

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

Alebidi, Abdullah

<https://pearl.plymouth.ac.uk/handle/10026.1/21689>

---

10.3390/agronomy13112717

Agronomy




MDPI AG

---

*All content in PEARL is protected by copyright law. Author manuscripts are made available in accordance with publisher policies. Please cite only the published version using the details provided on the item record or document. In the absence of an open licence (e.g. Creative Commons), permissions for further reuse of content should be sought from the publisher or author.*

## Article

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

Abdullah Alebidi <sup>1</sup>, Mahmoud Abdel-Sattar <sup>1,\*</sup>, Laila Y. Mostafa <sup>2</sup>, Alhussein S. A. Hamad <sup>2</sup> and Hail Z. Rihan <sup>3</sup>

<sup>1</sup> Department of Plant Production, College of Food and Agriculture Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia; aalebidi@ksu.edu.sa

<sup>2</sup> Tropical Fruit Research Department, Horticulture Research Institute, Agricultural Research Centre, Giza P.O. Box 256, Egypt; layla\_yehya2009@yahoo.com (L.Y.M.); saberali.77@yahoo.com (A.S.A.H.)

<sup>3</sup> School of Biological and Marine Sciences, University of Plymouth, Plymouth PL4 8AA, UK; hail.rihan@plymouth.ac.uk

\* Correspondence: mmarzouk1@ksu.edu.sa or marzouk\_fakha@yahoo.com

**Abstract:** The current investigation represents of the synergistic effects of application of potassium nitrate (KNO<sub>3</sub>) 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<sub>3</sub>, 4% KNO<sub>3</sub>, 50 ppm Put, 75 ppm Put, 2% KNO<sub>3</sub> + 50 ppm Put, 2% KNO<sub>3</sub> + 75 ppm Put, 4% KNO<sub>3</sub> + 50 ppm Put, 4% KNO<sub>3</sub> + 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<sub>3</sub> 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<sub>3</sub> and putrescine to improve mango fruit yield and quality.

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



**Citation:** Alebidi, A.; Abdel-Sattar, M.; Mostafa, L.Y.; Hamad, A.S.A.; Rihan, H.Z. Synergistic Effects of Applying Potassium Nitrate Spray with Putrescine on Productivity and Fruit Quality of Mango Trees cv. Ewais. *Agronomy* **2023**, *13*, 2717. <https://doi.org/10.3390/agronomy13112717>

Academic Editor: Pasquale Losciale

Received: 8 October 2023

Revised: 24 October 2023

Accepted: 27 October 2023

Published: 28 October 2023



**Copyright:** © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 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].  $\text{KNO}_3$  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%  $\text{KNO}_3$ , 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<sub>3</sub>) 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<sub>2</sub>O<sub>5</sub>) during February, both at a rate of 60 m<sup>3</sup>, 300 kg per hectare,. Organic manure used was composed of 22% organic C, 44% organic matter, 1.24% N, 0.36% P<sub>2</sub>O<sub>5</sub>, 1.40% K<sub>2</sub>O, 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<sub>2</sub>O), and magnesium sulphate heptahydrate (15.9% MgO, 47.8% MgSO<sub>4</sub>) 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 <sub>3</sub> (%) | OM (%) | Soluble Cations (meq/L) |                  |                  |                | Soluble Anions (meq/L)        |                 |                              |
|-----------------|----------------|----------|----------|--------------|------|-----------|-----------------------|--------|-------------------------|------------------|------------------|----------------|-------------------------------|-----------------|------------------------------|
|                 | Sand (%)       | Clay (%) | Silt (%) |              |      |           |                       |        | Na <sup>+</sup>         | Ca <sup>2+</sup> | Mg <sup>2+</sup> | K <sup>+</sup> | HCO <sub>3</sub> <sup>-</sup> | Cl <sup>-</sup> | SO <sub>4</sub> <sup>-</sup> |
|                 |                |          |          |              |      |           |                       |        |                         |                  |                  |                |                               |                 |                              |
| 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  $\times$  4 replicates  $\times$  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<sub>3</sub> (T2), 4% KNO<sub>3</sub> (T3), 50 ppm Put (T4), 75 ppm Put (T5), 2% KNO<sub>3</sub> + 50 ppm Put (T6), 2% KNO<sub>3</sub> + 75 ppm Put (T7), 4% KNO<sub>3</sub> + 50 ppm Put (T8), 4% KNO<sub>3</sub> + 75 ppm Put (T9). KNO<sub>3</sub> and Put were sprayed at three different phenological 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  $\times$  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)  $\times$  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 to 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].

