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Efficiency of Fruit Thinning Using Naphthalene Acetic Acid in Murcott Mandarin Trees

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Abstract

This study aimed to evaluate the response of "Murcott" mandarin trees to naphthalene acetic acid (NAA) as a fruit thinning agent and its impact on productivity and fruit quality. Naphthalene acetic acid (NAA) was applied during the early physiological fruit drop at diameters of 1 cm, 1.5 cm, and 2 cm, using concentrations of 0 (CTRL), 200, and 400 ppm. Data were collected on fruit quantity, number of sunburned fruits per tree at harvest, and fruit characteristics. Overall, the findings showed that applying NAA as a chemical thinner led to a decrease in the number of fruits per tree and a reduction in sunburn incidence, while enhancing fruit weight, length, diameter, and size. These enhancements were evident in the fruit's internal characteristics, yield, and overall productivity. Moreover, the use of NAA as a thinner for "Murcott" fruit was largely influenced by its concentration and the timing of application; for instance, applying 200 ppm of NAA when the fruit reached a diameter of 1 or 1.5 cm was notably effective.

Keywords: *Citrus*, foliar spray, fruit size, mandarin, NAA, thinning.

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1. Introduction

Citrus is one of the primary fruit crops in Egypt, ranking first in terms of cultivated area, production, and export volume. It is rich in carbohydrates, proteins, dietary fibers, minerals, and vitamins, with a notably high concentration of vitamin C. The "Murcott" variety, a subtropical fruit, has become one of the most important mandarin cultivars in recent years due to its successful cultivation under the Egyptian conditions [1]. It holds considerable commercial value in both domestic and international markets. The total area dedicated to citrus and orange cultivation in Egypt was estimated at 519,788 feddans, producing approximately 4,708,427 tons, according to the Economic Affairs Sector of the Ministry of Agriculture and Land Reclamation [2]. The significance of fruit size as a standard for citrus fruit quality has notably increased in recent times, with consumers showing a growing preference for larger fruits over smaller ones. This has resulted in a price advantage for larger fruits, particularly in varieties such as "Murcott", across most export markets. Consequently, there is now a greater focus on achieving larger fruit sizes, even at the expense of total yield [3]. Several factors impact tree yield and fruit quality. A significant factor influencing fruit quality traits, particularly fruit size, is the phenomenon of alternate bearing [4]. Some citrus cultivars are susceptible to alternate bearing, where trees yield large quantities of small fruit during the "on"-year and much smaller yields of larger fruit in the "off"-year [5]. This pattern can negatively impact the overall fruit value and quality, as the excess fruit produced in the "on"-year may have significantly reduced or no market value, while the low yield in the "off"-year may compromise commercial viability. Additionally, heavy fruit loads during the "on"-year can cause considerable tree stress, reducing growth, breaking branches, and potentially affecting future production [6]. Thus, fruit thinning practice enhances fruit yield, quality, and subsequent flowering. Thus, fruitlet thinning involves removing a portion of the crop before it matures on the tree. This practice improves the marketability of the remaining fruit and helps to reduce the tree's tendency for biennial bearing [7]. Thinning techniques are carried out using several agricultural practices, such as hand thinning, pruning-based thinning, and chemical thinning. Among these, chemical thinning is the most widely used method [8,9]. On the other hand, the high cost of hand thinning labor encourages many farmers to choose chemical thinning methods. Auxins play a significant role in the fruit thinning process and in managing the occurrence of alternate bearing phenomenon. The synthetic auxin naphthalene acetic acid (NAA) is a widely used chemical thinning agent, proven effective for thinning citrus, and was the first hormone-type thinner used commercially [7,10].

Given the high demand for the "Murcott" mandarin fruits locally and for export, this study evaluated the effectiveness of naphthalene acetic acid (NAA) for fruitlet thinning at various fruitlet diameters and consequently assessed its impact on productivity and fruit quality.

2. Materials and Methods

2.1. Experimental site and plant materials

This study was conducted to assess how "Murcott" mandarin trees (*Citrus sinensis* (L.) Osbeck x Citrus reticulata Blanco) responds to naphthalene acetic acid (NAA) as a fruit thinning agent and to examine its effect on productivity and fruit quality.

