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FRUIT THINNING CHEMICAL AGENTS IMPROVES FRUIT SIZE AND QUALITY IN 'KINNOW' MANDARIN (*CITRUS RETICULATA* BLANCO) - RUTACEAE

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Abstract

'Kinnow' mandarin (*Citrus reticulata* Blanco) fruit needs to be thinned to increase the availability of photosynthates used to increase fruit size, fruit quality, profitability and can also help to overcome alternate bearing. This study evaluated 'Kinnow' fruit thinning using three chemical agents with different levels of concentration *i.e.* naphthalene acetic acid (NAA) @ 0.2, 0.3, 0.4, and 0.5 gL^{-1}; 3,5,6-trichloro-2-pyridyloxyacetic acid (3,5,6-TPA) at TPA at 0.2, 0.5, and 0.7 gL^{-1}, and ethephon @ at 0.4, 0.5, and 0.6 gL^{-1}, in Pakistani orchards just after the June fruit drop for two growing seasons 2017-19. Fruit weight was increased due to chemical thinning application when compared with the respective controls. The soluble solid contents were also higher than control in plants that had having chemical thinning treatment. The Application of fruit thinning chemical treatment increased the growth rate of fruit during the development cycle. Compared with the controls, the cost-benefit ratio was higher in 3,5,6-TPA at 0.5 gL^{-1}, ethephon at 0.5 gL^{-1}, and NAA at 0.3 gL^{-1}. It was positively concluded that fruit thinning efficiently improved the fruit quality and fruit crop profitability of 'Kinnow' by sustaining the carbohydrate supply and overcoming alternate bearing.

Key words: Citrus, Fresh fruit, Fruit drop, Alternate bearing, Economic benefit.

Introduction

There is great demand for 'Kinnow' mandarin (*Citrus reticulata* Blanco) due to the exceptional fruit quality. 'Kinnow' is best grown in sandy loam soils and under moderate environmental conditions (Temp >32°C and 80-95% RH) to maintain its original flavor and quality (Ahmad *et al*., 2022. The environmental conditions and fruit ripening stages predispose physicochemical quality and quantity in citrus fruit (Porras *et al*., 2014; Nawaz *et al*., 2021). In Pakistan, citrus orchards face challenges with fruit size, color, quality, and excessive premature fruit drop (Ibrahim *et al*., 2007; Ashraf *et al*., 2013; Asad *et al*., 2023). Fruit size is important in determining citrus fruit profitability and economic return. Standard horticultural practices, including fertilization, irrigation, pruning, and fruit thinning, have become mandatory to achieve maximum profitability (Guardiola & García-Luis, 2000; Davis *et al*., 2004). Therefore, fruit thinning has been implemented at the cost of reducing crop load, which helps optimize fruit size and improve fruit color, shape, and quality. Fruit thinning also helps to maintain tree growth and structure, maximize crop value, and promote early blooming (Byers *et al*., 2010).

Fruit growth results from the accumulation of dry matter and water. The fruit growth and size are affected by the ratio between the source organs that provide sugars for growth and the number of sinks, such as the fruit and other non-photosynthetic organs that compete for the sugars. The competition for photosynthetic occurs among different organs (fruit-shoot) and between individual units of the same type of organ (fruit-fruit) before the competition between the vegetative and reproductive organs starts (Mesejo *et al*., 2012; Qureshi *et al*., 2021b). When any organ in the tree develops, it needs more carbohydrates than a low priority storage compartment to store carbohydrates. The tree has a high demand for carbohydrates during the fruit enlargement period, with starch reserves building up in the growing twigs. However, the tree's carbohydrate status is strongly influenced by orchard management practices, including girdling and fruit thinning (Afshari-Jafarbigloo *et al*., 2020; Talat *et al*., 2020; Noreen *et al*., 2022). These practices balance the source and sink relationship.

The early stages of fruit development strongly correlate with the fruit diameter at the end of the June drop and the fruit size at maturity (Ortola *et al*., 1998; Guardiola & García-Luis, 2000; Akhlaghi-Amiri *et al*., 2016). Fruit sink strength and the supply of metabolites are affected by the genetic potential of the cultivar. However, it is primarily influenced by environmental conditions such as temperature, rain, and flower quality, including flower number, type of inflorescence, and location on the tree (Lado *et al*., 2018; Qureshi *et al*., 2021a). A high crop load reduces tree storage nutrition, substantially affecting vegetative growth and flower bud differentiation during the second year. The vegetative summer flush is slow when there is a heavy crop load because fruit development is the priority of the sink. Citrus competition between fruit-fruit is more pronounced than in other fruit trees. The progressive reduction in the fruit number during the early fruit development stage has been linked to compensation for the carbohydrate economy (Goldschmidt, 1999; Byers *et al*., 2010; Mafrica *et al*., 2023).

Fruit thinning is a widely used technique that balances the carbohydrate level and source-sink relationship. Thinning is the removal of some of the developing fruit to increase photosynthate availability for the tree and remaining fruit, leading to an increase in fruit size. A substantial increase in the fruit size can considerably reduce the fruit number (total yield). In some cases, this may offset the economic benefit obtained from the increase in fruit size (Stander & Cronjé, 2016; Ashraf *et al*., 2012). Fruit thinning has also been used to correct alternate bearing cycles. These cycles may be induced by unfavorable weather conditions (Shafqat *et al*., 2021a, 2021b) but are characteristic of several mandarins and hybrids, including ‘Kinnow’. Alternate bearing is characterized by a heavy crop followed by little to no crop the following year. Therefore, thinning the fruit may increase the fruit size, increase the crop value, and induce flowering the next year.

Effective thinning products are necessary for optimum fruit size at harvest and return blooming for consistent annual cropping. The relative importance of each one depends on the thinning product, concentration applied, development stage of the fruit, and cultivar. The most important factor is the concentration used and the fruit development stage. 2,4-dichlorophenoxyacetic acid (2,4-D) effectively increases fruit growth without affecting ethylene synthesis. 4-chlorophenoxyacetic acid (4CPA), naphthalene acetic acid (NAA), and dichlorprop (2,4-DP) induce ethylene synthesis and cause substantial thinning when applied before the end of the natural drop (Purewal *et al*., 2020).

The effectiveness of thinning agents must be assessed in the context of the profitability of the orchard. In citrus, market profitability is linked to fruit size (grades). Grade a fruit fetches a higher price than Grade B and C fruit sizes. Since the introduction of the ‘Kinnow’ mandarin in Pakistan from the United States during the 1960s, the ‘Kinnow’ mandarin has become the most cultivated citrus fruit with the highest cultivation area and yield. However, the fruit export has not yet met its potential despite good yields. This research aimed to assess the effectiveness of commercially available chemical thinning agents for improving fruit grade quality and increasing profitability for growers.

Materials and Methods

Plant materials, experimental site, and growing conditions: The experiment was conducted on 20-year-old healthy uniform-sized ‘Kinnow’ trees grafted onto rough lemon (*Citrus jambhiri*) rootstock and planted in a square system (7.3 × 7.3 m) at Fruit Orchard Square #9, University of Agriculture Faisalabad, Pakistan, for two consecutive seasons during 2017–19. The Faisalabad region is characterized by an average annual rainfall of 346 mm, and an average temperature of 25.74°C. All the trees were grown using recommended agronomic practices (Siddique *et al*., 2020).

Treatments: The trees were foliar sprayed with three chemical thinning agents: 3,5,6-trichloro-2-pyridyloxyacetic acid (3,5,6-TPA), ethephon, and NAA at the initial stage of fruit development (June for both years). Treatments were administered of four concentrations of 3,5,6-TPA (control, 0.2, 0.5, and 0.7 gL^{-1}), 4 concentrations of ethephon (control, 0.4, 0.5, and 0.6 gL^{-1}), and 5 concentrations of NAA (control, 0.2, 0.3, 0.4, and 0.5 gL^{-1}). Trees that received no chemical applications during the experiment were used as controls.

Fruit thinning percentage: The total number of fruits per tree was determined using a 0.5 × 0.5 × 0.5 m counting frame with a pad holder and prongs in each corner (Falivene & Hardy, 2008; Government of Western Australia, 2019). The frame was randomly placed on all four sides of the tree, and the number of fruits were counted before thinning. The fruit thinning percentage was calculated by recording the total number of thinned fruit divided by the total before thinning and multiplying the resulting value by 100.