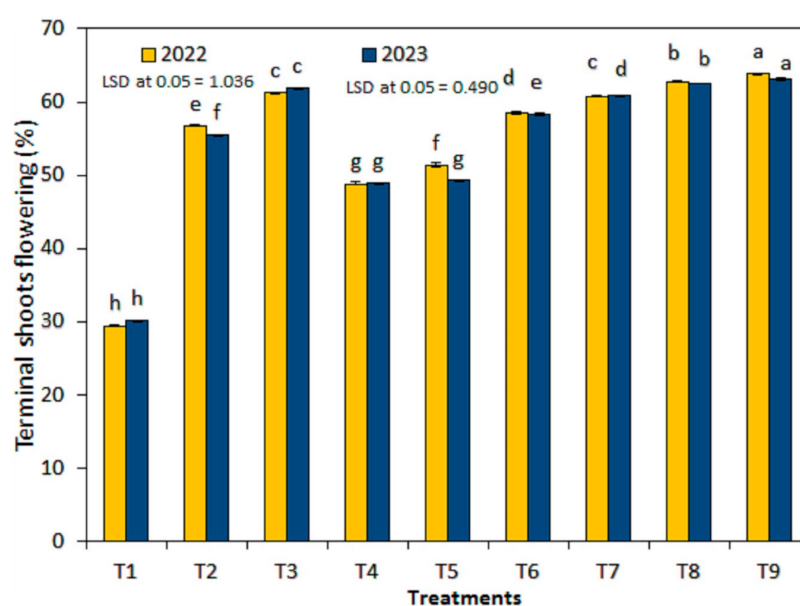
#### 2.4. Statistical Analysis

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  $\text{KNO}_3$  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%  $\text{KNO}_3$  + 75 ppm Put), which was significantly superior to all other treatments, followed by treatment T8 (4%  $\text{KNO}_3$  + 50 ppm Put) and T3 (4%  $\text{KNO}_3$ ). 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  $p \leq 0.05$ .

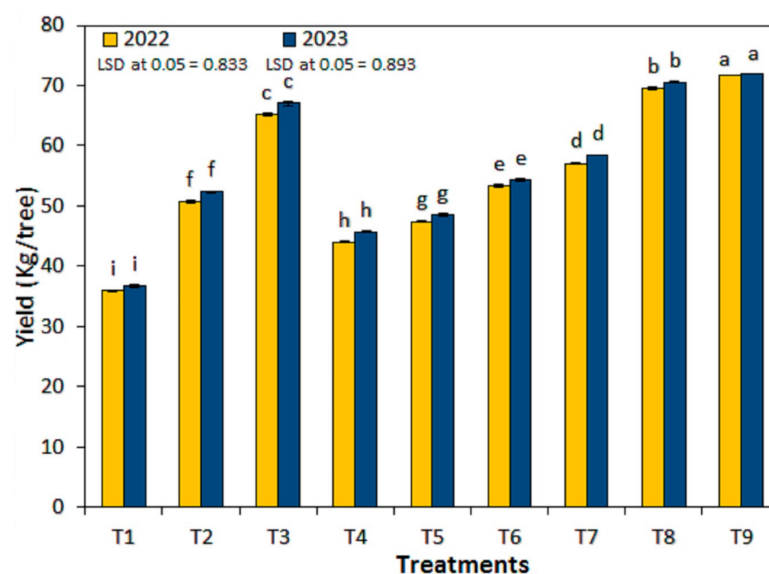
Data regarding the foliar spray of  $\text{KNO}_3$  or putrescine at various concentrations, either alone or in combination, show significantly induced high positive effects on fruit set and fruit retention, as compared with control in both seasons, as shown in Table 2. Results illustrated that the treatment T9 (4%  $\text{KNO}_3$  + 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%  $\text{KNO}_3$  + 75 ppm Put) and T5 (75 ppm Put). All treatments with  $\text{KNO}_3$  and putrescine succeeded in reducing fruit drop as compared with control in both seasons. The lowest fruit drop was recorded with T9 (4%  $\text{KNO}_3$  + 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  $\text{KNO}_3$ . Similarly, all tested treatments exerted a higher number of fruits per tree, as compared with control. Generally, T9 (4%  $\text{KNO}_3$  + 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.

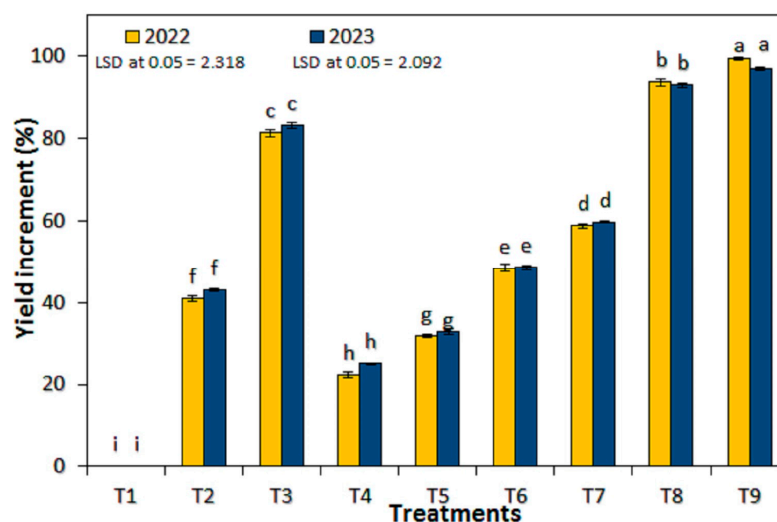
| Treatments       | Fruit Set (%) |       | Fruit Drop (%) |        | Fruit Retention (%) |        | Number of Fruit per Tree |         |
|------------------|---------------|-------|----------------|--------|---------------------|--------|--------------------------|---------|
|                  | 2022          | 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  $\text{KNO}_3$  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%  $\text{KNO}_3$  + 75 ppm Put), followed by T8 (4%  $\text{KNO}_3$  + 50 ppm Put) and T3 (4%  $\text{KNO}_3$ ).