The experiment took place during the 2021 and 2022 growing seasons at a private orchard in the Wadi El Natroun district (30°16'12.5"N 30°13'08.7"E), located in El-Behera governorate. The 5-year-old "Murcott" mandarin trees were grafted on 'Volkamer Lemon' rootstock (*Citrus volkameriana*), planted at 4X6 meters in sandy soil and irrigated by the drip irrigation system. In each season, trees of comparable age and size were carefully selected, ensuring they were in their "on"-year of production. All trees were provided with the recommended monthly amounts of irrigation and fertilization doses (Table 1).

Table 1. Irrigation and fertilization program implemented at the "Murcott" mandarin farm of this study

	Irrigation rates (M^3/ Fed/Month)	Fertilization doses (Unit /Fed/ Month)				
		N	P_2O_5	K_2O	CaO	MgO
Jan	233	0	0	3	4	0
Feb	273	8	4	4	4	0
Mar	424	15	5	6	6	2
Apr	492	20	6	6	6	2
May	540	17	6	8	6	2
Jun	684	22	5	11	4	1
Jul	741	23	4	17	2	0.5
Aug	793	20	4	20	2	0.5
Sep	586	12	5	18	4	2
Oct	511	10	5	10	4	2
Nov	277	5	3	5	4	0
Dec	213	0	0	3	4	0
Total	5767	152	47	111	50	12

2.2. Treatments

Naphthalene acetic acid (NAA) was applied during the early stage of physiological fruit drop, when 80% of the fruit diameters reached 1 cm (on 25 and 30 April for the first and second season, respectively), 1.5 cm (on 12 and 18 May for the first and second season, respectively), and 2 cm (on 26 and 1 June for the first and second season, respectively) using concentrations of 0 (CTRL), 200, and 400 ppm with 0.1% v/v lower 7 a non-ionic, low foam surfactant.

2.3. Measurements

By the end of the two successive seasons of this study, fruit number/tree, number of sunburned fruits per tree, fruit weight (g), yield (Kg/tree), estimated productivity (Ton/Fed.) were recorded at harvesting time (15 and 21 January for the first and second season, respectively). Then, thirty fruits from each treatment (ten fruits per replicate) were taken randomly for determining the physical and chemical characteristics, including fruit length (cm), fruit diameter (cm), L/D ratio, fruit size (cm^3), peel thickness (mm), juice volume (ml). Titratable acidity (TA %) by following the A.O.A.C. [11] methods, total soluble solids (TSS %) using refractometer at room temperature, TSS/TA ratio, vitamin C (mg/100g) by following the A.O.A.C. [12] methods.

2.4. Statistical analysis

The experiment was designed with three replicates per each treatment and three trees per replicate in a completely randomized design. The obtained data for 2021 and 2022 were pooled and statistically analysed using the two-way variance analysis (ANOVA) by the R statistical language, version 4.4.1 [13]. The data were presented as an average of the two combined seasons. The significance of differences was evaluated with the Duncan range test at 5 % level [14].

3. Results and Discussion

3.1. Effect of naphthalene acetic acid (NAA) on the number of fruits per tree and the number of sunburned fruits per tree at harvest:

From **Table 2**, it was found that there is a significant difference ($P \leq 0.05$) in the average number of "Murcott" fruits remaining on the tree at the time of harvest, depending on the concentration of naphthalene acetic acid (NAA) used. The results indicated that the 400 ppm concentration of NAA resulted in the lowest average fruit count on the tree (562.38), followed by the 200 ppm concentration (660.38). In contrast, the control group had the highest average number of fruits (845.05). The timing of naphthalene application also showed significant differences in the average number of fruits remaining on the tree at harvest. The results indicated that spraying when the fruits reached a diameter of 2 cm resulted in the highest number of fruits remaining on the tree (719.44). The fruit count decreased significantly when sprayed at 1.5 cm in diameter (689.38), and the lowest number of fruits was observed when spraying occurred at a fruit diameter of 1 cm (659.00). The interaction between treatments also revealed significant differences ($P \leq 0.05$) in the average number of fruits remaining on the tree at harvest. The results showed that the control at any fruit diameter resulted in the highest number of fruits remaining on the tree, while the lowest significant number of fruits was observed with the 400 ppm NAA treatment applied when the fruit diameter was 1 cm (425.83). Also, **Table 2** showed a notable difference in the incidence of sunburn on "Murcott" fruits, based on the varying concentrations of NAA applied.

