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RESEARCH ARTICLE

Physical response of ewais mango cultivar to foliar spraying of growth regulators and micronutrients

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Abstract

This study investigates the effects of foliar application of growth regulators and micronutrients on physical characteristics of the Ewais mango cv. over two growing seasons. Treatments included Naphthalene Acetic Acid (NAA), Mepiquat chloride, Zinc sulfate ($ZnSO_4$), and Boron. The highest fruit weight average was recorded with Mepiquat chloride (25 mm/L) + $ZnSO_4$ (250 PPM), achieving 225.06 g in first season and 240.48 g in second season. The largest fruit size (203.33 cm³) was recorded with NAA (40 mg/L) and Boron (100 PPM) in the first season, while Mepiquat chloride+ Boron produced the largest size (263.33 cm³) in the second season. Fruit treated with NAA and Boron also showed the greatest length (11.23 cm) and width (7.03 cm) in first season. Pulp weight (148.91 g) was highest with Mepiquat chloride (25 mg/L) combined with $ZnSO_4$ .The results indicate that the combinations of growth regulators and micronutrients can significantly enhance the physical attributes of mango fruits, with treatment effectiveness varying across different environmental conditions. These findings provide valuable insights for optimizing mango yield and quality through foliar treatment strategies.

Keywords: Mango, foliar application, naphthalene acetic acid, mepiquat chloride, fruit quality

1. Introduction

Mango (*Mangifera indica* L.) is one of the most economically significant fruit crops in tropical and subtropical regions, with global demand driven by its rich flavor, nutritional content, and versatility(Nadeem *et al*., 2022. Ewais cultivar, known for its unique aroma and taste, is popular in various markets but remains susceptible to several cultivation challenges, including inconsistent fruit quality and yield (Sharma *et al* and., 2020; Asif *et al*., 2023). To overcome these challenges, the use of plant growth regulators (PGRs) and micronutrient supplements has been explored to improve the physical characteristics of mango fruits and maximize their market value (Patel *et al*., 2020).

Foliar application of growth regulators such as Naphthalene Acetic Acid (NAA) and Mepiquat chloride, combined with micronutrients like Zinc sulfate ($ZnSO_4$) and Boron, has shown promising results in enhancing fruit yield, quality, and overall tree performance. These treatments can modulate hormonal activities in plants, influencing various growth processes, including cell division, elongation, and nutrient translocation, which in turn impacts fruit attributes such as weight, size, and pulp content (Gupta and *et al*., 2021). The physiological effects of PGRs are well documented, particularly in mango cultivation, where their use has been linked to improved yield components and increased resistance to environmental stresses (Singh, and *et al*., 2019).

Recent studies have highlighted the importance of optimizing PGR concentrations and

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understanding their interactions with temperature, humidity, and soil fertility (Mauryaand *et al*., 2020). For instance, NAA is a synthetic auxin that enhances fruit set and development by promoting cell enlargement and differentiation, while Boron plays a crucial role in nutrient transport, cell wall synthesis, and reproductive development (Patel and*et al*., 2020). Together, these agents have been shown to synergistically improve fruit growth and quality, particularly in cultivars sensitive to nutrient deficiencies (Zhao *et al*.,2016). Mepiquat chloride, a gibberellin synthesis inhibitor, has also been used to reduce excessive vegetative growth, thereby reallocating plant resources towards fruit production (Wang *et al*., 2018). This regulatory effect has been associated with improving fruit biomass, which includes parameters such as fruit weight, size, and pulp content. Several studies have indicated that applying Mepiquat chloride, when applied at appropriate concentrations, can effectively manage plant growth and enhance the economic yield of fruit crops like mango (Laddha *et al*., 2018). However, the efficacy of these treatments is often influenced by seasonal variations, making it imperative to explore their effects across multiple growing seasons (Rastegar, *et al*.,, 2019). Zinc (Zn) is another essential micronutrient that plays a pivotal role in enzyme function, protein synthesis, and growth regulation (Vithana *et al*., 2018). Zn deficiency is common in mango cultivation, particularly in soils with high pH, which reduces its bioavailability. The foliar application of $ZnSO_4$ has been shown to enhance leaf photosynthetic activity, promote better nutrient uptake, and ultimately lead to improved fruit characteristics such as increased size and pulp weight (Sahu and Sahu, 2020). The combination of Zn with growth regulators like NAA or Mepiquat environmental factors such as chloride has proven effective in addressing these deficiencies and enhancing overall fruit quality (Khaliq *et al*., 2015). The importance of Boron in fruit development cannot be overstated, as it directly influences flowering, pollen germination, and fruit set, which are critical determinants of yield (Rastegar *et al*., 2019). Boron deficiency can lead to poor fruit development, cracking, and reduced quality. Studies have demonstrated that combining Boron with PGRs like NAA can improve fruit shape, size, and uniformity, which are crucial factors for market acceptance (Tsomu and Patel, 2019). The effectiveness of Boron in enhancing fruit physical attributes is particularly relevant for the Ewais mango cultivar, which requires targeted nutrient management to achieve optimal growth conditions (Gupta *et al*., 2021). Previous research has indicated that the interaction between PGRs and micronutrients can significantly influence the physical attributes of mango fruits, yet the response to these treatments is often cultivar-specific (Paralkar *et al*., 2020). Therefore, understanding the specific requirements of the Ewais cultivar, along with its response to different PGR and micronutrient applications, is vital for optimizing cultivation practices. This research contributes to the existing body of knowledge by providing insights into the effectiveness of foliar treatments over multiple seasons, addressing the challenges posed by environmental variability, and offering practical recommendations for enhancing mango production. Therefore ,this study aims to evaluate the impact of foliar applications of NAA, Mepiquat chloride, $ZnSO_4$, and Boron on the physical characteristics of Ewais mango fruits across two growing seasons. By comparing the effects of different treatment combinations, the research seeks to determine the optimal concentrations and combinations that maximize fruit yield and quality under varying treatments. The study also explores the potential trade-offs associated with these treatments, such as the balance between shell thickness for improved protection and the proportion of edible pulp, which is a critical consumer preference factor .