**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  $\text{KNO}_3$ , 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%  $\text{KNO}_3$  + 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%  $\text{KNO}_3$  + 50 ppm Put) and T3 (4%  $\text{KNO}_3$ ) 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%  $\text{KNO}_3$ ), 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  $\text{KNO}_3$  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<sub>3</sub> + 75 ppm Put), which was significantly superior to all other treatments. Spraying trees with T3 (4% KNO<sub>3</sub>), 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<sub>3</sub> +75 ppm Put) recorded the highest firmness (24.90 N and 24.85 N) in 2022 and 2023, respectively, followed by T3 (4% KNO<sub>3</sub>) 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 with T9 (4% KNO<sub>3</sub> + 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<sub>3</sub> + 50 ppm Put), which was, however, at par with T3 (4% KNO<sub>3</sub>). The minimum TSS was recorded with control (15.63% and 15.55%) in both seasons. In terms of mango fruit acidity, all treatments with KNO<sub>3</sub> alone or combined with putrescine gave higher reductive effect values of acidity, as compared with control, in both seasons. Briefly, T9 (4% KNO<sub>3</sub> + 75 ppm Put) recorded the lowest value of acidity (0.54% and 0.56%) in both seasons. Conversely, both KNO<sub>3</sub> and Put increased the TSS/acid ratio. Treatment with T9 (4% KNO<sub>3</sub> +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<sub>3</sub> + 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<sub>3</sub> + 50 ppm Put) and T3 (4% KNO<sub>3</sub>). The reducing sugar contents in fruits were significantly increased by all tested treatments. The highest value for reducing sugars (4.10% and 4.18%)

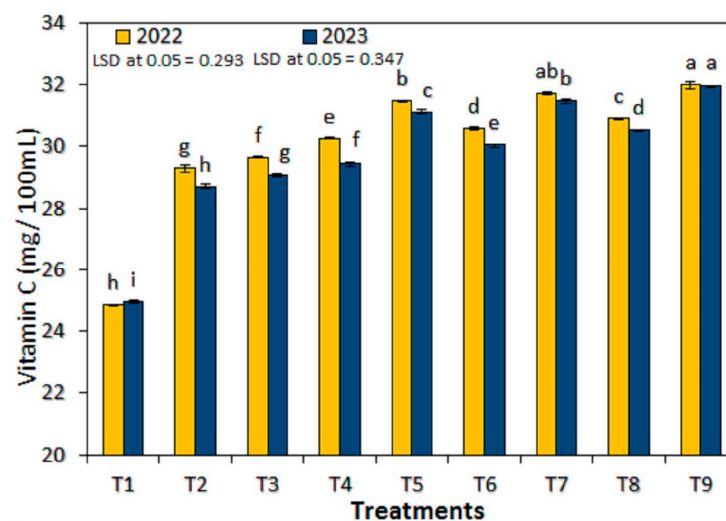
was recorded in the fruits treated with T9 (4% KNO<sub>3</sub> + 75 ppm Put), closely followed by T8 (4% KNO<sub>3</sub> + 50 ppm Put), which were statistically at par with each other in the first season.

**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.

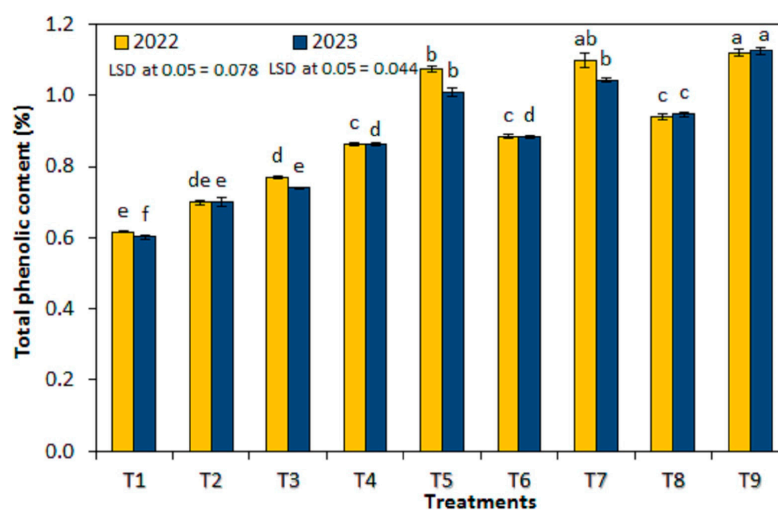
| Treatments   | TSS (%) |         | Acidity (%) |       | TSS/Acidity |        | Total Sugars (%) |        | Reducing Sugar (%) |        |
|--------------|---------|---------|-------------|-------|-------------|--------|------------------|--------|--------------------|--------|
|              | 2022    | 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 ( $p < 0.05$ ).

