seasons, respectively, followed by T8 (4% KNO_3 + 50 ppm Put) and T3 (4% KNO_3). The reducing sugar contents in fruits were significantly increased by all tested treatments. The highest value for reducing sugars (4.10% and 4.18%)

was recorded in the fruits treated with T9 (4% KNO_3 + 75 ppm Put), closely followed by T8 (4% KNO_3 + 50 ppm Put), which were statistically at par with each other in the first season.

Table 4. Effect of the sprayed potassium nitrate and putrescine on chemical properties of the Ewais mango fruits of cv. in the 2022 and 2023 seasons.

Treatments	TSS (%)		Acidity (%)		TSS/Acidity		Total Sugars (%)		Reducing Sugar (%)	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
T1 (control)	15.63f	15.55g	1.22a	1.26a	12.81i	12.32i	10.55h	10.25h	3.43f	3.45f
T2	17.93d	18.00d	0.88d	0.91d	20.49f	19.89f	12.95f	12.66f	3.72d	3.72d
T3	18.75b	18.96b	0.61g	0.63g	30.74c	30.11c	13.65c	13.75c	4.03b	4.05b
T4	16.80e	16.63f	1.13b	1.13b	14.93h	14.71h	11.85g	11.70g	3.49ef	3.54e
T5	16.88e	16.93e	0.99c	1.04c	17.13g	16.33g	11.95g	11.78g	3.56e	3.60e
T6	18.05d	18.16cd	0.83e	0.86e	21.68e	21.25e	13.16e	12.93e	3.80cd	3.78cd
T7	18.35c	18.40c	0.80f	0.82f	23.01d	22.45d	13.40d	13.28d	3.85c	3.83c
T8	18.88ab	19.14ab	0.55h	0.58h	34.33b	33.01b	13.90b	14.10b	4.08ab	4.09b
T9	19.10a	19.25a	0.54i	0.56i	35.37a	34.74a	14.30a	14.38a	4.10a	4.18a
LSD at $_{0.05}$	0.215	0.250	0.016	0.023	0.767	0.993	0.197	0.175	0.086	0.065

Values within a column with the same letter(s) are not significantly different by LSD ($p < 0.05$).

All trees treated with KNO_3 and putrescine exerted higher positive effects on V.C content (Figure 4). The highest V.C content (32 mg/100 g.fw and 31.95 mg/100 g.fw) was recorded with T9 (4% KNO_3 + 75 ppm Put), followed by T7 (2% KNO_3 + 75 ppm Put) and T5 (75 ppm Put), which were statistically at par with each other in 2022. The data regarding the effect of KNO_3 and putrescine on total phenol content in mango fruits varied significantly among all treatments (Figure 5). Generally, T9 (4% KNO_3 + 75 ppm Put) exhibited the highest content of phenols (1.12% and1.13%) in both seasons, as compared with control. Also, all tested treatments with KNO_3 and putrescine gave higher positive effects on total carotenoid content (mg/100 g.fw) as compared with control (Figure 6). The maximum carotenoid content (4.65 mg/100 g.fw and 4.40 mg/100 g.fw) was found under treatment of T9 (4% KNO_3 + 75 ppm Put) in 2022 and 2023, respectively, which was somewhat at par with T7 (2% KNO_3 + 75 ppm Put) (4.45 mg/100 g.fw) in 2023.