Fruit physical analyses: A total of 25 uniform fruit based on diameter and physical appearance were tagged per tree for each treatment. The fruit diameter was recorded monthly using a caliper (Digital Digimatic Vernier Caliper 500-197-20/30; Mitutoyo, Kawasaki, Japan) until harvesting. Fruit harvesting was undertaken during the third week of January for 2017-18 and 2018-19 in both years. The weight of 10 randomly selected fruit from each tree was recorded using a digital scale (PL602E; Mettler Toledo, Columbia, MD). The average fruit weight was calculated by dividing the total fruit sample weight by the number of fruits in each sample.

The fruit from each sample was peeled by hand and weighed on a digital scale. The average peel percentage was calculated by dividing the average peel weight by the average fruit weight multiplied by 100. The fruit peel thickness was measured using the vernier caliper. The rag weight of each fruit was calculated using a scale. The rag percent was calculated by dividing the rag weight by the fruit weight and multiplying the resulting value by 100. The fruit juice was extracted using a manual extractor, sieved to eliminate the pulp and seeds, and then weighed. The number of seeds per fruit was also calculated. The juice percentage was calculated by dividing the juice weight by the fruit weight and multiplying the resulting value by 100.

Fruit chemical analyses: The total soluble solids (TSS) were recorded for each sample using a digital refractometer (Atago 2350 R5000; Cole-Parmer, Vernon Hills, IL). The titratable acidity of the fruit juice was determined using the method described by Liao *et al*., (2019). Juice (5 mL) was collected in a 100 mL conical flask and then diluted up to 50 mL with distilled water. It was titrated against 0.1 N NaOH using 2–3 drops of phenolphthalein as an indicator until a pink color was achieved. The titratable acidity was expressed as a percentage (Equation 1), and the total soluble solids-to-titratable acidity ratio (TSS: TA) was calculated using the following equation:

$$\text{Titratable acidity (\%)} = \frac{\text{0.1 N NaOH used} \times 0.0064}{\text{Volume of juice used}} \times 100. \quad \text{Equation 1}$$

The ascorbic acid content of the juice was determined using the method described by (Ruck, 2012). The reducing, non-reducing, and total sugars in the juice were estimated using the method described by Nawaz *et al.*, (2019). The total antioxidants and total phenolic contents (TPC) in the juice of the 'Kinnow' fruit were determined using a 2,2-diphenyl-1–picrylhydrazyl radical (DPPH) assay as described by Xie & Schaich, (2014).

Economic analysis of 'Kinnow' fruit thinning: The fruit was harvested from the trees that received the respective treatments and then weighed. The fruit was graded and packed according to the classes shown in (Table 1).

Table 1. Estimation of fruit yield and cost based on fruit grades.

Fruit diameter	No. of fruit/carton	Price/carton ($)
> 70 mm	48–52	4.00
60–70 mm	65–72	3.33
50–60 mm	80–100	2.00

The rates were obtained from the Pakistan citrus industry during the 2017–18 season

Estimation of cost of production: To estimate the cost of production, a questionnaire was developed and pre-tested. A total of 30 'Kinnow' orchards were selected to estimate the cost of production in the Sargodha district, which is a hub of 'Kinnow' production in Pakistan. The data was analyzed using Equations 2 and 3.

$$AM = \frac{\Sigma X}{N} \qquad \text{Equation 2}$$

where *AM* = arithmetic mean, ΣX = total sum of variables, and *N* = total number of observations.

$$P = \frac{F}{N} \times 100 \qquad \text{Equation 3}$$

where *F* = frequency of class and *N* = total number of observations.

Economic Analysis: The orchard's cost-benefit ratio (BCR) was calculated from the total revenue and total economic analysis costs (Equation 4).

$$\text{BCR} = \frac{\text{Total income or benefit}}{\text{Total cost}} \qquad \text{Equation 4}$$

Conversion of Income/Acre into Yield/Plant and Acre: Citrus growers sell the fruit to contractors before they reach maturity, and the conversion is based on a future estimation of the yield per plant or hectare. The average price per kg is required to convert the income per hectare into yield per plant and per acre. We used Equation 5 to convert the revenue per hectare of 'Kinnow' into yield per acre in kg. The average yield per acre of 'Kinnow' was used to calculate the average yield per plant (Equation 6).

Experimental design and statistical analysis: The experiment was arranged in a randomized block design with three chemicals and different concentrations, with four for 3,5,6-TPA; four for ethephon; and five for NAA with four replications each. The data collected were analyzed using analysis of variance (ANOVA) and a Tukey mean comparison test at 5% probability (p<0.05).

$$\text{Average yield per hectare (kg)} = \frac{\text{Average income per hectare (\$)}}{\text{Average price per kg (\$)}} \qquad \text{Equation 5}$$

$$\text{Average yield per plant (kg)} = \frac{\text{Average yield per acre (kg)}}{\text{Average no.of plants per acre}} \qquad \text{Equation 6}$$

Results

Fruit thinning percentage: The thinning percentage was significantly affected by applying thinning chemicals during both growing seasons, and a gradual increase in the chemical treatment concentration increased thinning. The thinning percentage was higher at 0.7 gL^{-1} with 3,5,6-TPA, 0.6 gL^{-1} in ethephon, and 0.5 gL^{-1} in NAA during the 2017–18 and 2018–19 seasons compared with the controls (Table 2).

Fruit morphology: A significant difference in fruit weight was observed across all treatments except 3, 5, 6-TPA in the 2018–19 season *(p*<0.05). The fruit weight in 3,5,6-TPA at 0.2 gL^{-1} was 17% higher than the control in 2017–18. Ethephon at 0.4 gL^{-1} increased fruit weight by 47% and 46% in 2017–18 and 2018–19, respectively, compared with the control. Compared with the control, NAA at 0.2 gL^{-1} increased fruit weight by 27% and 57% in both seasons (Table 2).

The fruit size was significantly improved with thinning chemicals in both seasons (p<0.05). 3,5,6-TPA at 0.5 gL^{-1} increased fruit size by 13.5% and 12.9% for both seasons, respectively, compared with the controls. Ethephon increased fruit size by 24.7% and 21.8% for both seasons, respectively, compared with the controls. NAA at 0.3 gL^{-1} increased fruit size by 6.1% in 2017–18 and at 0.4 gL^{-1} by 5% in 2018–19 compared with the controls (Table 2).

Thinning chemicals and concentration were not significantly different for the number of seeds for both years except for 3,5,6-TPA in 2017–18. The control and 0.7 gL^{-1} 3,5,6-TPA presented with 14 seeds/fruit, while a minimum number of seeds (10 seeds/fruit) were observed with 0.2 gL^{-1} treatment, which was statistically the same as 0.5 gL^{-1} (12 seeds/fruit) (Table 2).

The fruit juice weight was also significantly different for all the chemical treatments during both years (p<0.05) except NAA in 2017–18. The fruit juice weight was increased by 36% during 2017–18 and 11.5% during 2018–19 in 3,5,6-TPA (0.2 gL^{-1}). Ethephon at 0.4 gL^{-1} increased the juice weight by 15.6% and 13.2% during 2017–18 and 2018–19, compared with the controls. NAA at 0.2 gL^{-1} increased the juice weight by 41.5% during 2018–19 (Table 3).

Table 2. Effect of independent chemical treatments on the thinning, fruit weight, fruit size, and the number of seeds/fruit of ‘Kinnow’ mandarin (*Citrus reticulata* Blanco) in the 2017/18 and 2018/19 growing seasons. Data represent the mean ± standard deviation (*n* = 4).