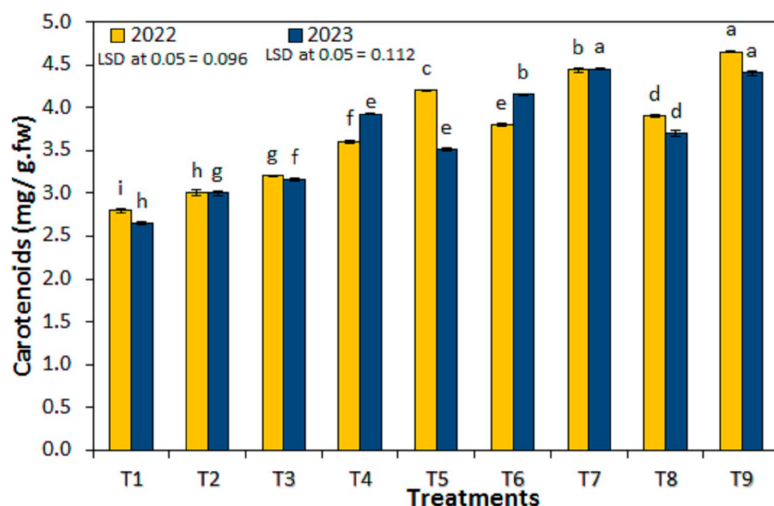
All trees treated with KNO<sub>3</sub> and putrescine exerted higher positive effects on V.C content (Figure 4). The highest V.C content (32 mg/100 g.fw and 31.95 mg/100 g.fw) was recorded with T9 (4% KNO<sub>3</sub> + 75 ppm Put), followed by T7 (2% KNO<sub>3</sub> + 75 ppm Put) and T5 (75 ppm Put), which were statistically at par with each other in 2022. The data regarding the effect of KNO<sub>3</sub> and putrescine on total phenol content in mango fruits varied significantly among all treatments (Figure 5). Generally, T9 (4% KNO<sub>3</sub> + 75 ppm Put) exhibited the highest content of phenols (1.12% and 1.13%) in both seasons, as compared with control. Also, all tested treatments with KNO<sub>3</sub> 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<sub>3</sub> + 75 ppm Put) in 2022 and 2023, respectively, which was somewhat at par with T7 (2% KNO<sub>3</sub> + 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  $\text{KNO}_3$  may result in buds more sensitive to floral stimulus. The  $\text{NO}_3$  ion is the active portion in  $\text{KNO}_3$ , which can easily break the dormancy of flower buds [62,63]. Similarly, Swamy 2012 reported that  $\text{KNO}_3$  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  $\text{KNO}_3$  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  $\text{KNO}_3$  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  $\text{KNO}_3$  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  $\text{KNO}_3$  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  $\text{KNO}_3$  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  $\text{KNO}_3$ , the enhancement of fruit yield due to  $\text{KNO}_3$  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  $\text{KNO}_3$  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  $\text{KNO}_3$  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  $\text{KNO}_3$ , 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 that K 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 ( $\text{KNO}_3$  + 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  $\text{KNO}_3$  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  $\text{KNO}_3$  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,  $\text{KNO}_3$  sprayed at 4% along with putrescine at 75 ppm proved to be the most efficient in increasing the quality and quantity of Ewais fruits.

**Author Contributions:** Conceptualization, M.A.-S. and A.A.; Data curation, M.A.-S. and L.Y.M.; Formal analysis, M.A.-S., A.A., A.S.A.H. and L.Y.M.; Methodology, M.A.-S. and L.Y.M.; Investigation, M.A.-S., A.S.A.H. and L.Y.M.; Resources, M.A.-S., A.A., H.Z.R. and L.Y.M.; Software, M.A.-S., A.A. and L.Y.M.; Validation, M.A.-S. and H.Z.R.; Visualization, M.A.-S. and H.Z.R.; Writing—original draft preparation, M.A.-S., A.A., H.Z.R., A.S.A.H. and L.Y.M.; Writing—review and editing, M.A.-S., A.A., H.Z.R., A.S.A.H. and L.Y.M.; Supervision, M.A.-S. and A.A.; Funding acquisition, M.A.-S. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Researchers Supporting Project (number: RSPD2023R707), King Saud University, Riyadh, Saudi Arabia.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Acknowledgments:** The authors extend their appreciation to the Researchers Supporting Project (number: RSPD2023R707), King Saud University, Riyadh, Saudi Arabia.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Normand, F.; Lauri, P.É.; Legave, J.M. Climate change and its probable effects on mango production and cultivation. *Acta Hort.* **2015**, *1075*, 21–31. [[CrossRef](#)]