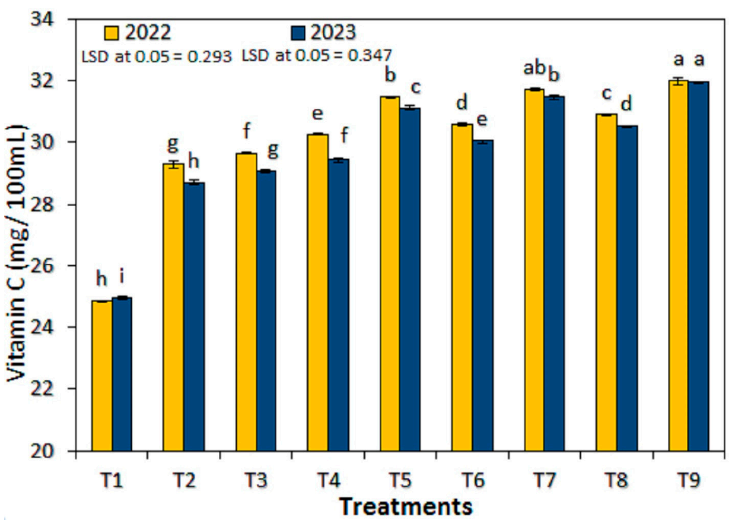

Figure 4. Effect of the sprayed potassium nitrate and putrescine on vitamin C of the Ewais mango fruits in the 2022 and 2023 seasons. Different letters indicate significant differences at $p \leq 0.05$.

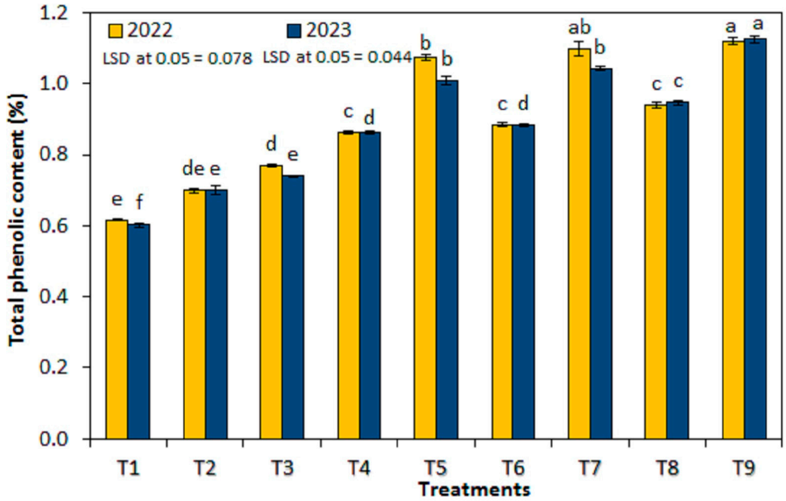

Figure 5. Effect of the sprayed potassium nitrate and putrescine on total phenols of the Ewais mango fruits in the 2022 and 2023 seasons. Different letters indicate significant differences at $p \leq 0.05$.

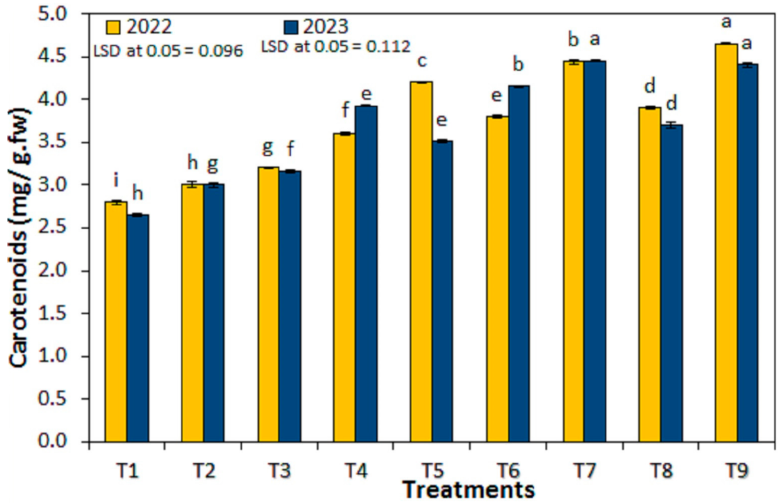

Figure 6. Effect of the sprayed potassium nitrate and putrescine on carotenoids of the Ewais mango fruits in the 2022 and 2023 seasons. Different letters indicate significant differences at $p \leq 0.05$.