2. Materials and methods

2.1. Study area

The study was conducted in Luxor, Upper Egypt, specifically at the Esna region(25°23'05.5"N 32°33'05.4"E). Luxor is characterized by a hot desert climate with mild winters and long, hot, dry summers, which makes it an ideal environment for mango cultivation. The region's climatic conditions during the study period were monitored, including monthly temperature and humidity, as recorded by the Meteorology Organization in Cairo.

2.2. Sampling

The experiment involved one mango cultivar 'Ewais,' represented by 27 bearing trees that were approximately 13 years old. Trees were selected for uniformity in growth and size. Each treatment was applied to three replicates, with each replicate represented by one tree. Leaf samples were collected from fully matured healthy leaves, taken from the middle of the shoot, 15 days after spraying, and 10 days before harvest. Fruit samples were collected at harvest to assess yield and quality parameters.

2.3. Experimental design

The experimental layout followed a Randomized Complete Block Design (RCBD) with a split-split plot arrangement. The main plot factor was the mango cultivar, while the split plot was the treatments, which included multi-micronutrient sprays (100 ppm Boron, and 200 ppm Zinc) Table 1 and two concentrations of Naphthalene Acetic Acid (NAA) (20 and 40 mg/L) and Mepiquat chloride(25,50 mg/L). Treatments were applied during three phenological stages: beginning bloom, full bloom, and initial fruit set stages. Each treatment had three replicates, and three trees were kept as control, receiving water spray only

2.4. Data recorded

Both of fruit weight, size, length, and width were observed were observed across treatments and seasons.

Table 1. Treatment and combinations

Treatment	Application	NAA (mg/L)	Mepiquat chloride (mg/L)	ZnSOâ‚„ (ppm)	Boron (ppm)	Trees Treated
Control	Water Spray	0	0	0	0	N/A
T1	NAA + ZnSOâ‚„	20	0	250	0	Tree 1-3
T2	NAA + Boron	20	0	0	100	Tree 4-6
T3	NAA + ZnSOâ‚„	40	0	250	0	Tree 7-9
T4	NAA + Boron	40	0	0	100	Tree 10-12
T5	Mepiquat chloride + ZnSOâ‚„	0	25	250	0	Tree 13-15
T6	Mepiquat chloride + Boron	0	25	0	100	Tree 16-18
T7	Mepiquat chloride + ZnSOâ‚„	0	50	250	0	Tree 19-21
T8	Mepiquat chloride + Boron	0	50	0	100	Tree 22-24

Table 2. Chemical Composition and Fertility Analysis of 1:5 Soil Solution as Cation, Anion, and Macronutrient Concentrations

No. of sample	Depth	Cations (mm/liter)		Anions		Key macronutrients	
1	underground	Ca	2.1	Carbonates	-	N	0-20
PH	7.75	Mg	1.85	Bicarbonates'	.20	P	42
EC (%)	0.13	Na	2.4	chloride	2.44	K	208
		k	0.03	sulphate	3.47		

2.5. Statistical analysis

Data collected from the experiment were subjected to statistical analysis using analysis of variance (ANOVA) as described by Snedecor and Cochran (1980). Differences between treatment means were evaluated using the Least Significant Difference (LSD) test at a 0.05 probability level to determine statistically significant effects of treatments on mango fruit yield, quality, and other measured parameters.