2. Abdel-Sattar, M.; Ibrahim, A.M.; Ashmawy, N.A.; Shams, E. A study on normal and nubbin productivity of some mango trees in relation to quantification of expressed gene levels. *J. Plant Prod. Mansoura Univ.* **2017**, *8*, 805–811. [[CrossRef](#)]
3. Yadav, D.; Singh, S. Mango: History, origin, and distribution. *J. Pharmacogn. Phytochem.* **2017**, *6*, 1257–1262.
4. Rymbai, H.; Srivastar, M.; Sharma, R.R.; Patel, C.R. Bio-active compounds in mangoes and their roles in human health and plant defence. *J. Hort. Sci. Biotechnol.* **2013**, *88*, 369–379. [[CrossRef](#)]
5. Maldonado-Celis, M.E.; Yahia, E.M.; Bedoya, R.; Landázuri, P.; Loango, N.; Aguillón, J.; Restrepo, B.; Guerrero Ospina, J.C. Chemical Composition of Mango (*Mangifera indica* L.) Fruit: Nutritional and Phytochemical Compounds. *Front. Plant Sci.* **2019**, *10*, 1073. [[CrossRef](#)]
6. Wannabussapawich, B.; Seraypheap, K. Effects of putrescine treatment on the quality attributes and antioxidant activities of ‘Nam Dok Mai No.4’ mango fruit during storage. *Sci. Hort.* **2018**, *233*, 22–28. [[CrossRef](#)]
7. Kumari, J.; Kumar, R.; Sinha, S.; Kumari, A.; Kumari, P. Impact of chemicals on fruit set and yield contributing characteristics of mango (*Mangifera indica* L.) cv. Langra. *J. Pharmacogn. Phytochem.* **2018**, *7*, 1057–1059.
8. Sarker, B.C.; Rahim, M.A. Yield and quality of Mango (*Mangifera indica*) as influenced by foliar application of potassium nitrate and urea. *Bangladesh J. Agric. Res.* **2013**, *38*, 145–154. [[CrossRef](#)]
9. da Silva Santos, A.J.; de Paiva Neto, V.B.; Sanches, L.G.; Carreiro, D.A.; Pereira, M.P.M.; Borges, M.C.R.Z.; Rodrigues dos Santos, S.E.; Cavalcante, Í.H.L. Nitrate reductase activity in the different phenophases of ‘palmer’ mango cultivated in the semiarid. *J. Appl. Bot. Food Qual.* **2021**, *94*, 192–198. [[CrossRef](#)]
10. Sudha, R.; Balomomhan, T.N.; Sooriansundaram, K. Effect of foliar spray of nitrogenous chemicals on flowering, fruit set, yield in mango (*Mangifera indica* L.) cv. Alphonso. *J. Hort. Sci.* **2012**, *7*, 190–193. [[CrossRef](#)]
11. Parauha, S.; Pandey, S.K. Influence of plant growth regulators and nutrients on fruit retention, yield and quality attributes of mango (*Mangifera indica* L.) cv. Amrapali. *J. Pharmacogn. Phytochem.* **2019**, *8*, 550–555.
12. Moradinezhad, F.; Dorostkar, M. Pre-harvest Foliar Application of Calcium Chloride and Potassium Nitrate Influences Growth and Quality of Apricot (*Prunus armeniaca* L.) Fruit cv. ‘Shahroudi’. *J. Soil Sci. Plant Nutr.* **2021**, *21*, 1642–1652. [[CrossRef](#)]
13. Malik, A.U.; Singh, Z. Improved fruit retention, yield and fruit quality in mango with exogenous application of polyamines. *Sci. Hort.* **2006**, *110*, 167–174. [[CrossRef](#)]
14. Ramírez, F.; Davenport, T.L. Mango (*Mangifera indica* L.) flowering physiology. *Sci. Hort.* **2010**, *162*, 65–72. [[CrossRef](#)]
15. Anees, M.A.; Ali, A.; Shakoor, U.; Ahmed, F.; Hasnain, Z.; Hussain, A. Foliar applied potassium and zinc enhances growth and yield performance of maize under rainfed conditions. *Int. J. Agric. Biol.* **2016**, *18*, 1025–1032. [[CrossRef](#)]
16. Alebidi, A.; Almutairi, K.; Merwad, M.; Mostafa, E.; Saleh, M.; Ashour, N.; Al-Obeed, R.; Elsabagh, A. Effect of Spraying Algae Extract and Potassium Nitrate on the Yield and Fruit Quality of Barhee Date Palms. *Agronomy* **2021**, *11*, 922. [[CrossRef](#)]