Table 2. Effects of NAA concentrations (0, 200, and 400 ppm) applied at three stages of "Murcott" fruit development (1 cm, 1.5 cm, and 2 cm fruitlet diameters) on the number of harvested fruits per tree and the number of sunburned fruits per tree over the two combined seasons

NAA concentration	Fruitlet diameter			Mean
	1 cm	1.5 cm	2 cm	
	Fruit Number/tree			
Control	854.16 a	842.66 a	838.33 a	845.05 A
NAA (200 ppm)	697.00 c	542.16 d	742.00 b	660.38 B
NAA (400 ppm)	425.83 e	683.33 c	578.00 d	562.38 C
Mean	659.00 C	689.38 B	719.44 A	
	No. of sunburned fruits/tree			
Control	34.50 a	35.33 a	36.50 a	35.44 A
NAA (200 ppm)	22.83 bc	16.66 d	26.33 b	21.94 B
NAA (400 ppm)	9.00 e	21.33 c	19.167 cd	16.50 C
Mean	22.11 C	24.44 B	27.33 A	

Different upper-case bold letters indicate statistical differences ($P \leq 0.05$, Duncan) between NAA concentrations over spraying times (vertical mean), and spraying times based on fruitlet diameters over NAA concentrations (horizontal mean), whereas lower-case letters represent statistical differences between the interactions (NAA concentrations × spraying times based on fruitlet diameters) ($P \leq 0.05$, Duncan).

The results indicated that the 400 ppm concentration of NAA resulted in the lowest significant number of sunburned fruits on the tree (16.50), while the 200 ppm concentration resulted in a higher significant number of sunburned fruits (21.94). In contrast, the control had the highest significant number of damaged fruits by sunburn, with a value equal to 35.44. The timing of NAA application also had a significant impact on the number of sunburned fruits remaining on the tree at harvest. The results indicated that spraying when the fruits reached a diameter of 2 cm resulted in the highest sunburned fruits (27.33). The sunburned fruits decreased significantly when sprayed at 1.5 cm in diameter (24.44), and the lowest number was observed when spraying occurred at a fruit diameter of 1 cm (22.11). The interaction between treatments also revealed significant differences ($P \leq 0.05$) in the number of sunburned fruits. The results showed that the lowest significant value was observed with the 400 ppm NAA treatment applied when the fruit diameter was 1 cm (9.000) compared to control. Fruit thinning is a common horticultural practice in citrus and other fruit orchards, primarily used to manage crop load. It plays a key role in optimizing fruit size, improving fruit quality attributes such as colour, shape, and overall quality, while also supporting tree health and structure. Additionally, thinning enhances crop value and promotes consistent blooming, which is crucial for mitigating the effects of alternate bearing cycles [15]. Moreover, the rise in the number of fruits per plant following auxin application may be due to its ability to decrease pre-harvest fruit drop [16]. In citrus, synthetic auxins promote the dropping of developing fruitlets during the cell division phase. Applying auxins at the start of the cell enlargement phase may have a limited impact on preventing fruit drop but can lead to an increase in fruit size [17]. The application of synthetic auxins to developing citrus fruits affects both fruitlet growth and abscission in several ways: i) a temporary slowdown in fruitlet growth, which is a common response, especially when applied early in development, though the effect is minimal if done near the end of the June drop; ii) a direct influence on delaying abscission, which can ultimately lead to increased fruit set; and iii) enhanced fruitlet abscission due to auxin-triggered ethylene production [18-21, 3]. In 2002, Stover *et al.*, [7] studied the effects of NAA thinning on "Murcott" mandarins during the early stage of physiological fruit drop, when the average fruitlet size ranged from 2.2 to 2.4 cm. They observed that NAA application increased fruit size and weight by 25-34%, while reducing the number of fruits per tree by 24-38% and lowering the overall yield per tree by 4-24%. Additionally, NAA treatment boosted the production of 64-100 count fruit by 59-100%, even though no fruit were removed for being undersized in the unthinned control group. A similar result was noted in Washington Navel Orange by Hifny *et al*. [22]. Moreover, this study revealed that higher concentrations of NAA reduced sunburn damage to the fruits, which aligns with the findings of Alabdallah and Qrunfleh [23].