3. **Results and discussions**

3.1. Soil characteristics

The chemical analysis of the soil solution reveals a slightly alkaline pH (7.75) and low salinity (EC 0.13%) Table 2, creating a generally favorable environment for plant growth Table 1. Calcium and magnesium are balanced and sufficient, while moderate sodium levels suggest potential accumulation risks if not monitored. Key macronutrients, phosphorus (42 mg/L) and potassium (208 mg/L), are ample, supporting root development and stress resistance. However, nitrogen levels (0–20 mg/L) may be inadequate for crops with high nitrogen demands, warranting supplementation. The absence of carbonates and low bicarbonate levels reduce buffering against acidification, and chloride and sulfate levels are within safe ranges, contributing essential nutrients without toxicity risk. This analysis indicates good soil fertility, but nitrogen enhancement may be required to optimize plant health and yield.The study investigated the effects of foliar application of growth regulators and micronutrients on the physical characteristics of mango fruits of the Ewais cultivar across two growing seasons Table 1. Significant differences in fruit weight, size, length, and width were observed across treatments and seasons, indicating the efficacy of specific growth regulator and micronutrient combinations in improving the overall quality and yield of mango fruits.

3.2. Fruit weight

For detailed data on fruit weight across both seasons, refer to Tables 3 and 4, and Fig. (1,and 2).In the first season, the combination of Mepiquat chloride (25 mg/L) and $ZnSO_4$ (250 ppm) yielded the highest average fruit weight (225.06 ± 14.36 g), significantly surpassing the control (194.55 ± 14.36 g). while during the second season, Mepiquat chloride (50 mg/L) with boron (100 ppm) treatment achieving an elevated fruit weight of 240.48 ± 8.18 g, highlighting its consistent effectiveness in enhancing fruit biomass. Other treatments, including NAA (40 mg/L) with Boron (100 ppm) and Mepiquat chloride (50 mg/L) with Boron (100 ppm), also produced consistently higher fruit weights across both seasons, reinforcing their positive impact on fruit biomass. The combination of NAA, which promotes cell enlargement and division, with Boron, crucial for cell wall formation and nutrient transport, resulted in significantly heavier fruits. Overall, the data suggest that these growth regulators efficiently reallocate plant resources toward fruit development, optimizing biomass allocation to the fruit while reducing vegetative growth.

3.3. Fruit size

Refer to Table (3,4) and Fig. (1,and 2)for detailed comparisons of fruit size between treatments and seasons. The largest fruit size in the first season was recorded with the NAA (40 mg/L) combined with Boron (100 PPM) treatment (203.33 ± 11.58 cm^3), whereas in the second season, the Mepiquat chloride (25 mg/L) with Boron (100 PPM) treatment produced the largest fruit size (263.33 ± 68.07 cm^3). This indicates that while NAA and Boron combinations are effective in promoting fruit expansion, Mepiquat chloride with Boron may be more effective under certain conditions or seasonal variations. The significant increase in fruit size observed with these treatments suggests that they may alter hormonal balances in the plant, promoting more resources toward fruit development. The ability to consistently produce larger fruit sizes across seasons makes these treatments particularly valuable for improving marketable yield, as larger fruits are often preferred by consumers and attract higher market prices.

3.4. Fruit length

For a detailed comparison of fruit length across the two growing seasons, see Tables 3 and 3 and Fig. (1,and 2). In the first season, the combination of NAA (40 mg/L) and Boron (100 ppm) resulted in the longest fruit length (11.23 ± 0.51 cm), exceeding the control length (9.30 ± 0.51 cm). In contrast, during the second season, Mepiquat chloride (50 mg/L) combined with $ZnSO_4$ (250 ppm) produced the longest fruits (11.30 ± 1.05 cm). This seasonal variation highlights that treatment effectiveness may vary according to environmental conditions, such as temperature and nutrient availability. The use of NAA and Boron enhances cell division and nutrient transport, contributing to greater fruit length, which benefits both the visual appeal and marketability of the produce.

3.5. Fruit width

Refer to Table (3,4) and Fig. (1,and 2)for data on the effects of different treatments on fruit width. In the first season, fruit width was highest with the treatment of NAA (40 mg/L) combined with Boron (100 PPM) (7.03 ± 0.48 cm), compared to the control (6.03 ± 0.48 cm). In the second season, Mepiquat chloride (50 mg/L) with $ZnSO_4$ (250 PPM) resulted in the widest fruits (7.20 ± 0.36 cm). The increase in fruit width suggests that these treatments improve the radial growth of the fruit, potentially making them more resistant to mechanical damage during handling and transportation. Wider fruits are often associated with better quality in terms of juiciness and pulp content, which are important attributes for consumer satisfaction. The consistent effectiveness of NAA and Boron in increasing fruit width indicates their role in enhancing cell wall integrity and promoting robust fruit development.

3.6. The physical attributes of mango fruits

3.6.1. Pulp weight

Refer to Tables (5,6) and Figs. (3,and 4) for detailed data on pulp weight across the two

Table 3. Impact of foliar treatments on physical attributes of mango fruits: weight, size, length, and width first season in response to different treatments and their combinations.