17. Mirza, H.; Borhannuddin, M.H.M.; Nahar, K.; Hossain, S.; AlMahmud, J.; Hossen, S.; Masud, A.A.; Fujita, M. Potassium: a vital regulator of plant responses and tolerance to a biotic stresses. *Agronomy* **2018**, *8*, 31. [[CrossRef](#)]
18. Kanai, S.; Moghaieb, R.E.; El-Shemy, H.A.; Panigrahi, R.; Mohapatra, P.K.; Ito, J.; Fujita, K. Potassium deficiency affects water status and photosynthetic rate of the vegetative sink in green house tomato prior to its effects on source activity. *Plant Sci.* **2011**, *180*, 368–374. [[CrossRef](#)] [[PubMed](#)]
19. Maloba, S.; Ambuko, J.; Hutchinson, M.; Owin, W. Off-Season Flower Induction in Mango Fruits Using Ethephon and Potassium Nitrate. *J. Agric. Sci.* **2017**, *9*, 158–167. [[CrossRef](#)]
20. Al-Saif, A.M.; Mosa, W.F.A.; Saleh, A.A.; Ali, M.M.; Sas-Paszt, L.; Abada, H.S.; Abdel-Sattar, M. Yield and Fruit Quality Response of Pomegranate (*Punica granatum*) to Foliar Spray of Potassium, Calcium and Kaolin. *Horticulturae* **2022**, *8*, 946. [[CrossRef](#)]
21. Rojas, E.; Leal, F.; Campbell, R.J. Control of flowering and shooting in mango (*Mangifera indica* L.) with various chemical products. *Proc. Int. Soc. Trop. Trop. Hort.* **1993**, *37*, 142–147.
22. Catchpoole, D.W.; Bally, I.S.E. Earlier flowering and more fruit. *Mango Care Newsl.* **1993**, *8*, 2–3.
23. Rani, K.U. Advances in crop regulation in mango (*Mangifera indica* L.). *Int. J. Curr. Microbiol. Appl. Sci.* **2018**, *7*, 35–42. [[CrossRef](#)]
24. Kulkarni, V.J. The tri-factor hypothesis of flowering in mango. *Acta Hort.* **2004**, *645*, 61–70. [[CrossRef](#)]
25. Davenport, T.L. Reproductive physiology. In *The Mango: Botany, Production and Uses*, 2nd ed.; Litz, R.E., Ed.; CAB International: Wallingford, UK, 2009; pp. 97–169. [[CrossRef](#)]
26. Yeshitela, T.; Robbertse, P.J.; Stassen, P.J.C. Potassium nitrate and urea sprays affect flowering and yields of ‘Tommy Atkins’ (*Mangifera indica*) mango in Ethiopia. *S. Afr. Tydskr. Plant Grond* **2005**, *22*, 28–32. [[CrossRef](#)]
27. Ramírez, F.; Davenport, T.L.; Fischer, G.; Pinzón, J.C.A. The Stem Age Required for Floral Induction of Synchronized Mango Trees in the Tropics. *HortScience* **2010**, *45*, 1453–1458. [[CrossRef](#)]
28. Chen, D.; Shao, Q.; Yin, L.; Younis, A.; Zheng, B. Polyamine Function in Plants: Metabolism, Regulation on Development, and Roles in Abiotic Stress Responses. *Front. Plant Sci.* **2019**, *9*, 1945. [[CrossRef](#)]
29. Galston, A.W.; Kaur-Sawhney, R. Polyamines as endogenous growth regulators. In *Plant Hormones. Physiology, Biochemistry and Molecular Biology*; Davies, P.J., Ed.; Kluwer: Dordrecht, The Netherlands, 1990; pp. 158–178.
30. Bouchereau, A.; Aziz, A.; Larher, F.; Tanguy, J.M. Polyamines and environmental challenges: Recent development. *Plant Sci.* **1999**, *140*, 103–125. [[CrossRef](#)]
31. Childs, A.C.; Mehta, D.J.; Gerner, E.W. Polyamines dependent gene expression. *Cell. Mol. Life Sci.* **2003**, *60*, 1394–1406. [[CrossRef](#)]
32. Song, J.; Nadab, K.; Tachibanab, S. Ameliorative effect of polyamines on high temperature inhibition of in vitro pollen germination in Tomato (*Lycopersicon esculentum* Mill.). *Sci. Hort.* **1999**, *80*, 203–212. [[CrossRef](#)]