Chemical	Treatment	Thinning %		Fruit weight (g)		Fruit size (mm)		No seeds/fruit	
		2017	2018	2017	2018	2017	2018	2017	2018
3,5,6-Trichloro-2-pyridyloxy-acetic acid (3,5,6-TPA)	Control	15.0±2.1^{c}	19.5±1.9^{c}	135.8±3.6^{c}	132.2±1.4	135.5±1.2^{b}	135.5±1.2^{b}	13.8±0.9^{a}	17.0±1.7
	0.2 gL^{-1}	51.0±2.7^{b}	44.8±1.0^{b}	159.5±0.6^{a}	136.9±0.9	148.8±3.0^{a}	148.6±3.1^{a}	10.5±0.7^{b}	16.3±1.8
	0.5 gL^{-1}	60.5±1.3^{a}	54.8±1.5^{a}	126.0±2.8^{d}	133.8±1.8	153.8±4.0^{a}	150.9±1.6^{a}	11.5±0.7^{b}	12.5±0.7
	0.7 gL^{-1}	66.8±0.9^{a}	60.8±2.7^{a}	147.3±4.0^{b}	132.6±2.1	150.0±2.7^{a}	152.9±1.1^{a}	14.0±0.4^{a}	16.3±2.9
	p-value	0.0001*	0.0001*	0.0001*	0.2256	0.0169**	0.0009*	0.0110*	0.4185
Ethephon	Control	8.5±1.3^{d}	19.3±2.1^{c}	150.5±1.0^{b}	134.0±2.9^{b}	138.6±2.6^{c}	140.1±2.3^{c}	11.0±0.4	19.5±1.9
	0.4 gL^{-1}	46.0±1.6^{c}	52.0±1.5^{b}	221.4±5.2^{a}	193.8±1.7^{b}	172.8±0.7^{a}	171.6±0.7^{a}	9.0±0.4	20.3±2.4
	0.5 gL^{-1}	55.0±1.5^{b}	58.5±1.4^{ab}	136.1±4.0^{c}	135.8±1.8^{b}	155.0±1.6^{b}	155.0±1.6^{b}	9.8±0.5	18.5±1.3
	0.6 gL^{-1}	64.8±1.7^{a}	60.5±3.1^{a}	161.7±3.2^{b}	150.9±2.5^{a}	156.8±5.2^{b}	159.4±1.7^{b}	9.5±0.7	19.5±0.7
	p-value	0.0001*	0.0001*	0.0001*	0.002*	0.0001*	0.0001*	0.0956	0.9332
Naphthalene acetic acid (NAA)	Control	20.0±0.9^{e}	17.1±0.9^{e}	143.5±1.3^{c}	116.8±1.0^{c}	133.3±1.5^{c}	132.7±1.6^{b}	9.8±1.1	19.8±2.8
	0.2 gL^{-1}	39.0±1.1^{c}	36.5±0.9^{d}	181.7±0.9^{a}	182.7±1.8^{a}	145.4±1.7^{a}	148.5±2.4^{a}	13.5±1.5	19.3±1.6
	0.3 gL^{-1}	34.5±1.6^{d}	47.7±0.9^{c}	137.4±4.3^{c}	130.9±1.6^{b}	140.7±1.6^{ab}	144.6±1.3^{a}	8.8±1.1	17.8±2.2
	0.4 gL^{-1}	55.1±0.4^{b}	58.3±1.3^{b}	155.4±1.1^{b}	132.1±2.7^{b}	139.7±1.3^{ab}	132.9±1.2^{b}	10.8±1.8	13.8±0.8
	0.5 gL^{-1}	60.0±2.0^{a}	62.7±0.6^{a}	161.2±2.6^{b}	131.2±1.8^{b}	137.0±0.9^{bc}	133.7±2.3^{b}	13.3±1.9	17.0±0.6
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.156	0.2688

Means followed by the same lowercase letter in the column within the same chemical do not differ statistically by Tukey multiple comparison tests ($p<0.05$)

Table 3. Effect of independent chemical treatments on the fruit juice weight, peel thickness, peel weight, and rag weight of ‘Kinnow’ mandarin (*Citrus reticulata* Blanco) in the 2017/18 and 2018/19 growing seasons. Data represent the mean ± standard deviation (*n* = 4).

Chemical	Treatment	Juice weight (g)		Fruit juice pH		Peel thickness (mm)		Peel weight (g)		Rag weight (g)	
		2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
3,5,6-Trichloro-2-pyridyloxy-acetic acid (3,5,6-TPA)	Control	67.6±2.2^{c}	61.8±1.0^{b}	3.3±0.1^{c}	3.3±0.1^{b}	3.4±0.1^{a}	3.2±0.1^{a}	16.7±1.0^{b}	18.6±1.5^{b}	83.4±3.0^{a}	54.3±3.1^{c}
	0.2 gL^{-1}	92.0±2.1^{a}	68.9±1.4^{a}	3.6±0.1^{a}	3.6±0.1^{a}	2.5±0.1^{c}	3.1±0.2^{a}	24.6±1.7^{a}	25.6±0.6^{a}	89.3±2.4^{a}	83.9±1.2^{b}
	0.5 gL^{-1}	62.3±1.7^{c}	65.5±1.7^{ab}	3.3±0.1^{c}	3.3±0.1^{b}	3.4±0.1^{a}	2.5±0.2^{b}	17.7±1.6^{b}	23.1±0.5^{a}	96.2±1.8^{a}	92.4±1.3^{a}
	0.7 gL^{-1}	79.5±4.3^{b}	64.0±2.2^{b}	3.5±0.1^{b}	3.5±0.1^{a}	2.8±0.1^{b}	2.7±0.1^{b}	17.9±0.4^{b}	18.1±0.4^{b}	80.3±10.6^{a}	83.1±2.7^{b}
	p-value	0.0002*	0.043**	0.001*	0.002*	0.000*	0.004*	0.014**	0.001*	0.3037	0.000*
Ethephon	Control	80.7±0.6^{b}	63.4±2.0^{c}	3.4±0.1	3.3±0.1	3.2±0.1^{a}	3.3±0.1	20.1±1.3^{c}	20.7±0.7^{b}	59.9±5.3^{b}	49.9±0.6^{b}
	0.4 gL^{-1}	93.3±1.5^{b}	71.8±0.7^{a}	3.3±0.1	3.3±0.1	2.9±0.1^{b}	3.3±0.2	39.5±2.4^{a}	25.6±1.1^{a}	86.3±1.8^{a}	86.4±0.7^{a}
	0.5 gL^{-1}	71.9±0.7^{c}	66.4±1.2^{bc}	3.4±0.1	3.3±0.1	3.0±0.1^{ab}	3.5±0.1	19.8±1.8^{c}	26.2±1.1^{a}	87.0±2.9^{a}	88.2±4.1^{a}
	0.6 gL^{-1}	80.1±0.6^{b}	69.8±1.4^{ab}	3.3±0.1	3.4±0.1	2.7±0.1^{c}	3.2±0.1	28.5±1.4^{b}	28.6±1.4^{a}	88.0±2.6^{a}	80.0±2.3^{a}
	p-value	0.000*	0.014**	0.1636	0.398	0.001*	0.5149	0.0001*	0.006*	0.0007*	0.000*
Naphthalene acetic acid (NAA)	Control	73.6±0.9	47.5±0.6^{e}	3.3±0.1^{b}	3.3±0.1^{b}	3.2±0.1^{a}	3.2±0.1^{a}	19.7±1.2^{b}	19.5±1.0^{d}	50.2±0.7^{b}	49.7±0.6^{c}
	0.2 gL^{-1}	72.6±1.2	67.2±0.7^{a}	3.3±0.1^{b}	3.2±0.1^{c}	3.0±0.1^{ab}	2.8±0.1^{bc}	21.6±0.4^{b}	28.2±0.2^{a}	87.6±2.1^{a}	87.3±2.1^{a}
	0.3 gL^{-1}	72.9±2.4	63.6±0.5^{b}	3.4±0.1^{b}	3.4±0.1^{ab}	2.7±0.2^{c}	2.8±0.1^{b}	19.7±1.8^{b}	24.7±0.5^{b}	95.6±3.0^{a}	82.6±1.9^{a}
	0.4 gL^{-1}	73.3±1.9	56.8±1.6^{c}	3.3±0.1^{b}	3.4±0.1^{b}	2.7±0.1^{c}	2.6±0.2^{c}	28.2±1.5^{a}	22.5±0.4^{c}	87.5±1.3^{a}	75.3±3.7^{b}
	0.5 gL^{-1}	74.5±3.9	53.4±0.8^{d}	3.6±0.1^{a}	3.5±0.1^{a}	2.8±0.1^{bc}	2.7±0.1^{bc}	29.9±2.8^{a}	21.5±0.3^{c}	88.6±3.6^{a}	83.8±2.4^{a}
	p-value	0.9838	0.000*	0.0032*	0.0006*	0.012**	0.0007*	0.001*	0.000*	0.000*	0.000*

Means followed by the same lowercase letter in the column within the same chemical do not differ statistically by Tukey multiple comparison test ($p<0.05$)

A significant difference was observed in peel thickness from applying thinning chemicals during both years ($p<0.05$), except for ethephon in 2018–19. 3,5,6-TPA reduced the peel thickness by 27% at 0.2 gL^{-1} during 2017–18 and by 21.2% and 14.4% at 0.5 and 0.7 gL^{-1}, respectively, during 2018–19 relative to the control. Ethephon at 0.6 gL^{-1} reduced the peel thickness by 13.9% in 2017–18, whereas there was no significant difference from 2018–19. NAA reduced peel thickness by 15% at both 0.3 and 0.4 gL^{-1} during 2017–18, whereas during 2018–19, 0.4 gL^{-1} reduced peel thickness by 18.3% relative to the control (Table 3).