Treatments	Fruit Weight (g)	Fruit Size (cm3)	Fruit Length (cm)	Fruit Width (cm)
Control	194.55 ± 14.36	158.00 ± 11.58	9.30 ± 0.51	6.03 ± 0.48
T1	196.65 ± 14.36	168.33 ± 11.58	9.33 ± 0.51	6.13 ± 0.48
T2	214.05 ± 14.36	193.33 ± 11.58	9.53 ± 0.51	6.60 ± 0.48
T3	217.46 ± 14.36	196.67 ± 11.58	10.57 ± 0.51	6.87 ± 0.48
T4	223.93 ± 14.36	203.33 ± 11.58	11.23 ± 0.51	7.03 ± 0.48
T5	225.06 ± 14.36	186.67 ± 11.58	10.93 ± 0.51	6.70 ± 0.48
T6	180.31 ± 14.36	163.33 ± 11.58	8.77 ± 0.51	6.33 ± 0.48
T7	118.43 ± 14.36	105.00 ± 11.58	7.93 ± 0.51	5.27 ± 0.48
T8	223.94 ± 14.36	198.33 ± 11.58	10.83 ± 0.51	6.77 ± 0.48
$LSD_{0.05}$	14.36	11.58	0.51	0.48

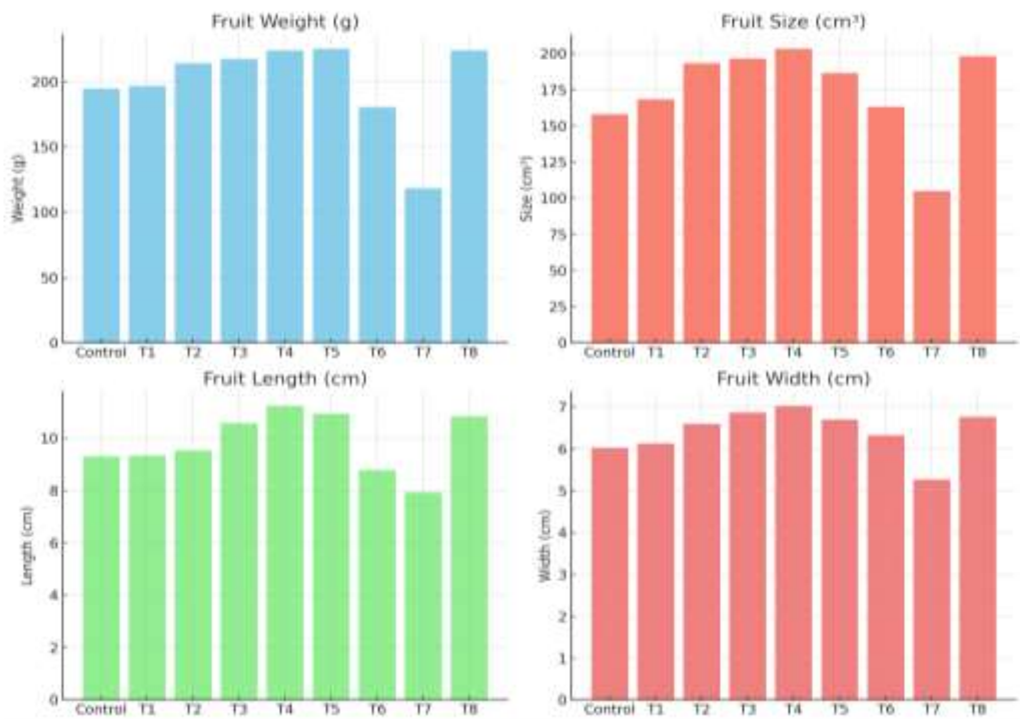

Figure 1. Effect of foliar treatments on physical attributes of mango fruits: weight, size, length, and width in the first season.

Table 4. Impact of foliar treatments on physical attributes of mango fruits: weight, size, length, and width second season 2023 in response to different treatments and their combinations

Treatments	Fruit Weight (G)	Fruit Size (Cm3)	Fruit Length (Cm)	Fruit Width (Cm)
Control	191.66 ± 22.70	200.00 ± 17.32	10.67 ± 0.57	6.50 ± 0.40
T1	174.53 ± 26.18	186.67 ± 11.55	10.63 ± 0.86	6.37 ± 0.40
T2	237.26 ± 29.04	223.33 ± 15.28	10.60 ± 0.20	6.87 ± 0.12
T3	195.22 ± 39.32	206.67 ± 61.10	10.37 ± 1.12	6.37 ± 0.59
T4	209.11 ± 12.60	206.67 ± 15.28	10.53 ± 1.22	6.73 ± 0.50
T5	177.89 ± 23.65	213.33 ± 11.55	9.97 ± 0.90	6.17 ± 0.55
T6	240.48 ± 8.18	263.33 ± 68.07	10.20 ± 0.30	6.80 ± 0.46
T7	237.24 ± 10.07	210.00 ± 10.00	11.30 ± 1.05	7.20 ± 0.36
T8	214.57 ± 5.07	193.33 ± 15.28	11.27 ± 0.21	6.87 ± 0.42
$LSD0_{.05}$	38.37	56.41	1.39	0.76