3.2. Effect of NAA on yield components of "Murcott" trees

The data in **Table 3** indicated a significant difference in the average fruit weight based on the NAA concentration, irrespective of the spraying time. The 200 ppm concentration of NAA produced the highest significant value (164.38 g) compared to the other treatments.

Table 3. Effects of NAA concentrations (0, 200, and 400 ppm) applied at three stages of "Murcott" fruit development (1 cm, 1.5 cm, and 2 cm fruitlet diameters) on the fruit weight, yield, and productivity over the two combined seasons

NAA concentration	Fruitlet diameter			Mean
	1 cm	1.5 cm	2 cm	
	Fruit weight (g)			
Control	118.00 f	117.66 f	117.66 f	117.77 C
NAA (200 ppm)	191.16 a	159.33 c	142.66 e	164.38 A
NAA (400 ppm)	170.33 b	155.33 d	155.66 d	160.44 B
Mean	159.83 A	144.11 B	138.66 C	
	Yield (kg/tree)			
Control	100.79 bc	99.15 c	98.64 c	99.53 B
NAA (200 ppm)	133.24 a	86.39 d	105.86 b	108.50 A
NAA (400 ppm)	72.52 e	106.14 b	89.98 d	89.55 C
Mean	102.18 A	97.23 B	98.16 B	
	Productivity (ton/fed)			
Control	17.64 bc	17.35 c	17.26 c	17.48 B
NAA (200 ppm)	23.32 a	15.12 d	18.53 b	18.99 A
NAA (400 ppm)	12.69 e	18.58 b	15.75 d	15.67 C
Mean	17.88 A	17.02 B	17.18 B	

Different upper-case bold letters indicate statistical differences ($P \leq 0.05$, Duncan) between NAA concentrations over spraying times (vertical mean), and spraying times based on fruitlet diameters over NAA concentrations (horizontal mean), whereas lower-case letters represent statistical differences between the interactions (NAA concentrations × spraying times based on fruitlet diameters) ($P \leq 0.05$, Duncan).

Regarding the spraying time, spraying with NAA, regardless of the concentration used, recorded the highest significant value for fruit weight at 1 cm diameter (159.83 g) compared to the other treatments. Examining the interaction values, significant differences in fruit weight were also observed. The results indicate that spraying with 200 ppm NAA when the fruits reached a diameter of 1 cm produced the highest significant ($P \leq 0.05$) fruit weight (191.16 g), while the lowest significant values were recorded in the control group. The highest significant yield was observed with 200 ppm concentration (108.50 kg/tree), regardless of the spraying time. Additionally, the greatest yield was recorded when NAA was applied at a fruit diameter of 1 cm (102.18 kg/tree), regardless of the concentration used. The interaction between treatments also revealed significant differences in tree yield. The highest significant ($P \leq 0.05$) yield (133.24 kg/tree) was achieved when NAA was sprayed at a concentration of 200 ppm when the fruit diameter reached 1 cm, while the lowest yield (72.52 kg/tree) was observed with a 400 ppm concentration at the same fruit diameter.

As shown also in Table 3, productivity was notably impacted by the concentration of auxin spray, regardless of the timing of its application. The highest significant ($P \leq 0.05$) productivity was achieved with a spray concentration of 200 ppm (18.99 ton/fed). At the same time, significant production values were recorded depending on the timing of the exogenous treatment with NAA, regardless of the concentration used, as the treatment with NAA recorded the highest value when the diameter of the fruits was 1 cm (17.88 ton/fed). Concerning the interaction, the 200 ppm NAA treatment produced the highest significant values (23.32 ton/fed) when applied at a fruit diameter of 1 cm, compared to all other treatments (Table 3). Fruit weight increased significantly with the application of fruit thinning. This finding aligns with the observations of Ortolá *et al*. [24], who noted a greater fruit weight in NAA treated Satsuma mandarin trees. Also, Duarte *et al*. [25] researched auxin as a chemical thinner for 'Esbel' clementine and found that it resulted in a yield increase of 25% to 38%.