4. Discussion

Mango fruit cv. Ewais is one of the most famous kinds of fruit in Egypt, receiving great attention due to its sweet taste and popularity in the market. Due to that, this research was conducted in an effort to improve its production and fruit quality. Foliar application of KNO_3 has been reported to improve mango fruit productivity by stimulating flower induction and inhibiting fruit growth, by increasing cell elongation and cell division [56,57]. Moreover, foliar spray of putrescine has been reported to display favorable changes on fruit growth, in addition to some physical and chemical characteristic changes [58,59]. In addition, fruit set, retention, and quality, and yield of trees grown could be improved by spraying putrescine [37]. Consequently, our experiment represents, for the first time, the synergistic effects of foliar spray of KNO_3 combined with putrescine on mango fruit growth, production, and finally, quality.

In this current study, more ascending percentages of flowering terminal shoots were noticed with increasing concentrations of KNO_3. This effect might be attributed to additional N from KNO_3, as increased nitrogen level to surpass the threshold allowing the plant to flower [60,61]. According to Rani [23], the buds will remain quiescent until conditions are favorable for flowering. Providing high concentrations of KNO_3 may activate those quiescent buds for floral initiation, as well as promote their early flowering, especially in mango.

Similar perceptions were also proclaimed by Kulkarni [24], who reported that KNO_3 may result in buds more sensitive to floral stimulus. The NO_3 ion is the active portion in KNO_3, which can easily break the dormancy of flower buds [62,63]. Similarly, Swany 2012 reported that KNO_3 can induce flowering by stimulating nitrate reductase, which is a key enzyme in the nitrate assimilatory pathway for amino acid synthesis (Methionine), which promotes mango flowering, and is a precursor of ethylene. It has been reported that the flowering of mango is mediated by high levels of ethylene [64]. Lauchli et al. [65] and Afiqah et al. [66] explained that KNO_3 could transform the shoots from their vegetative phase (dormant terminal bud) to their reproductive phase, from which they then grow in panicles and finally bear flowers. Generally, all treatments with KNO_3 and putrescine improved fruit set, fruit retention, and number of fruits per tree. The increase in fruit set due to putrescine could be attributed to improved embryo development [67], increased availability of ovules, and prolonged pistil longevity [68] by increasing pollen germination and improving the growth of pollen tubes [33]. Using putrescine earlier in the pre-anthesis stage of Comice pears delayed the senescence of visible flower parts and increased the ovule longevity [69]. According to Brown [70]; Singh and Janes [46], application of putrescine may be related to inhibiting endogenous ethylene by preventing 1-aminocyclopropane-1-carboxylic acid synthase biosynthesis, which is the mainly known trigger in abscission, especially during the initial 4–6 weeks of heavy fruitlets [13]. In litchi and apple, application of polyamine also increased fruit set, fruit retention, and the number of fruits/tree [71,72]. Likewise, Abd EL-Migeed et al. [73], revealed a synergistic effect between KNO_3 and putrescine on fruit set, fruit retention and yield. This suggestion is supported by the findings reported in this research, stating that combined spraying of KNO_3 and putrescine results in the highest fruit retention and the biggest decrease in the percentage of fruit drop, and consequently, increased fruit yield, in comparison with KNO_3 alone, in Ewais mango trees.