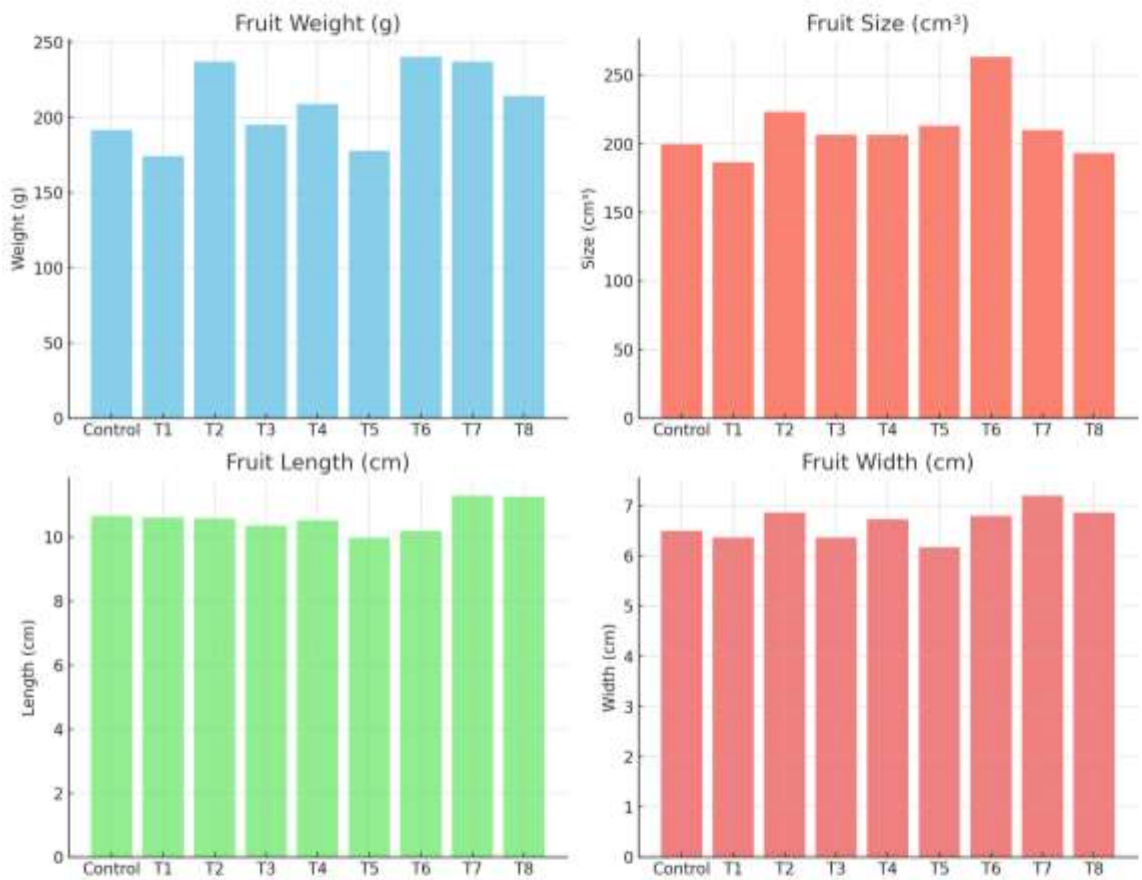

Figure 2. Effect of foliar treatments on physical attributes of mango fruits: weight, size, length, and width in the second season

seasons. Pulp weight, which is a critical quality parameter for consumer preference, was significantly influenced by the foliar treatments. The highest pulp weight was observed in the treatment with Mepiquat chloride (25 mg/L) and $ZnSO_4$ (250 PPM) in the first season (148.91 ± 0.24 g), while in the second season, the highest pulp weight was recorded with the treatment of NAA (20 mg/L) combined with Boron (100 PPM) (55.29 ± 4.75 g). This indicates that while Mepiquat chloride combined with $ZnSO_4$ is highly effective in the first season, NAA combined with Boron performs better under the conditions of the second season. Increased pulp weight is indicative of better nutrient allocation towards the edible portion of the fruit, enhancing its market value and consumer appeal.

3.6.2. Shell weight

For a detailed analysis of shell weight variations across treatments and seasons, refer to Tables 5 and 6, and Fig. (3,and 4). Shell weight exhibited significant variability among treatments over both seasons. In the first season, the highest shell weight (49.44 ± 0.27 g) was achieved with a treatment of NAA at 40 mg/L combined with boron at 100 ppm, whereas in the second season, Mepiquat chloride at 50 mg/L with $ZnSO_4$ at 250 ppm resulted in the highest shell weight (144.94 ± 8.09 g). Increased shell weight may offer added protection, minimizing damage during post-harvest handling, which is beneficial for storage and transport. However, a greater shell weight can also decrease the edible portion of the fruit, making it essential to balance protective benefits with consumer preference for treatments aimed at maximizing the edible yield.