The peel weight was also significantly affected by applying thinning chemicals during the two growing seasons. 3,5,6-TPA at 0.2 gL^{-1} increased peel weight by 47.2% in 2017–18 and by 37.5% and 23.9% at 0.2 and 0.3 gL^{-1}, respectively, during 2018–19 compared with the controls. Ethephon at 0.4 gL^{-1} increased peel weight by 96% in 2017–18. NAA at 0.4 and 0.5 gL^{-1} increased peel weight by 42.9% and 51.4%, respectively, during 2017–18 and 2018–19 by 44.3% at 0.2 gL^{-1} compared with the controls (Table 3).

The rag weight was also increased with different concentrations of chemicals. 3,5,6-TPA at 0.5 gL^{-1} increased the rag weight by 70.2% in 2018–19. Ethephon at 0.6 gL^{-1} increased the rag weight by 46.8% in 2017–18 and 76.7% at 0.5 gL^{-1} during 2018–19 compared with the controls. NAA at 0.3 gL^{-1} increased the rag weight by 90.4% during 2017–18, whereas during 2018–19, NAA at 0.2, 0.3, and 0.5 gL^{-1} increased the rag weight by 75.4%, 66%, and 68.4%, respectively, relative to the control (Table 3).

Fruit quality parameters: The total soluble solids in the fruit juice were affected by the chemicals, their concentrations, and the growing season. 3,5,6-TPA at 0.2 and 0.5 gL^{-1} increased the total soluble solids by 10.8% and 25.4%, respectively, in 2017–18, and by 11.5% and 26.8%, respectively, in the 2018–19 season compared with the controls. Ethephon at 0.4 gL^{-1} increased the total soluble solids by 28.3% during 2017–18 compared with the control. Although significantly different from the control, NAA did not lead to a significant difference between concentrations observed during both growing seasons (Fig. 1).

The titratable acidity was significantly different based on the chemical treatment (and concentration) in both growing seasons except for 3,5,6-TPA and ethephon during 2018–19. 3,5,6-TPA treatment showed lower titratable acidity during the 2017–18 season than the control and had the highest titratable acidity value. Ethephon and NAA during 2017–18 were significantly different from the control, but there were no significant differences between concentrations of titratable acidity. NAA at 0.5 gL^{-1} increased titratable acidity by 25.9% during 2018–19 compared with the control (Fig. 2).

The fruit juice pH was significantly affected by 3,5,6-TPA and NAA treatment during both growing seasons, whereas ethephon application had no significant effect. 3,5,6-TPA at 0.2 gL^{-1} increased the juice pH by 9% and 7.8% in 2017–18 and 2018–19, respectively, compared with the controls. NAA at 0.5 gL^{-1} increased the juice pH by 8.15% and 4.53% in 2017–18 and 2018–19, respectively, compared with the controls (Table 3).

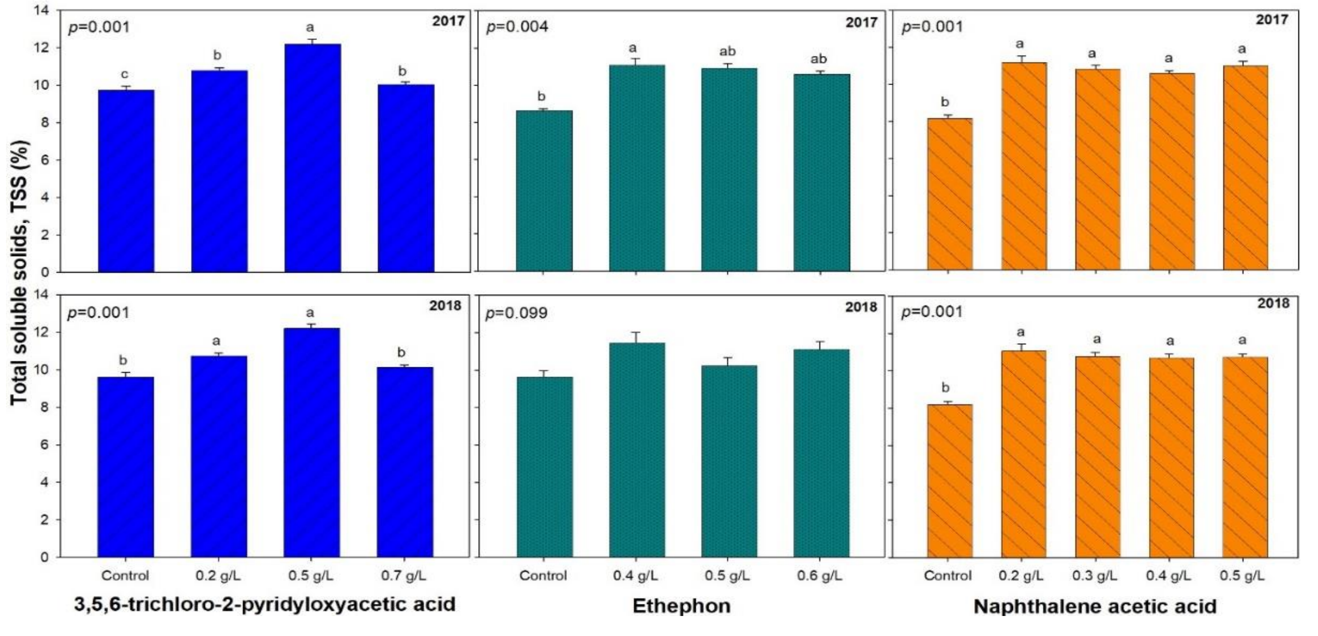

Fig. 1. Fruit total soluble solids of ‘Kinnow’ mandarin (*Citrus reticulata* Blanco) exposed to different chemical treatments in the 2017/18 and 2018/19 growing seasons. Different lowercase letters indicate significant differences at 5% probability.

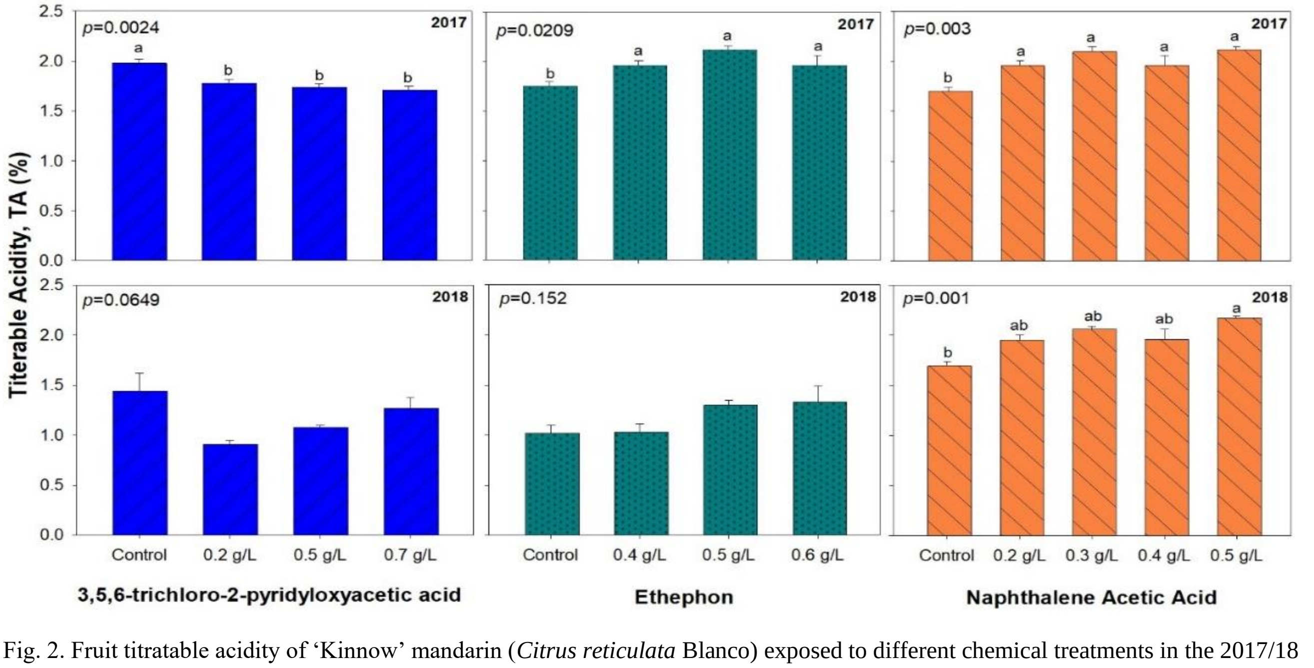

Fig. 2. Fruit titratable acidity of ‘Kinnow’ mandarin (*Citrus reticulata* Blanco) exposed to different chemical treatments in the 2017/18 and 2018/19 growing seasons. Different lowercase letters indicate significant differences at 5% probability.