3.3. Effect of NAA on physical fruit characteristics

Table 4 presents the impact of applying NAA auxin at various concentrations and times on the physical characteristics of "Murcott" fruits. Regardless of the timing of NAA application, the results revealed that the 400 ppm NAA treatment resulted in the significant ($P \leq 0.05$) longest fruit (4.88 cm) and largest diameter (6.46 cm) compared to the other treatments. Additionally, applying NAA when the fruit reached a diameter of 1 cm, regardless of concentration, also produced the significant ($P \leq 0.05$) longest fruit (4.84 cm) and largest diameter (6.10 cm) compared to other application times. This pattern was similarly reflected in the fruit length-to-diameter ratio. Moreover, the data tabulated in Table 5 showed that the treatment with a concentration of 200 ppm of NAA, regardless of timing, gave the largest significant ($P \leq 0.05$) size of fruits (210.88 cm^3) compared to the rest of the treatments, while the treatment with NAA at a diameter of 1 cm, regardless of the concentration, gave the largest significant fruit size (157.82 cm^3) compared to other timings.

Table 4. Effects of NAA concentrations (0, 200, and 400 ppm) applied at three stages of "Murcott" fruit development (1 cm, 1.5 cm, and 2 cm fruitlet diameters) on the fruit length, diameter, and L/D ratio over the two combined seasons

NAA concentration	Fruitlet diameter			Mean
	1 cm	1.5 cm	2 cm	
	Fruit length (cm)			
Control	4.21 g	4.21 g	4.21 g	4.21 C
NAA (200 ppm)	5.26 a	5.20 b	4.58 f	4.21 C
NAA (400 ppm)	5.05 c	4.71 e	4.90 d	4.88 B
Mean	4.84 A	4.71 B	4.56 C	
	Fruit diameter (cm)			
Control	5.31 d	5.31 d	5.32 d	5.31 C
NAA (200 ppm)	6.50 a	6.38 b	5.95 c	6.28 B
NAA (400 ppm)	6.50 a	6.38 b	6.50 a	6.46 A
Mean	6.10 A	6.02 B	5.92 C	
	L/D ratio			
Control	0.79 b	0.79 b	0.79 b	0.79 A
NAA (200 ppm)	0.80 a	0.81 a	0.77 c	0.79 A
NAA (400 ppm)	0.77 c	0.73 e	0.75 d	0.75 B
Mean	0.79 A	0.78 B	0.77 C	

Different upper-case bold letters indicate statistical differences ($P \leq 0.05$, Duncan) between NAA concentrations over spraying times (vertical mean), and spraying times based on fruitlet diameters over NAA concentrations (horizontal mean), whereas lower-case letters represent statistical differences between the interactions (NAA concentrations × spraying times based on fruitlet diameters) ($P \leq 0.05$, Duncan).

Regarding the interaction between treatments, the treatment with spraying NAA at a concentration of 200 ppm when the fruit reached 1 cm in diameter recorded the largest significant size (235.16 cm^3) compared to the rest of the treatments. In terms of peel thickness, there were no significant differences among treatments, except for the control, which recorded the lowest significant value (1.18 mm) compared to the other concentrations. Additionally, no significant differences were observed between the various spraying times. Regarding NAA concentrations, it was found that the 200 ppm treatment produced the largest significant volume of fruit juice (126.55 ml), followed by the NAA concentration of 400 ppm (102.05 ml) and then the control (65.52 ml). Regarding the timing of NAA spraying, it was found that when the fruits reached a diameter of 1 cm recorded the largest significant ($P \leq 0.05$) volume of fruit juice (116.05 ml), followed by spraying at a diameter of 1.5 cm (97.56 ml), and then the lowest significant value was at a diameter of 2 cm (80.51 ml).

Table 5. Effects of NAA concentrations (0, 200, and 400 ppm) applied at three stages of "Murcott" fruit development (1 cm, 1.5 cm, and 2 cm fruitlet diameters) on the fruit size, peel thickness, and fruit juice volume over the two combined seasons

NAA concentration	Fruitlet diameter			Mean
	1 cm	1.5 cm	2 cm	
	Fruit size (cm³)			
Control	73.96 f	73.96 f	73.95 f	73.96 C
NAA (200 ppm)	235.16 a	231.50 b	166.00 c	210.88 A
NAA (400 ppm)	164.33 d	165.66 c	141.66 e	157.22 B
Mean	157.82 A	157.04 B	127.20 C	
	Peel thickness (mm)			
Control	1.18 c	1.18c	1.18 c	1.18 B
NAA (200 ppm)	1.96 a	1.73 b	1.95 a	1.88 A
NAA (400 ppm)	1.83 ab	1.96 a	1.87 ab	1.89 A
Mean	1.66 A	1.62 A	1.66 A	
	Juice volume (ml)			
Control	65.50 g	65.52 g	65.53 g	65.52 C
NAA (200 ppm)	150.16 a	143.33 b	86.16 e	126.55 A
NAA (400 ppm)	132.50 c	83.83 f	89.83 d	102.05 B
Mean	116.05 A	97.56 B	80.51 C	