33. Wolukau, J.N.; Zhang, S.L.; Xu, G.H.; Chen, D. The effect of temperature, polyamines and polyamine synthesis inhibitor on in vitro pollen germination and pollen tube growth of *Prunus mume*. *Sci. Hortic.* **2004**, *99*, 289–299. [[CrossRef](#)]
34. Kitashiba, H.; Hao, Y.-J.; Honda, C.; Moriguchi, T. Two types of spermine synthase gene: MdACL5 and MdSPMS are differentially involved in apple fruit development and cell growth. *Gene* **2005**, *361*, 101–111. [[CrossRef](#)] [[PubMed](#)]
35. Faust, M.; Wang, S.Y. Polyamines in horticulturally important plants. *Hortic. Rev.* **2010**, *14*, 3–356.
36. Mahgoub, M.H.; Abd El Aziz, N.G.; Mazhar, A.M.A. Response of *Dahlia pinnata* L. plant to foliar spray with putrescine and thiamine on growth, flowering and photosynthetic pigments. *Am. Eurasian J. Agric. Environ. Sci.* **2011**, *10*, 769–775.
37. Abdel-Sattar, M.; Marzouk, H.; Al-Sabrou, M. Enhancement of Hollywood plum setting, retention and fruit quality. *J. Appl. Sci. Res.* **2013**, *9*, 4125–4131.
38. Gonzalez-Aguilar, G.A.; Zacarias, L.; Mulas, M.; Lafuente, M.T. Temperature and duration of water dips influence chilling injury, decay and polyamine content in Fortune mandarins. *Postharvest Biol. Technol.* **1997**, *12*, 61–69. [[CrossRef](#)]
39. Sharma, M.; Kumar, B.; Pandey, D.M. Effect of pre-flowering foliar application of putrescine on ion composition of seeds of chick pea (*Cicer arietinum* L. cv. H-82-2) raised under saline conditions. *Ann. Agric Bio Res.* **1997**, *2*, 111–113.
40. Singh, A.; Ansari, M.W.; Rani, V.; Singh, C.P.; Shukla, A.; Pant, R.C.; Tuteja, N.; Bains, G. First evidence of putrescine involvement in mitigating the floral malformation in mangoes: A scanning electron microscope study. *Protoplasma* **2014**, *251*, 1255–1261. [[CrossRef](#)]
41. Pandey, S.; Ranade, S.A.; Nagar, P.K.; Kumar, N. Role of polyamines and ethylene as modulators of plant senescence. *J. Biosci.* **2000**, *25*, 291–299. [[CrossRef](#)]
42. Ali, M.S.; Elhamahmy, M.A.; El-Shiekh, A.F. Mango trees productivity and quality as affected by Boron and Putrescine. *Sci. Hortic.* **2017**, *216*, 248–255. [[CrossRef](#)]
43. Kakkar, R.K.; Rai, V.K. Plant polyamines in flowering and fruit ripening. *Phytochemistry* **1993**, *33*, 1281–1288.
44. Malik, A.U.; Singh, Z.; Dhaliwal, S.S. Exogenous Application of Putrescine Affects Mango Fruit Quality and Shelf Life. *Acta Hortic.* **2003**, *628*, 121–127. [[CrossRef](#)]
45. Razzaq, K.; Khan, A.S.; Malik, A.U.; Shahid, M.; Ullah, S. Role of putrescine in regulating fruit softening and antioxidative enzyme systems in ‘Samar Bahisht Chaunsa’ mango. *Postharvest Biol. Technol.* **2014**, *96*, 23. [[CrossRef](#)]
46. Singh, Z.; Janes, J. Regulation of fruit set and retention in mango with exogenous application of polyamines and their biosynthesis inhibitors. *Acta Hortic.* **2000**, *509*, 675–680. [[CrossRef](#)]
47. Shaban, A.E.A.; Kamel, H.M.; Rashedy, A.A.; Abd El-Migeed, M.M.M.; Moawad, H.M. Effect of putrescine and whey on improving productivity and fruit quality of Eweis mango. *Middle East J. Agric. Res.* **2017**, *6*, 908–915.
48. Jawandha, S.K.; Gill, M.S.; Singh, N.P.; Gill, P.P.S.; Singh, N. Effect of post-harvest treatments of putrescine on storage of mango cv. Langra. *Afr. J. Agric. Res.* **2012**, *7*, 6432–6436.
49. Association of Official Analytical Chemists (AOAC). *Official Method of Analysis*, 21st ed.; AOAC: Washington, DC, USA, 2019.
50. Malik, C.P.; Singh, M.B. *Plant Enzymology and Histochemistry*; A Text Manual; Kalyani Publishers: New Delhi, India, 1980.
51. Egan, H.; Kirk, R.S.; Sawyer, R. *Pearson’s Chemical Analysis of Food*; Churchill Livingstone: Edinburgh, UK, 1981; p. 591.
52. Swain, T.; Hillis, W.E. The phenolic constituents of *Prunus domestica*. I.—The quantitative analysis of phenolic constituents. *J. Sci. Food Agric.* **1959**, *10*, 63–68. [[CrossRef](#)]
53. Moran, R.; Porath, D. Carotenoids determination in intact tissues. *Plant Physiol.* **1980**, *65*, 479. [[CrossRef](#)]
54. Snedecor, G.W.; Cochran, W.G. *Statistical Methods*, 7th ed.; Iowa State University Digital Press: Ames, IA, USA, 1990; p. 593.
55. XLSTAT Statistical Package. *The XLSTAT System for Windows*; Version 2019.1; Excel Add-ins soft SARL: New York, NY, USA, 2019.
56. Koheri, A.; Mariati, M.; dan Simanungkalit, T. Tanggap Pertumbuhan Dan Produksi Bawang Merah (*Allium ascalonicum* L.) Terhadap Waktu Aplikasi Dan Konsentrasi Pupuk KNO<sub>3</sub>. *J. Agroekoteknologi Univ. Sumat. Utara* **2015**, *3*, 102974.
57. Utomo, P.S.; Suprianto, A. Respon Pertumbuhan dan produksi tanaman bawang merah (*Allium ascalonicum* L.) varietas thailand terhadap perlakuan dosis pupuk kusuma bioplus dan KNO<sub>3</sub> putih. *J. Ilm. Hijau Cendekia* **2019**, *4*, 28–33.
58. Hagagg, L.F.; Abd-Alhamid, N.; Hassan, H.S.A.; Hassan, A.M.; Geanidy, E.A.E. Influence of foliar application with putrescine, salicylic, and ascorbic acid on the productivity and physical and chemical fruit properties of Picual olive trees. *Bull. Natl. Res. Cent.* **2020**, *44*, 2–11.
59. Talaat, N.B.; Nesiem, M.R.A.; Gadalla, E.G.; Ali, S.F. Putrescine, in Combination with Gibberellic Acid and Salicylic Acid, Improves Date Palm Fruit Quality via Triggering Protein and Carbohydrate Accumulation and Enhancing Mineral, Amino Acid, Sugar, and Phytohormone Acquisition. *J. Plant Growth Regul.* **2023**. [[CrossRef](#)]
60. Protacio, C.M. A model for potassium nitrate-induced flowering in mango. *Acta Hortic.* **2000**, *509*, 545–552. [[CrossRef](#)]
61. Yeshitela, T.; Robbertse, P.I.; Stassen, P.I.C. Effects of various inductive periods and chemicals on flowering and vegetative growth of ‘Tommy Atkins’ and ‘Keitt’ mango (*Mangifera indica*) cultivars. *N. Z. J. Crop Hortic. Sci.* **2004**, *32*, 209–215. [[CrossRef](#)]
62. Patil, K.R.; Burondkar, M.M.; Bhave, S.G.; Nigade, P.M. Post-harvest chemical induction of vegetative growth and its physiological behavior in relation to regulation of flowering in ‘Alphonso’ mango (*Mangifera indica* L.). *Acta Hortic.* **2013**, *992*, 193–200. [[CrossRef](#)]
63. Katwesige, A.; Ddamulira, G.; Katurumunda, S. Effect of Potassium Nitrate Spray on the Flowering and Fruiting of Mango Varieties Grown in Uganda. *Int. J. Plant Soil Sci.* **2022**, *34*, 80–93. [[CrossRef](#)]
64. Davenport, T.L.; Nunez-Elisea, R. Ethylene and other endogenous factors possibly involved in mango flowering. *Acta Hortic.* **1997**, *275*, 441–448. [[CrossRef](#)]