Table 4. Effects of independent chemical treatments on fruit juice pH, reducing sugar, non-reducing sugar, total sugar, total phenolic contents, and ascorbic acid of 'Kinnow' mandarin (*Citrus reticulata* Blanco) in the 2017/18 and 2018/19 growing seasons. Data represent the mean ± standard deviation (*n* = 4).

Chemical	Treatment	Reducing sugar (%)		Non-reducing sugar (%)		Total sugar (%)		Total phenolic contents (ug g^{-1} FW)		Ascorbic acid (mg 100 g^{-1})	
		2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
3,5,6-Trichloro-2-pyridyloxy-acetic acid (3,5,6-TPA)	Control	3.2±0.1bc	3.1±0.1c	3.3±0.1	3.3±0.2	6.5±0.1b	6.4±0.1c	163.7±0.6bc	162.3±1.2b	91.9±0.6a	88.8±1.2a
	0.2 gL^{-1}	3.5±0.1ab	3.4±0.1b	3.6±0.1	3.6±0.1	7.0±0.1a	7.0±0.1b	163.2±1.0c	163.5±1.0b	89.9±1.9a	87.4±1.1ab
	0.5 gL^{-1}	2.9±0.1c	2.9±0.1d	3.4±0.1	3.4±0.1	6.3±0.1b	6.2±0.1c	171.2±0.5a	172.6±1.1a	84.6±1.1b	84.0±0.7c
	0.7 gL^{-1}	3.7±0.1a	3.8±0.1a	3.6±0.1	3.6±0.1	7.3±0.1a	7.4±0.1a	166.7±1.3b	173.3±0.9a	83.8±0.7b	84.8±0.9bc
	p-value	0.001*	0.001*	0.2345	0.2097	0.001*	0.001*	0.001*	0.001*	0.0047*	0.0212**
Ethephon	Control	3.0±0.1	3.2±0.1b	3.1±0.2b	3.9±0.2	6.1±0.3b	7.1±0.2b	162.0±1.1b	162.9±1.1b	81.5±0.5c	78.2±2.5b
	0.4 gL^{-1}	3.3±0.1	3.9±0.2a	3.1±0.0b	3.7±0.2	6.4±0.1b	7.5±0.2ab	166.7±2.3a	168.2±1.3a	90.1±1.8a	86.7±2.2a
	0.5 gL^{-1}	3.6±0.1	3.8±0.1a	2.8±0.1b	3.8±0.1	6.4±0.1b	7.5±0.1ab	167.7±1.4a	168.4±0.9a	85.8±0.2b	85.8±0.7a
	0.6 gL^{-1}	3.0±0.1	3.6±0.1a	4.1±0.2a	4.2±0.2	7.1±0.1a	7.8±0.3a	171.0±0.3a	163.2±0.3b	84.5±0.3bc	85.5±0.4a
	p-value	0.081	0.013**	0.001*	0.178	0.040**	0.03**	0.01*	0.008**	0.001*	0.009*
Naphthalene acetic acid (NAA)	Control	3.2±0.2bc	3.5±0.1	3.2±0.2	3.6±0.4	6.4±0.1c	7.1±0.5	159.8±0.4d	164.4±0.9d	81.1±0.8b	88.3±1.9ab
	0.2 gL^{-1}	3.3±0.1b	3.8±0.2	3.1±0.0	3.7±0.2	6.4±0.1c	7.5±0.4	163.9±0.7c	165.6±1.6cd	91.1±2.0a	89.1±2.5a
	0.3 gL^{-1}	3.6±0.1a	3.4±0.2	2.7±0.1	4.2±0.3	6.3±0.1c	7.7±0.3	169.9±0.6b	169.0±1.0bc	84.6±1.1b	85.3±1.0ab
	0.4 gL^{-1}	3.0±0.1c	3.9±0.3	4.2±0.2	4.7±0.5	7.1±0.1a	8.6±0.4	174.4±1.9a	169.9±1.5ab	83.8±0.7b	84.4±0.7b
	0.5 gL^{-1}	3.7±0.1a	4.1±0.3	3.1±0.1	4.2±0.2	6.8±0.2b	8.3±0.4	173.7±1.6a	173.4±1.0a	89.4±0.3a	85.0±1.4ab
	p-value	0.001*	0.4096	0.1782	0.2446	0.004*	0.1187	0.0001*	0.003*	0.005*	0.1097

Means followed by the same lowercase letter in the column within the same chemical do not differ statistically by Tukey multiple comparison test ($p<0.05$)

Table 5. Effect of independent chemical treatments on the yield per tree, number of fruits per tree, and yield per acre of 'Kinnow' mandarin (*Citrus reticulata* Blanco) in 2017/18 and 2018/19 growing seasons. Data represent the mean ± standard deviation (*n* = 4).

Chemical	Treatment	No. of fruit $tree^{-1}$		Yield (kg) $tree^{-1}$		Yield (kg) ha^{-1}	
		2017	2018	2017	2018	2017	2018
3,5,6-Trichloro-2-pyridyloxy-acetic acid (3,5,6-TPA)	Control	336.3±15.1^{a}	354.3±3.7^{d}	49.9±1.1^{a}	73.2±1.1^{d}	12254±185^{a}	18129±203^{d}
	0.2 gL^{-1}	253.3±16.3^{b}	297.8±7.1^{a}	38.8±0.9^{b}	60.4±1.5^{a}	9608±164^{b}	14918±233^{a}
	0.5 gL^{-1}	237.5±10.2^{b}	269.3±7.9^{b}	37.8±2.6^{b}	54.8±1.1^{b}	9361±146^{c}	13560±199^{b}
	0.7 gL^{-1}	253.8±7.2^{b}	243.8±7.8^{c}	32.5±0.8^{c}	46.8±0.5^{c}	8052±136^{d}	11584±150^{c}
	p-value	0.0001*	0.004*	0.0001*	0.0001*	0.0001*	0.0001*
Ethephon	Control	439.3±7.3^{a}	427.5±1.7^{a}	72.3±2.3^{a}	77.0±1.0^{a}	17882±201^{a}	19043±192^{a}
	0.4 gL^{-1}	319.5±10.4^{b}	327.0±6.8^{b}	56.8±1.6^{b}	63.5±0.9^{b}	13607±174^{b}	15709±185^{b}
	0.5 gL^{-1}	237.5±10.2^{c}	230.0±8.6^{d}	39.3±3.7^{c}	55.0±1.2^{c}	9731±121^{c}	13609±205^{c}
	0.6 gL^{-1}	256.0±8.6^{c}	266.8±11.8^{c}	39.8±1.0^{c}	47.3±0.9^{d}	9805±165^{c}	11707±184^{d}
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
Naphthalene acetic acid (NAA)	Control	429.0±8.6^{a}	440.3±6.3^{a}	72.0±2.3^{a}	84.5±1.2^{a}	17833±196^{a}	20846±214^{a}
	0.2 gL^{-1}	254.3±6.1^{b}	335.3±5.7^{b}	51.3±1.3^{b}	74.0±1.1^{b}	12695±183^{b}	18302±191^{b}
	0.3 gL^{-1}	230.0±8.6^{c}	315.3±5.3^{c}	46.0±1.5^{c}	62.5±1.1^{c}	11337±133^{c}	15462±209^{c}
	0.4 gL^{-1}	230.0±1.9^{c}	273.3±3.2^{d}	38.5±1.3^{d}	53.5±0.7^{d}	9509±199^{d}	13239±167^{d}
	0.5 gL^{-1}	228.0±8.6 c	251.3±5.0 e	35.8±1.8^{d}	45.3±1.0^{e}	8867±265^{d}	11213±184^{e}
	p-value	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*

Means followed by the same lowercase letter in the column within the same chemical do not differ statistically by Tukey multiple comparison test ($p<0.05$)

Fruit biochemical parameters: The fruit thinning chemical treatment significantly affected the reducing sugars during both growing seasons, but NAA had no significant effect in 2018–19. 3,5,6-TPA at 0.7 gL^{-1} increased the reducing sugars by 17% and 22% in 2017–18 and 2018–19, respectively, compared with the controls. Ethephon at 0.5 gL^{-1} increased the reducing sugars by 21.3% and 18.2% in 2017–18 and 2018–19, respectively, whereas 0.5 gL^{-1} increased reducing sugars by 4.5% in 2017–18 compared with the controls (Table 4).

The non-reducing sugars were significantly affected by ethephon and the NAA treatment for both growing seasons, but 3,5,6-TPA had no significant effect. Ethephon at 0.5 gL^{-1} increased the non-reducing sugars by 32% in 2017–18 and by 6.1% at 0.4 gL^{-1} during 2018–19 compared with the controls. NAA at 0.5 gL^{-1} increased the non-reducing sugars by 30.9% during 2017–18 compared with the control (Table 4).