Different upper-case bold letters indicate statistical differences ($P \leq 0.05$, Duncan) between NAA concentrations over spraying times (vertical mean), and spraying times based on fruitlet diameters over NAA concentrations (horizontal mean), whereas lower-case letters represent statistical differences between the interactions (NAA concentrations × spraying times based on fruitlet diameters) ($P \leq 0.05$, Duncan).

Regarding the interaction, it was found that the treatment with spraying NAA at a concentration of 200 ppm achieved the largest significant ($P \leq 0.05$) volume of fruit juice (150.16 ml) when the fruit reached 1 cm in diameter compared to the other treatments (Table 5). Fang *et al.* [26] reported that fruits from auxin-treated "Murcott" mandarin trees were significantly larger than those from untreated trees, a similar finding also observed by Yildirim *et al.* [27] in Valencia oranges and Amiri *et al*. [28] in Satsuma mandarin. Thinning agents influence growth rates indirectly by decreasing the number of fruits per tree and promoting abscission. This reduction in fruit competition for carbohydrates allows the remaining fruits to grow larger [29]. As the application of thinning chemicals increased, both fruit size and the number of thinned fruitlets generally rose. However, research by Shafqat *et al*. [9] indicated a negative correlation with overall yield, suggesting that while higher concentrations of chemical thinning agents enhanced the fruit thinning percentage, they ultimately led to a reduction in final yield. Additionally, a prior study found that higher auxin doses resulted in a slight increase in peel thickness, while lower doses had no significant effect (Dalal et al., 2019). Furthermore, earlier research reported a 55–65% increase in fruit juice weight in trees treated with chemical fruit thinning [30, 31].

3.4. Effect of NAA on chemical fruit characteristics

The chemical characteristics of the fruits are tabulated in Table 6. It is noted that there are significant differences in the titratable acidity of the fruits between the concentrations of NAA used, regardless of the timing of treatment, while no significant differences were recorded depending on the date of spraying, regardless of the concentration of NAA used. Through the interaction data between the treatments, it is observed that using a NAA concentration of 200 ppm gave the lowest acidity percentage at 1 and 2 cm in fruit diameter (1.10 and 1.13 %, respectively). Regarding the effect of the NAA concentrations used on TSS in fruits, the 200 ppm treatment recorded the lowest significant value among the used concentrations (12.25 %), followed by the 400 ppm treatment (13.27 %), then the control (14.35 %). Significant differences were also observed in relation to the timing of NAA application. Spraying when the fruits reached 1 cm in diameter recorded the highest TSS value (13.72 %), followed by spraying at 1.5 cm (13.435 %) and 2 cm (12.72 %). Significant differences were observed in the interaction values, with the control treatment across all fruit diameters yielding the highest TSS % (14.35, 14.35, 14.35) for 1, 1.5, and 2 cm, respectively. In contrast, the lowest significant TSS value (11.33 %) was recorded for the 200 ppm NAA treatment when applied at a fruit diameter of 2 cm. Significant differences were found in the TSS/TA ratio (Table 6) based on NAA concentrations, with the 200 ppm treatment showing the highest significant ratio (10.64), while the control had the lowest ratio (9.86). Spraying time also influenced this ratio, with the lowest significant ($P \leq 0.05$) ratio observed when NAA was applied at a fruit diameter of 2 cm (9.82). In terms of interaction, the highest TSS/TA ratio was recorded when fruits with a diameter of 1 cm were treated with 200 ppm NAA (12.48).