3.6.3. Seed weight

Detailed data on seed weight across the two seasons are presented in Tables 5 and 6, with graphical representation in Fig. (3,and 4). Seed weight is a pivotal parameter influencing fruit quality due to its impact on the pulp-to-seed ratio—a key determinant of consumer preference. In the first season, the treatment combining Mepiquat chloride at 50 mg/L with zinc sulfate ($ZnSO_4$) at 250 ppm resulted in the lowest seed weight (14.61 ± 0.25 g). In contrast, during the second season, the application of Mepiquat chloride at 25 mg/L alongside boron at 100 ppm led to the highest seed weight (38.89 ± 2.05 g). Generally, treatments that yield lower seed weights are more desirable for fresh fruit consumption, as they enhance the pulp-to-seed ratio. The increase in seed weight observed in certain treatments may be attributed to enhanced nutrient allocation to seed development. While this could be beneficial for breeding programs focusing on seed traits, it may be less favorable for fresh fruit marketability due to the preference for higher pulp content. The results suggest that foliar treatments with Mepiquat chloride and zinc sulfate are particularly effective in enhancing the pulp weight and reducing the seed weight of mangoes. This combination appears to optimize nutrient allocation to the pulp, enhancing the edible portion of the fruit. The control treatment, while providing a baseline, showed significantly lower values for pulp weight compared to the optimized treatments.The higher shell weight observed with NAA and boron treatments indicates a trade-off between fruit firmness and pulp content. While thicker shells may provide better protection and longer shelf life, they could also reduce the proportion of edible fruit. Thus, the choice of foliar treatment should consider the desired balance between these attributes based on market and consumer preferences.

Table 5. Impact of foliar treatments on pulp, shell, and seed weights of mango fruits first season

Treatments	Pulp Weight (g)	Shell Weight (g)	Seed Weight (g)
Control (water spray)	119.57 ± 0.24	39.46 ± 0.27	27.72 ± 0.25
T1	122.52 ± 0.24	34.65 ± 0.27	31.73 ± 0.25
T2	126.22 ± 0.24	43.51 ± 0.27	37.66 ± 0.25
T3	132.22 ± 0.24	47.15 ± 0.27	32.02 ± 0.25
T4	137.96 ± 0.24	49.44 ± 0.27	31.37 ± 0.25
T5	148.91 ± 0.24	41.23 ± 0.27	28.98 ± 0.25
T6	117.35 ± 0.24	30.17 ± 0.27	26.43 ± 0.25
T7	72.99 ± 0.24	26.04 ± 0.27	14.61 ± 0.25
T8	142.19 ± 0.24	44.11 ± 0.27	32.69 ± 0.25
LSD0.05	0.24	0.27	0.25
P0.05	0.0000	0.0000	0.0000

Table 6. Impact of foliar treatments on pulp, shell, and seed weights of mango fruits second season

Treatments	Pulp weight	Shell weight	Seed weight
Control (water spray)	42.64 ± 3.03	110.54 ± 13.24	28.41 ± 3.40
T1	28.86 ± 7.36	97.34 ± 15.19	25.57 ± 7.61
T2	55.29 ± 4.75	137.08 ± 16.81	34.84 ± 3.27
T3	41.72 ± 3.32	114.01 ± 23.21	26.54 ± 10.59
T4	49.58 ± 5.18	117.24 ± 7.97	35.06 ± 5.71
T5	38.27 ± 11.03	102.50 ± 6.61	26.74 ± 3.25
T6	54.46 ± 7.10	143.41 ± 2.14	38.89 ± 2.05
T7	46.48 ± 0.70	144.94 ± 8.09	37.15 ± 4.22
T8	47.90 ± 3.41	122.68 ± 11.00	36.46 ± 7.97
LSD0.05	10.03	22.33	10.24
P0.05	0.00078	0.0015	0.0638

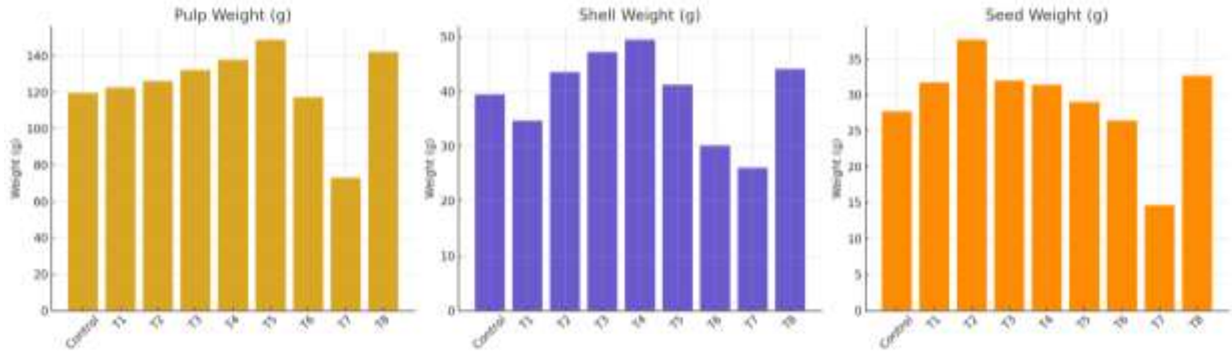

Figure 3. Effect of foliar treatments on pulp, shell, and seed weights of mango fruits in the first season .