The thinning chemical treatment significantly affected the total sugars during both growing seasons, except for NAA in 2018–19. 3,5,6-TPA at 0.2 gL^{-1} increased the total sugars by 12.8% in 2017–18 and at 0.7 gL^{-1} by 15.8% during 2018–19 compared with the controls. Ethephon at 0.6 gL^{-1} increased the total sugars by 16.2% and 9.1% during 2017–18 and 2018–19, respectively, relative to the controls (Table 4).

TPC was significantly affected by applying fruit thinning chemicals during both growing seasons. 3,5,6-TPA at 0.5 gL^{-1} increased the TPC by 4.6% in 2017–18 and at 0.5 and 0.7 gL^{-1} by 6.3% and 6.8%, respectively, during 2018–19 compared to the controls. In 2018–19, ethephon at 0.6 gL^{-1} increased the TPC by 5.5%. NAA at 0.4 and 0.5 gL^{-1} increased TPC by 9.1% and 8.7%, respectively, during 2017–18 and 2018–19 at 0.5 gL^{-1} by 5.5% compared with the controls (Table 4).

Ascorbic acid was significantly affected by applying selected chemicals and treatments, except for NAA during 2018–19. 3,5,6-TPA reduced the ascorbic acid contents with the increasing level of treatments. Ethephon at 0.4 gL^{-1} increased the ascorbic acid content by 10.7% in 2017–18 and 10.9% in 2018–19 compared with the controls. NAA at 0.2 and 0.5 gL^{-1} increased ascorbic acid contents by 12.3% and 10.2%, respectively, in 2017–18 compared with the controls (Table 4).

Fruit yield: The application of thinning chemicals decreased the total number of fruit with an increase in the concentration of chemicals. 3,5,6-TPA at 0.5 gL^{-1} reduced the number of fruits by 29.4% in 2017–18 and 2018–19 at 0.7 gL^{-1} by 31.2% compared with the control. Ethephon at 0.5 gL^{-1} reduced the number of fruits by 45.9–46.2% in 2017–19 compared with the controls. NAA at 0.5 gL^{-1} reduced the number of fruits by 46.8% and 42.9% during 2017–18 and 2018–19, respectively, compared with the controls (Table 5).

The application of thinning chemicals showed a negative relation with the yield per tree because increasing the chemical concentrations decreased the yield per tree. 3,5,6-TPA at 0.7 gL^{-1} reduced the yield per tree by 34.3% and 36% during 2017–18 and 2018–19, respectively, compared with the controls. Ethephon at 0.5 gL^{-1} reduced the yield per tree by 45.7% in 2017–18, during 2018–19 by 38.6% at 0.7 gL^{-1} compared with the controls. NAA at 0.5 gL^{-1} reduced the yield per tree by 50.5% and 46.3% in 2017–18 and 2018–19, respectively, compared with the controls (Table 5).

The reduction in fruit number and yield per tree resulted in a low yield per acre under chemical fruit thinning. 3,5,6-TPA at 0.7 gL^{-1} reduced the yield per acre by 34.3% and 50.3% during 2017–18 and 2018–19, respectively, compared with the controls. Ethephon at 0.4 gL^{-1} reduced the yield per acre by 45.6% during 2017–18 and 2018–19 by 8.5% at 0.6 gL^{-1} compared with the controls (Table 5).

Fruit grading: Fruit characterization based on the fruit size was also significantly affected by fruit thinning chemicals. 3,5,6-TPA at 0.2 and 0.5 gL^{-1} increased the fruit size by two times (2x) in 2017–18 compared with the controls. NAA at 0.3 gL^{-1} resulted in a 60.7% higher number of large fruit than the control. During the 2018-19 season, trees treated with 3,5,6-TPA at 0.2 gL^{-1} and ethephon at 0.4 gL^{-1} had 1.5 and 2x more fruit in the diameter of 60-70 mm fruit size than the controls. NAA at 0.2 and 0.3 gL^{-1} increased the number of fruit by 1.5x and 1.4x, respectively, in 2017–18, compared with the control. The number of fruit with 50–60 mm diameters was the lowest for all the chemical treatments than their respective controls (Table 6).

Number of fruit cartons/tree: Plants treated with chemicals were characterized based on the number of fruit (size-dependent) per carton, which indicated that trees under different chemical treatments produced a higher number of cartons with bigger fruit (>70 mm). 3,5,6-TPA at 0.5 gL^{-1} yielded three times more fruit per carton (>70 mm) during both seasons than the control. Ethephon at 0.5 gL^{-1} produced four times more cartons (>70 mm) in 2017–18 and three times more cartons (>70 mm) at 0.2 gL^{-1} in 2018–19. NAA at 0.3 gL^{-1} increased the number of cartons (>70 mm) by 75% in 2017–18 and by 109.3% at 0.2 gL^{-1} in 2018–19 compared with the controls (Table 7). The number of cartons/trees with fruit size 60–70 mm (65–72 fruit) was also high in the chemically thinned trees concerning the control. 3,5,6-TPA at 0.5 gL^{-1} increased the number of cartons by 49.5% and 34.2% during both growing seasons, respectively, compared with the controls. Ethephon at 0.4 gL^{-1} produced 30% more 60–70 mm fruit in 2017–18 and 48.5% more at 0.5 gL^{-1} in 2018–19 compared with the controls. NAA at 0.3 gL^{-1} produced 52.4% more 60–70 mm fruit per tree during 2018–19 compared with the control (Table 7). The number of cartons/trees with fruit size 50–60 mm (80–100 fruit) was high in the control and low in all the chemically treated trees (Table 7).

Fruit growth rate: Fruit size was recorded from June to January during both seasons, which indicated that irrespective of the chemical concentrations and season, all the fruit (control and chemically treated) showed a similar initial growth rate (Table 7). During July, 3,5,6-TPA at 0.7 gL^{-1} resulted in 8% higher fruit growth rate than the control for 2017–18. NAA at 0.5 gL^{-1} increased the fruit growth rate by 8.3% and 11.8% during 2017–18 and 2018–19, respectively, compared with the controls. Ethephon treatment had little effect on fruit size during 2017–18. However, in 2018–19 at concentrations of 0.5 gL^{-1}, ethephon increased the fruit size by 10.9% (Table 8). In August, the fruit size was larger in the groups treated with thinning chemicals during both growing seasons. All the NAA treatments increased the fruit size by 4–6% for both years compared with the controls. Ethephon at 0.5 gL^{-1} increased the fruit size by 9.8% in 2017–18 and 19.9% at 0.7 gL^{-1} in 2018–19 compared with the controls. 3,5,6-TPA at 0.5 and 0.7 gL^{-1} increased the fruit size by 4.7% and 5.6%, respectively, in 2017–18 compared with the control (Table 8). NAA increased fruit growth by 7–9%, ethephon by 10–12%, and 3,5,6-TPA by 6–8% in both growing seasons compared to the respective controls (Table 8). Compared to the controls, NAA at 0.5 gL^{-1} increased fruit growth by 7.5% and 13.7% during 2017–18 and 2018–19, respectively. Ethephon improved the fruit size by 14-16% and 3,5,6-TPA by 10-15% during both seasons, respectively, compared with the controls (Table 8). In November, for both seasons (2017-18 and 2018-19), NAA at 0.4 gL^{-1} increased fruit growth by 21% and 20%, respectively, compared with the controls. Ethephon at 0.5 gL^{-1} increased the fruit size by 25.3% in 2017–18 and by 17% at 0.2 gL^{-1} in 2018–19 compared with the controls. 3,5,6-TPA at 0.5 gL^{-1} increased fruit size by 18.6% and 14.4% in 2017–18 and 2018–19, respectively, compared with the controls (Table 8). Fruit size in December was significantly affected by chemical thinning treatments during both growing seasons. Compared with the controls, NAA at 0.4 gL^{-1} increased fruit size by 19.7% and 21% during 2017–18 and 2018–

19, respectively. Ethephon at 0.4 and 0.5 gL^{-1} increased fruit growth by 21.7% and 21.9%, respectively, in 2017–18, and by 20.2% and 18.9% in 2018–19 compared with the controls. 3,5,6-TPA at 0.5 gL^{-1} increased fruit growth by 17.5% and 15.6% in 2017–18 and 2018–19, respectively, compared with the controls (Table 8). The fruit size was also significantly affected by different chemicals and treatments in both growing seasons during January. Compared with the controls, NAA at 0.4 gL^{-1} increased fruit weight by 20.3% and 15.7% in 2017–18 and 2018–19, respectively. Ethephon at 0.5 gL^{-1} increased fruit growth by 21.3% and 17.9% during 2017–18 and 2018–19, respectively, compared with the controls. 3,5,6-TPA at 0.5 gL^{-1} increased fruit growth by 16.7% and 13.1% during 2017–18 and 2018–19, respectively, compared with the controls (Table 8).