Table 6. Effects of NAA concentrations (0, 200, and 400 ppm) applied at three stages of "Murcott" fruit development (1 cm, 1.5 cm, and 2 cm fruitlet diameters) on the titratable acidity (TA), TSS, TSS/TA ratio, and vitamin C concentration over the two combined seasons

NAA concentration	Fruitlet diameter			Mean
	1 cm	1.5 cm	2 cm	
	Titratable acidity (TA%)			
Control	1.45 ab	1.47 a	1.45 ab	1.46 A
NAA (200 ppm)	1.10 f	1.26 d	1.13 f	1.16 C
NAA (400 ppm)	1.40 b	1.17 e	1.32 c	1.30 B
Mean	1.32 A	1.30 A	1.30 A	
	TSS (%)			
Control	14.35 a	14.35 a	14.35 a	14.35 A
NAA (200 ppm)	13.66 b	11.75 e	11.33 f	12.25 C
NAA (400 ppm)	13.15 c	14.20 a	12.48 d	13.27 B
Mean	13.72 A	13.43 B	12.72 C	
	TSS/TA ratio			
Control	9.90 c	9.79 cd	9.90 c	9.86 C
NAA (200 ppm)	12.48 a	9.35 e	10.08 c	10.64 A
NAA (400 ppm)	9.39 e	12.10 b	9.47 de	10.32 B
Mean	10.59 A	10.41 A	9.82 B	
	Vitamin C (mg/100g)			
Control	26.16 e	26.16 e	26.13 e	26.15 C
NAA (200 ppm)	26.98 d	29.51 c	26.55 e	27.68 B
NAA (400 ppm)	30.95 b	26.33 e	32.33 a	29.87 A
Mean	28.03 B	27.33 C	28.33 A	

Different upper-case bold letters indicate statistical differences ($P \leq 0.05$, Duncan) between NAA concentrations over spraying times (vertical mean), and spraying times based on fruitlet diameters over NAA concentrations (horizontal mean), whereas lower-case letters represent statistical differences between the interactions (NAA concentrations × spraying times based on fruitlet diameters) ($P \leq 0.05$, Duncan).

Table 6 also included the vitamin C concentration of "Murcott" fruits, which was significantly affected by NAA spraying regardless of the timing of spraying (29.87, 27.68 and 26.15 mg/100g for 400, 200, and control, respectively) and was also significantly affected by the timing of spraying, regardless of NAA concentrations used (28.33, 28.03 and 27.33 mg/100g for 2, 1, and 1.5 cm fruit diameter, respectively). Concerning the interaction, 400 ppm NAA treatment recorded the highest vitamin C concentration in the fruits when applied at a fruit diameter of 2 cm (32.33 mg/100g). The improvement in fruit quality resulting from auxin application might be due to its function in postponing fruit maturity, which enables the fruits to remain on the tree longer and gather more nutrients and water [32]. It was observed that titratable acidity decreased as the fruit thinning percentage increased, a trend also noted in the studies of Shafqat *et al*. [9] and Saleem *et al*. [33]. Galliani *et al*. [34] assessed the effectiveness of chemical thinning and found that reduced fruit acidity had a more favorable impact on fruit size, with lower acidity observed in smaller fruits. Also, Safaei-Nejad *et al*. [4] reported that seven treatments increased juice total soluble solids and subsequently improved fruit growth indices, such as fruit weight, volume, diameter, and length, compared to the control. In this study, total soluble solids (TSS) varied between 11.333% and 14.354%. Previous studies similarly recorded an increase in TSS content in treated plants when compared to the control [27,22,9]. TSS:TA ratio serves as a maturity index for fruit and is linked to maintaining an adequate supply of metabolites to support fruit development. This ratio is used to assess the fruit's maturity level [25,35,9]. A field study conducted on sweet orange cultivar Pineapple showed that NAA (50 ppm) applications in April and July resulted in more medium-sized fruits, increased fruit weight, and improved peel quality, without affecting total soluble solids (TSS), titratable acidity (TA), or vitamin C content [35]. In contrast, Maurer and Kathryn [36] found that the average fruit weight, juice weight, juice percentage, peel thickness, total soluble solids (TSS), titratable acidity (TA), and the TSS to TA ratio remained consistent across all treatments when they examined the chemical thinning in 'Kinnow' mandarins.

4. Conclusion

In summary, the application of NAA had a marked effect on both fruit thinning and quality improvement. The effectiveness of NAA is largely determined by its concentration and the timing of its application; for example, using 200 ppm of NAA when the fruit reaches a diameter of 1 or 1.5 cm was particularly favourable.

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Conflict of interest:

The authors declare that they have no conflict of interest.

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