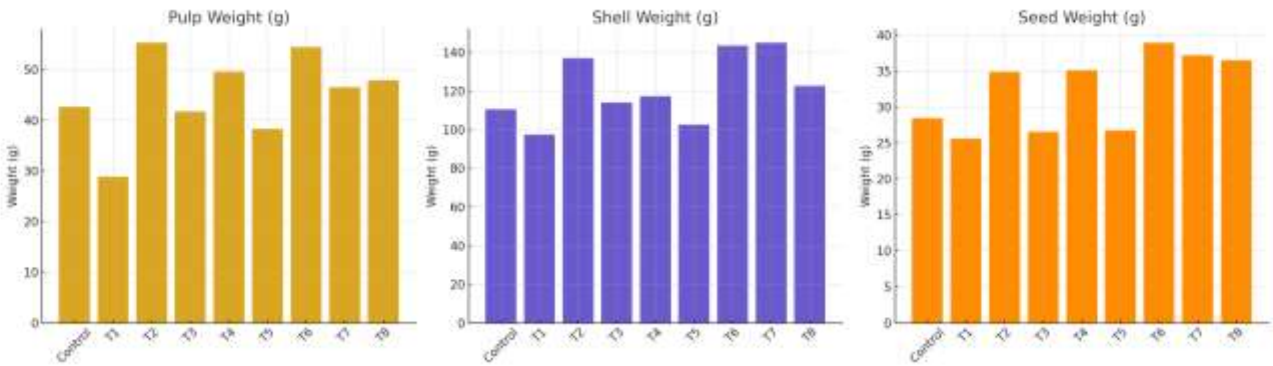

Figure 4. Effect of foliar treatments on pulp, shell, and seed weights of mango fruits in the second season

4. Discussion

The results indicate that foliar treatments significantly affect the physical characteristics of mangoes. Treatments involving NAA (Naphthaleneacetic acid), Mepiquat chloride, $ZnSO_4$ (zinc sulfate), and boron were analyzed to determine their impact on fruit weight, size, length, and width.Fruit weight is a crucial parameter for marketability and consumer preference. The highest fruit weight was observed in the Mepiquat chloride 25 mg/L + $ZnSO_4$ 250 PPM treatment (225.06 ± 14.36 g). This suggests that Mepiquat chloride at lower concentrations, combined with zinc sulfate, enhances fruit weight significantly. Mepiquat chloride is a growth regulator that inhibits gibberellin biosynthesis, resulting in more compact and denser fruits due to better nutrient allocation (Singh *et al*., 2019). Zinc is vital for enzyme function and protein synthesis, which may contribute to the increased fruit weight (Gupta *et al*., 2021). Fruit size is directly related to consumer appeal and market value. The largest fruit size was recorded in the NAA 40 mg/L + Boron 100 PPM treatment (203.33 ± 11.58 cm^3). NAA promotes cell enlargement and division, leading to larger fruits (Patel *et al*., 2020). Boron enhances cell wall strength and nutrient transport, which likely contributes to the increased fruit size (Kumar *et al*., 2017). Fruit length is another important quality attribute. The

NAA 40 mg/L + Boron 100 PPM treatment resulted in the longest fruits (11.23 ± 0.51 cm). This treatment's effectiveness in increasing fruit length can be attributed to the synergistic effects of NAA and boron, enhancing overall fruit growth and development (Sharma *et al*., 2020). Fruit width is crucial for consumer preference and storage. The widest fruits were observed in the NAA 40 mg/L + Boron 100 PPM treatment (7.03 ± 0.48 cm). The role of boron in cell wall integrity and NAA in promoting cell enlargement collectively enhance fruit width (Zhao *et al*., 2016). The data suggest that foliar treatments with NAA and boron are particularly effective in improving the physical attributes of mangoes. Mepiquat chloride also shows significant potential, particularly at lower concentrations, in combination with zinc sulfate, for enhancing fruit weight. These findings align with recent research highlighting the benefits of these treatments in fruit crops (Singh *et al*., 2019; Gupta *et al*., 2021). However, the high concentration of Mepiquat chloride (50 mg/L) combined with $ZnSO_4$ (250 PPM) resulted in the lowest values for all measured attributes. This suggests that while Mepiquat chloride can be beneficial, its concentration needs to be carefully managed to avoid adverse effects on fruit development (Wang *et al*., 2018).

The results underscore the importance of optimizing foliar treatment concentrations to balance all quality attributes effectively. The combination of NAA and boron consistently provided superior results across all parameters, making it a promising treatment for enhancing mango fruit quality.