Cost-benefit ratio: The BCR was also significantly different between chemicals and concentrations during both growing seasons. 3,5,6-TPA at 0.5 gL^{-1} increased the BCR by 54.3% in 2018–19 compared to the control. Ethephon at 0.5 gL^{-1} increased BCR by 54.7% and 54% during 2017–18 and 2018–19, respectively, compared with the controls. Compared with the controls, NAA at 0.3 gL^{-1} increased the BCR by 31% and 39.3% during 2017–18 and 2018–19, respectively (Fig. 3).

Table 6. Effect of independent chemical treatments on the fruit grading based on fruit diameter of 'Kinnow' mandarin (*Citrus reticulata* Blanco) in the 2017/18 and 2018/19 growing seasons. Data represent the mean ± standard deviation (*n* = 4).

Chemical	Treatment	Fruit grades (diameter)							
		>70 mm		60–70 mm		50–60 mm		<50 mm	
		2017	2018	2017	2018	2017	2018	2017	2018
3,5,6-Trichloro-2-pyridyloxy-acetic acid (3,5,6-TPA)	Control	50.3±10.2^{b}	66.0±9.4	62.0±13.0^{b}	62.5±1.5^{b}	217.8±12.8^{a}	217.3±12.7^{a}	6.3±2.5^{a}	8.5±1.7
	0.2 gL^{-1}	119.8±12.6^{a}	119.8±3.9	103.8±6.6^{a}	103.8±13.2^{a}	23.5±10.8^{c}	23.5±12.7^{c}	6.3±2.5^{a}	6.3±4.4
	0.5 gL^{-1}	112.8±12.4^{a}	119.8±12.6	76.3±7.8^{b}	83.8±6.6^{ab}	41.5±13.5^{bc}	47.0±10.8^{bc}	0.0±0.0	5.0±2.5
	0.7 gL^{-1}	95.5±9.5^{a}	95.8±12.4	81.5±4.6^{ab}	76.5±4.0^{b}	76.5±14.9^{b}	69.5±11.4^{b}	0.3±0.3^{b}	2.7±0.5
	p-value	0.008*	0.296	0.039**	0.017**	0.0001*	0.0001*	0.018**	0.7093
Ethephon	Control	91.8± 4.8	90.0±6.5	82.8±16.2^{b}	82.8±16.2^{b}	247.0±21.0^{a}	239.8±16.3^{a}	17.8±3.2^{a}	18.3±3.1^{a}
	0.4 gL^{-1}	116.8±12.6	112.8±12.6	165.3±15.2^{a}	154.4±16.1^{a}	29.8±10.6^{c}	48.3±15.5^{c}	4.8±2.9^{b}	4.8±2.9^{b}
	0.5 gL^{-1}	114.8±12.4	109.8±12.4	76.3±7.8^{b}	76.4±7.8^{b}	41.5±13.4^{bc}	41.5±13.5^{c}	0.0±0.0^{c}	0.0±0.0^{c}
	0.6 gL^{-1}	88.8±4.5	85.0±6.0	72.5±9.2^{b}	74.0±14.2^{b}	77.0±7.3^{b}	138.0±21.9^{b}	17.8±3.2^{a}	17.8±3.2^{a}
	p-value	0.077	0.0605	0.011**	0.003*	0.000*	0.001*	0.000*	0.000*
Naphthalene acetic acid (NAA)	Control	64.5±13.8	74.5±7.6^{c}	108.8±8.0^{a}	91.5±7.3^{b}	243.8±17.6^{a}	253.8±24.2^{a}	12.0±1.7^{a}	20.5±12.2
	0.2 gL^{-1}	117.3±13.5	111.3±4.4^{ab}	87.8±5.0^{bc}	127.0±2.6^{a}	41.8±13.3^{b}	86.0±2.7^{b}	7.5±2.9^{ab}	11.0±1.7
	0.3 gL^{-1}	119.8±12.4	119.8±12.4^{a}	76.3±7.8^{c}	120.2±13.2^{a}	41.5±13.5^{b}	71.3±16.8^{b}	0.0±0.0^{c}	4.0±2.4
	0.4 gL^{-1}	104.5±10.2	94.8±4.6^{bc}	97.5±1.7^{ab}	99.5±8.7^{b}	23.5±10.8^{b}	78.8±13.0^{b}	5.0±1.7^{bc}	0.3±0.3
	0.5 gL^{-1}	119.8±12.4	82.8±2.5^{c}	76.3±7.8^{c}	89.8±4.3^{b}	41.5±13.5^{b}	74.3±9.1^{b}	0.0±0.0^{c}	4.5±2.7
	p-value	0.0519	0.007*	0.011**	0.003*	0.001*	0.0001*	0.001*	0.1629

The values are the number of fruit per the fruit grade/diameter. Means followed by the same lowercase letter in the column from the same chemical do not differ statistically with the Tukey multiple comparison test ($p<0.05$)

Table 7. Effect of independent chemical treatments on the cartons per tree of 'Kinnow' mandarin (*Citrus reticulata* Blanco) in the 2017/18 and 2018/19 growing seasons. Data represent the mean ± standard deviation (*n* = 4).

Chemical	Treatment	Fruit cartons per tree					
		>70 mm (48–52 fruit)		60–70 mm (65–72 fruit)		50–60 mm (80–100 fruit)	
		2017	2018	2017	2018	2017	2018
3,5,6-Trichloro-2-pyridyloxy-acetic acid (3,5,6-TPA)	Control	0.93 ± 0.02^{c}	0.97 ± 0.01^{c}	1.01 ± 0.01^{b}	1.14 ± 0.06^{c}	3.31 ± 0.08^{a}	3.25 ± 0.09^{a}
	0.2 gL^{-1}	1.78 ± 0.19^{b}	2.13 ± 0.07^{b}	1.49 ± 0.14^{a}	1.36 ± 0.01^{b}	0.85 ± 0.07^{c}	0.75 ± 0.09^{c}
	0.5 gL^{-1}	2.42 ± 0.24^{a}	2.46 ± 0.19^{a}	1.51 ± 0.17^{a}	1.53 ± 0.01^{a}	0.90 ± 0.03^{c}	0.86 ± 0.03^{c}
	0.7 gL^{-1}	1.82 ± 0.09^{b}	1.93 ± 0.04^{b}	1.08 ± 0.01^{b}	1.11 ± 0.03^{c}	1.88 ± 0.06^{b}	1.86 ± 0.03^{b}
	p-value	0.0007*	0.0001*	0.0238**	0.000*	0.0001*	0.0001*
Ethephon	Control	0.80 ± 0.07^{c}	0.91 ± 0.05^{c}	1.16 ± 0.03^{b}	1.03 ± 0.03^{c}	3.47 ± 0.11^{a}	3.31 ± 0.02^{a}
	0.4 gL^{-1}	1.96 ± 0.02^{b}	2.28 ± 0.06^{a}	1.51 ± 0.16^{a}	1.36 ± 0.01^{b}	0.80 ± 0.03^{c}	0.55 ± 0.01^{d}
	0.5 gL^{-1}	2.40 ± 0.21^{a}	2.14 ± 0.05^{a}	1.49 ± 0.01^{a}	1.53 ± 0.01^{a}	0.39 ± 0.03^{d}	0.82 ± 0.02^{c}
	0.6 gL^{-1}	1.94 ± 0.03^{b}	1.91 ± 0.03^{b}	1.08 ± 0.01^{b}	1.11 ± 0.03^{c}	1.69 ± 0.02^{b}	1.75 ± 0.04^{b}
	p-value	0.0001*	0.0001*	0.011**	0.0001*	0.0001*	0.0001*
Naphthalene acetic acid (NAA)	Control	1.22 ± 0.11^{c}	1.07 ± 0.02^{b}	0.98 ± 0.01	1.01 ± 0.01^{e}	3.27 ± 0.01^{a}	3.33 ± 0.08^{a}
	0.2 gL^{-1}	1.60 ± 0.18^{b}	2.24 ± 0.05^{a}	1.29 ± 0.01	1.35 ± 0.01^{b}	0.79 ± 0.00^{e}	0.53 ± 0.03^{d}
	0.3 gL^{-1}	2.14 ± 0.01^{a}	2.09 ± 0.02^{a}	1.49 ± 0.01	1.54 ± 0.01^{a}	0.85 ± 0.00^{d}	0.82 ± 0.02^{d}
	0.4 gL^{-1}	1.69 ± 0.03^{b}	1.94 ± 0.05^{a}	1.08 ± 0.01	1.12 ± 0.02^{d}	1.02 ± 0.00^{b}	1.75 ± 0.04^{c}
	0.5 gL^{-1}	1.08 ± 0.09^{c}	1.19 ± 0.23^{b}	1.54 ± 0.30	1.24 ± 0.05^{c}	0.98 ± 0.01^{c}	2.39 ± 0.21^{b}
	p-value	0.0002*	0.0001*	0.0585	0.0001*	0.0001*	0.0001*