65. Lauchli, U.; Pierre, M.; Normand, F. Season effects of leaf nitrogen partitioning and photosynthetic water use efficiency in mango. *J. Plant Physiol.* **2006**, *163*, 48–57.
66. Afiqah, A.; Nulit, R.; Hawa, Z.E.J.; Kusnan, M. Improving the yield of ‘Chok Anan’ (Ma 224) mango with potassium nitrate foliar sprays. *Int. J. Fruit Sci.* **2014**, *14*, 416–423. [[CrossRef](#)]
67. Ponce, M.T.; Guinazu, M.; Tizio, R. Effect of Putrescine on embryo development in the stenopermocarpic grape cvs Emperatriz and Fantasy. *Vitis* **2002**, *41*, 53–54.
68. Wang, S.; Song, C.; Li, L.; Zhang, Y.; Wang, S.P.; Song, C.B.; Li, L.C.; Zhang, Y.M. Physiological function of polyamines during blossoming and fruit setting in apple. *Acta Hort. Sin.* **1996**, *23*, 319–325.
69. Crisosto, C.H.; Vasilakakis, M.D.; Lombard, P.B.; Richardson, D.; Tetley, R. Effect of ethylene inhibitors on fruit set, ovule longevity, and polyamine levels in ‘Comice pear’. *Acta Hort.* **1986**, *179*, 236–239.
70. Brown, K.M. Ethylene and abscission. *Physiol. Plant* **1997**, *100*, 567–576. [[CrossRef](#)]
71. Costa, G.; Bagni, N. Effect of polyamines on fruit set of apple. *Hortscience* **1983**, *18*, 59–61. [[CrossRef](#)]
72. Mitra, S.K.; Sanyal, D. Effect of putrescine on fruit set and fruit quality of litchi. *Gartenbauwissenschaft* **1990**, *55*, 83–84.
73. Abd El-Migeed, M.M.M.; Mostafa, E.A.M.; Ashour, N.E.; Hassan, H.S.A.; Mohamed, D.M.; Saleh, M.M.S. Effect of potassium and poly amine sprays on fruit set, fruit retention, yield and fruit quality of Amhat date palm. *Int. J. Agric. Res.* **2013**, *8*, 77–86. [[CrossRef](#)]
74. Malik, A.U.; Singh, Z. Endogenous free polyamines of mangos in relation to development and ripening. *J. Am. Soc. Hort. Sci.* **2004**, *129*, 280–286. [[CrossRef](#)]
75. Shiozaki, S.; Ogata, T.; Horiuchi, S.; Zhuo, X. Involvement of polyamines in gibberellin-induced development of seedless grape berries. *Plant Growth Regul.* **1998**, *25*, 187–193. [[CrossRef](#)]
76. Fraga, M.F. Changes in polyamine concentration associated with aging in pinus radiata prunus persica. *Tree Physiol.* **2004**, *24*, 1221–1226. [[CrossRef](#)]
77. Krishnamoorthy, H.N. *Plant Growth Regulators Substances including Application in Agriculture*; Tata McGraw Hill Publishing Co., Ltd.: New Delhi, India, 1981; pp. 1–87.
78. Ali, E.A.M.; Sarrwy, S.M.A.; Hassan, H.S.A. Improving Canino Apricot Trees Productivity by Foliar Spraying with Polyamines. *J. Appl. Sci. Res.* **2010**, *6*, 1359–1365.
79. Arora, R.; Singh, N.P.; Gill, M.S.; Kaur, S. Influence of foliar feeding of KNO<sub>3</sub> on fruit yield and quality parameters of mango. *Agric. Res. J.* **2021**, *58*, 828–834. [[CrossRef](#)]
80. Wahdan, M.T.; Habib, S.E.; Bassal, M.A.; Qaoud, E.M. Effect of some chemicals on growth, fruiting, yield and fruit quality of mango “Succary Abiad”. *J. Am. Sci.* **2011**, *7*, 651–658.
81. Prasad, B.; Dimri, D.C.; Bora, L. Effect of pre-harvest foliar spray of calcium and potassium on fruit quality of Pear cv. *Patharnakh. Sci. Res. Essays* **2015**, *10*, 376–380.
82. Singh, N.P.; Malhi, C.S.; Sharma, R.C. Effect of foliar feeding of N, P and K on vegetative and fruiting characters of Mango cv. Dusehri. In Proceedings of the International Conference on Mango and Date Palm: Culture and Export, Faisalabad, Pakistan, 20–23 June 2005.
83. Serafini-Fracassini, D.; Del Duca, S. Transglutaminases: Wide spread cross linking enzymes in plants. *Ann. Bot.* **2008**, *102*, 145–152. [[CrossRef](#)] [[PubMed](#)]
84. Venu, A.; Ramdevputra, M.V. Effect of polyamines and NAA application on quality and shelf life of mango (*Mangifera indica* L.) cv. Kesar. *Int. J. Curr. Microbiol. App. Sci.* **2018**, *7*, 2906–2911. [[CrossRef](#)]
85. Selvaraj, Y.; Kumar, R.; Pal, D.K. Changes in sugars, organic acids, amino acids, lipid constituents and aroma characteristics of ripening mango (*Mangifera indica* L.) fruit. *J. Food Sci. Technol.* **1989**, *26*, 308–313.
86. Costa, G.; Biasi, R.; Bagni, N. Effect of putrescine on fruiting performance on apple (cv. Hi Early). *Acta Hort.* **1986**, *149*, 189–195. [[CrossRef](#)]
87. Ishaq, S.; Rathore, H.A.; Majeed, S.; Awan, S.; Zulfiqarali-Shah, S. The studies on the physico-chemical and organoleptic characteristics of apricot (*Prunus armeniaca* L.) produced in Rawalakot, Azad Jammu and Kashmir during storage. *Pak. J. Nutr.* **2009**, *8*, 856–860. [[CrossRef](#)]
88. Davarynejad, G.H.; Zarei, M.; Ardakani, E.; Nasrabadi, M.E. Influence of Put. application on storability, postharvest quality and antioxidant activity of two Iranian apricots (*Prunus armeniaca*) cultivars. *Sci. Biol.* **2013**, *5*, 212–219.
89. Hosseini, M.S.; Fakhar, Z.; Babalar, M.; Askari, M.A. Effect of pre-harvest Putrescine treatment on quality and postharvest life of pear cv. *Spadona. Adv. Hort. Sci.* **2017**, *31*, 11–17.
90. Arora, A.; Sairamr, K.; Srivastava, G.C. Oxidative stress and antioxidative system in plants. *J. Curr. Sci.* **2002**, *82*, 1227–1238.
91. Ghasemnezhad, M.; Shiri, M.A.; Sanavi, M. Effect of chitosan coatings on some quality indices of apricot (*Prunus armeniaca* L.) during cold storage. *Casp. J. Env. Sci.* **2010**, *8*, 25–33.

**Disclaimer/Publisher’s Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.