The positive increase in most fruits' physical characteristics—fruit length, fruit width, seed weight, pulp weight, pulp/fruit firmness, and fruit shape—may be attributed to the positive action of this combination, which supplied mangoes with their needed requirements of various nutrients involved in their cell division, cell enlargement, and increased volume of inter-cellular spaces in the mesocarpic cells [35–37,74]. High concentrations of polyamine may be related to high rates of fruit growth [37,75,76]. The high growth rate and active cell division of fruit development may increase fruit weight [8,77,78]. With respect to KNO_3, the enhancement of fruit yield due to KNO_3 could be related to the role of N and K nutrients to obtain higher productivity, and it might also be responsible for the improvement in the mobilization of minerals and food from other parts of the tree, towards developing fruits, which results in higher fruit retention, fruit weight, and marketable yield [79]. Positive response of the K nutrient as foliar spray in promoting fruit yield of mango was observed [20,26]. All treatments of KNO_3 have enhanced fruit chemical parameters when applied alone or combined with putrescine; meanwhile, the opposite trend was observed with putrescine alone. This prominent effect of KNO_3 is due to its fundamental role in the accumulation and assimilation of metabolic compounds in the fruits, resulting in higher accumulation of sugar content, and consequently improving TSS concentrations [80]. K helps with the translocations of sugars from leaves to developing fruits, as well as greater TSS content and better fruit quality [81]. There was a remarkable increase in sugar as a result of spraying with KNO_3, which contributed to greater concentrations of volatile components in fruits and hydroxylation of starch into reducing sugar. The usage of K resulted in earlier ripening, acid neutralization, due to development of high concentrations of K in plant tissue, and organic acid reduction [79]. Recently, it was reported thatK ions help loading and unloading of starch, because their sucrose synthetase enzyme is activated, thus converting starch into sugars [80]. The increase in reducing sugars could be attributed to the conversion of starch and acids into sugars, and also to the continuous mobilization of carbohydrates from leaves to fruits [82]. The enhanced effect of putrescine on fruit chemical properties may be attributed to the bioregulatory impact on enzymatic activity and translocation of the nutrients from the leaves to the developing fruits [83,84]. Contradictory results reported by Malik and Singh [13] suggested that spraying of putrescine decreased fruit sugar content, TSS, and firmness. The possible reason for lowering fruit sugar content might be the slower conversion of starch to sugars. Selvaraj et al. [85] also explained that putrescine may have suppressed the activities of the enzymes which are involved in sucrose metabolism (sucrose-phosphate synthase). Similarly, Costa et al. [86] reported that the application of putrescine decreased fruit sugar content and TSS in apple fruit. In litchi fruit, Mitra and Sanyal [72] found a reduction in total sugar content and an increase in fruit acidity when putrescine was applied before anthesis. The lower firmness, as a result of earlier spraying of putrescine in apple, could have also been attributed to this [71]. The respective increase in V.C (ascorbic acid) might be attributed to the effect of putrescine in inhibiting ascorbic acid oxidation by decreasing the ascorbate oxidase activity, accordingly maintaining ascorbic acid concentration [87]. These results are supported by Davarynejad et al. [88] in apricots, Razzaq et al. [45] in mangoes, and Hosseini et al. [89] in pears. The reason why total phenol increases in treated fruit might be attributed to its anti-senescence properties, because the activity of anti-oxidants increases with senescence [45,90,91]. Based on the results of this experiment, the improvement in the essential inherent plant properties (flowering, fruit growth, fruiting parameter, yield, total sugars, acidity, V.C, total phenols, and carotenoids) in response to the foliar applications may involve the synergistic effect of the combined treatments (KNO_3 + Put) tested in our experiment, and its clear dominance over the individual treatments.

5. Conclusions

The findings of this current study illustrated a positive effect of KNO_3 either alone or in combination with putrescine on the productivity and fruit quality of Ewais mango fruits. These foliar applications not only promoted fruit growth and yield, but also enhanced fruit quality (total sugar, acidity, V.C, TSS, total phenol content, and carotenoids). Therefore, the application of KNO_3 and putrescine enhanced the internal physiology of fruit, assuring that it obtained a reasonable supply of nutrients, essential for its growth and development, and thus, resulting in elevated flowering percentage and promotion of productivity, as well as, fruit quality. Specifically, KNO_3 sprayed at 4% along with putrescine at 75 ppm proved to be the most efficient in increasing the quality and quantity of Ewais fruits.

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