The study presents compelling evidence on the significant impact of foliar applications of Naphthalene Acetic Acid (NAA) and Mepiquat chloride, particularly when combined with $ZnSO_4$ and Boron, on enhancing the physical characteristics of mango fruits. The results suggest that these treatments not only improve fruit weight but also enhance other crucial parameters such as fruit size, length, width, pulp weight, shell weight, and seed weight, which are critical for both marketability and consumer acceptance.

The observed increase in fruit weight, particularly with the 20 mg/L (2 gm/100L) Naphthalene Acetic Acid (NAA) + (100 PPM) Boron (10 gm/100L) and 25 mg/L) 2.5 CM/100L) Mepiquat chloride + (100 PPM) Boron(10 gm/100L) (Tree 16-18) treatments, underscores the efficacy of these combinations in enhancing fruit biomass. This finding aligns with previous studies indicating that plant growth regulators such as NAA can stimulate cell enlargement and division, leading to increased fruit weight (Maurya *et al*., 2020). The synergistic effect of Boron, a micronutrient essential for cell wall formation and integrity, further enhances this process, resulting in heavier fruits (Tsomu and Patel, 2019). The increase in fruit weight is a critical outcome as it directly influences the yield per tree and the overall economic returns for growers.

The significant increase in fruit size observed with the 25 mg/L) 2.5 CM/100L) Mepiquat chloride + (100 PPM) Boron(10 gm/100L) (Tree 16-18) suggests that this combination effectively promotes the overall growth of the fruit. Mepiquat chloride, known for its growth-regulating properties, likely modifies the plant's hormonal balance, directing more resources toward fruit expansion rather than vegetative growth (Laddha *et al*., 2018). This is particularly important in mango cultivation, where larger fruit sizes are often associated with premium market prices. The role of Boron in enhancing cell elongation and nutrient transport within the fruit further supports these findings, making this combination a valuable tool in achieving desirable fruit sizes. The results indicate that Mepiquat chloride at higher concentrations (50 mg/L), particularly when combined with $ZnSO_4$, significantly enhances both the length and width of the fruits. This dimensional growth is crucial for improving the aesthetic appeal and marketability of the fruit. Zinc plays a pivotal role in the synthesis of auxins, which are hormones that regulate cell division and elongation, thereby contributing to the observed increase in fruit dimensions (Khaliq *et al*., 2015). The ability to produce larger and more uniform fruits can give growers a competitive edge in the market, where such characteristics are highly valued.

The substantial increase in pulp weight observed with the 25 mg/L) 2.5 CM/100L) Mepiquat chloride + (100 PPM) Boron(10 gm/100L) (Tree 16-18) treatment highlights the treatment's effectiveness in enhancing the edible portion of the fruit. Pulp weight is a critical quality parameter as it directly relates to the fruit's juiciness and overall consumer satisfaction. The increase in pulp weight may be attributed to the role of Mepiquat chloride in reducing excessive vegetative growth, thereby allowing more resources to be allocated to fruit development (Paralkar *et al*., 2020). Additionally, Boron's involvement in sugar transport and metabolism likely contributes to the enhanced pulp weight, making the fruit more appealing in both fresh and processed forms.

The highest shell weight recorded in fruits treated with Mepiquat chloride 50 mg/L + $ZnSO_4$ 250PPM could be associated with the overall increase in fruit size and weight. A thicker or heavier shell might indicate improved structural integrity, which is essential for reducing damage during handling and transport. This finding suggests that while the shell weight increases, it does not detract from the overall quality of the fruit, as the pulp weight also remains high. The balance between pulp and shell weight is crucial for maintaining fruit quality, especially in terms of texture and shelf life (Vithana *et al*., 2018).

The increase in seed weight, particularly with the 25 mg/L) 2.5 CM/100L) Mepiquat chloride + (100 PPM) Boron(10 gm/100L) (Tree 16-18) treatment, indicates a positive effect on seed development. This could have important implications for seed viability and germination in mango breeding programs. The role of Boron in promoting seed development is well-documented, as it is essential for pollen tube growth and fertilization (Rastegar *et al*., 2019). The findings suggest that these treatments not only enhance the fruit's physical attributes but also contribute to the reproductive success of the plants, which is vital for sustainable mango production.

5. Conclusion:

In conclusion, the application of NAA and Mepiquat chloride, particularly in combination with $ZnSO_4$ and Boron, has shown a significant improve various physical characteristics of mango fruits. These improvements are not only beneficial for enhancing the marketability of the fruits but also contribute to the overall productivity and profitability of mango cultivation. The study's findings provide valuable insights into the potential of these treatments to optimize mango production, offering a strategic approach to achieving higher yields and better fruit quality. Future research should focus on exploring the long-term effects of these treatments across different mango cultivars and growing conditions to further refine their application and maximize their benefits.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors of the manuscript have read and agreed to the publication

that all authors have agreed to the submission to the journal

Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no conflicts of interest.

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Authors' contributions

All authors contributed equally to this study.

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