Means followed by the same lowercase letter in the column within the same chemical do not differ statistically by Tukey multiple comparison test ($p<0.05$)

Table 8. Effect of independent chemical treatments on the Fruit growth rate of 'Kinnow' mandarin (*Citrus reticulata* Blanco) by month in the 2017/18 and 2018/19 growing seasons. Data represent the mean ± standard deviation (n = 4)

Treatment		2017-18							
		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
3, 5, 6-Trichloro-2-pyridyloxy-acetic acid (3, 5, 6-TPA)	Control	23.6±0.6	38.7±0.3^{c}	47.7±0.3^{b}	54.5±0.5^{d}	60.6±0.3^{c}	62.2±0.4^{c}	66.3±0.3^{c}	68.3±0.4^{c}
	0.4 gL^{-1}	23.6±0.3	38.4±0.6^{c}	48.2±0.8^{b}	55.9±0.5^{c}	67.3±0.9^{b}	72.2±0.4^{b}	75.5±0.3^{b}	78.3±0.8^{ab}
	0.5 gL^{-1}	24.0±0.7	40.0±0.1^{b}	49.9±0.3^{a}	59.3±0.4^{b}	70.0±0.1^{a}	73.8±0.3^{a}	77.9±0.1^{a}	79.7±0.3^{a}
	0.6 gL^{-1}	24.4±0.3	41.8±0.5^{a}	50.4±0.4^{a}	61.5±0.3^{a}	70.6±0.3^{a}	74.8±0.5^{a}	75.6±0.4^{b}	76.8±0.6^{b}
	p-value	0.5673	0.7213	0.001*	0.003*	0.001*	0.001*	0.001*	0.001*
Ethephon	Control	23.9±0.7	37.9±0.2^{b}	46.4±0.4^{c}	55.6±0.3^{c}	61.4±0.3^{b}	61.1±0.6^{d}	66.2±0.3^{c}	82.6±0.2^{a}
	0.4 gL^{-1}	24.7±0.3	39.8±0.2^{a}	49.3±0.3^{ab}	57.1±0.2^{b}	65.0±0.3^{a}	75.0±0.2^{b}	80.5±0.3^{a}	81.0±0.3^{b}
	0.5 gL^{-1}	25.5±0.5	39.4±0.4^{a}	51.0±0.6^{a}	57.8±0.4^{ab}	66.1±0.3^{a}	76.6±0.7^{a}	80.7±0.6^{a}	74.6±0.5^{c}
	0.6 gL^{-1}	25.4±0.5	39.3±0.2^{a}	48.1±0.7^{bc}	58.7±0.3^{a}	65.6±0.4^{a}	72.1±0.1^{c}	73.8±0.3^{b}	68.1±0.3^{d}
	p-value	0.1094	0.001*	0.003*	0.002*	0.001*	0.001*	0.001*	0.001*
Naphthalene acetic acid (NAA)	Control	23.2±0.3^{bc}	38.2±0.2^{c}	47.1±0.2^{b}	55.6±0.1^{d}	61.0±0.1^{d}	61.7±0.3^{d}	66.9±0.2^{d}	68.1±0.5^{d}
	0.2 gL^{-1}	25.1±0.2^{a}	39.3±0.3^{bc}	49.3±0.3^{a}	57.1±0.3^{c}	62.1±0.3^{c}	72.1±0.5^{b}	73.0±0.2^{c}	74.0±0.2^{c}
	0.3 gL^{-1}	23.6±0.5^{bc}	39.5±0.3^{b}	50.0±0.4^{a}	58.1±0.2^{b}	64.2±0.2^{b}	72.0±0.3^{b}	74.8±0.1^{b}	77.1±0.2^{b}
	0.4 gL^{-1}	23.9±0.3^{b}	39.7±0.5^{b}	47.7±0.4^{b}	58.3±0.3^{b}	65.6±0.4^{a}	74.1±0.6^{a}	80.1±0.5^{a}	81.9±0.2^{a}
	0.5 gL^{-1}	22.9±0.3^{c}	41.4±0.4^{a}	49.3±0.3^{a}	59.3±0.3^{a}	65.6±0.4^{a}	70.0±0.1^{c}	73.1±0.3^{c}	73.9±0.2^{c}
	p-value	0.001*	0.1281	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*
Treatment		**2018-19**							
		Jun	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**
3, 5, 6-Trichloro-2-pyridyloxy-acetic acid (3, 5, 6-TPA)	Control	22.6±0.5	38.9±0.4^{a}	48.7±0.3^{b}	56.6±0.3^{b}	63.0±0.3^{c}	63.9±0.3^{c}	67.3±0.6^{d}	70.0±0.2^{d}
	0.4 gL^{-1}	23.4±0.3	35.0±0.3^{b}	50.8±0.4^{a}	54.7±0.4^{c}	62.0±0.4^{d}	69.0±0.6^{b}	76.2±0.4^{b}	78.1±0.4^{b}
	0.5 gL^{-1}	23.7±0.8	39.9±0.4^{a}	51.4±0.4^{a}	59.7±0.2^{a}	66.0±0.3^{b}	73.1±0.7^{a}	77.8±0.3^{a}	79.2±0.4^{a}
	0.6 gL^{-1}	23.0±0.7	34.5±0.4^{b}	50.4±0.4^{a}	60.0±0.4^{a}	67.1±0.4^{a}	72.8±0.3^{a}	74.8±0.2^{c}	76.7±0.4^{c}
	p-value	0.001*	0.7213	0.001*	0.004*	0.001*	0.001*	0.001*	0.001*
Ethephon	Control	22.2±0.4^{c}	39.0±0.2^{b}	49.1±0.3^{c}	56.0±0.4^{c}	62.5±0.3^{c}	63.5±0.3^{c}	67.3±0.4^{c}	70.9±0.5^{d}
	0.4 gL^{-1}	25.4±0.3^{b}	39.2±0.6^{b}	50.7±0.3^{b}	57.7±0.4^{b}	64.8±0.4^{b}	74.6±0.4^{a}	80.9±0.5^{a}	81.6±0.6^{b}
	0.5 gL^{-1}	26.1±0.3^{ab}	40.3±0.4^{b}	50.4±0.5^{b}	58.6±0.3^{b}	65.6±0.3^{ab}	75.0±1.0^{a}	80.0±0.2^{a}	83.6±0.3^{a}
	0.6 gL^{-1}	27.2±0.8^{a}	43.3±0.4^{a}	58.8±0.3^{a}	62.1±0.4^{a}	66.1±0.2^{a}	70.5±0.2^{b}	73.9±0.2^{b}	75.9±0.3^{c}
	p-value	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*
Naphthalene acetic acid (NAA)	Control	22.7±0.6	39.3±0.2^{d}	48.9±0.5^{c}	56.4±0.3^{d}	61.9±0.2^{e}	63.4±0.4^{d}	67.1±0.2^{d}	70.5±0.3^{c}
	0.2 gL^{-1}	23.9±0.5	39.9±0.2^{d}	49.2±0.3^{c}	58.3±0.7^{c}	62.9±0.3^{d}	73.9±0.7^{bc}	78.0±0.6^{b}	76.8±0.5^{b}
	0.3 gL^{-1}	24.7±0.5	41.2±0.4^{c}	49.7±0.2^{c}	58.6±0.5^{c}	66.4±0.5^{c}	74.5±0.4^{b}	80.4±0.3^{a}	80.7±0.3^{a}
	0.4 gL^{-1}	24.8±0.5	42.6±0.8^{b}	50.9±0.5^{b}	60.5±0.4^{b}	68.5±0.7^{b}	76.1±0.3^{a}	81.2±0.1^{a}	81.6±0.3^{a}
	0.5 gL^{-1}	24.9±0.9	44.0±0.3^{a}	52.5±0.4^{a}	61.6±0.3^{a}	70.4±0.3^{a}	73.1±0.3^{c}	75.2±0.2^{c}	76.6±0.5^{b}
	p-value	0.001*	0.1281	0.001*	0.001*	0.001*	0.001*	0.001*	0.001*

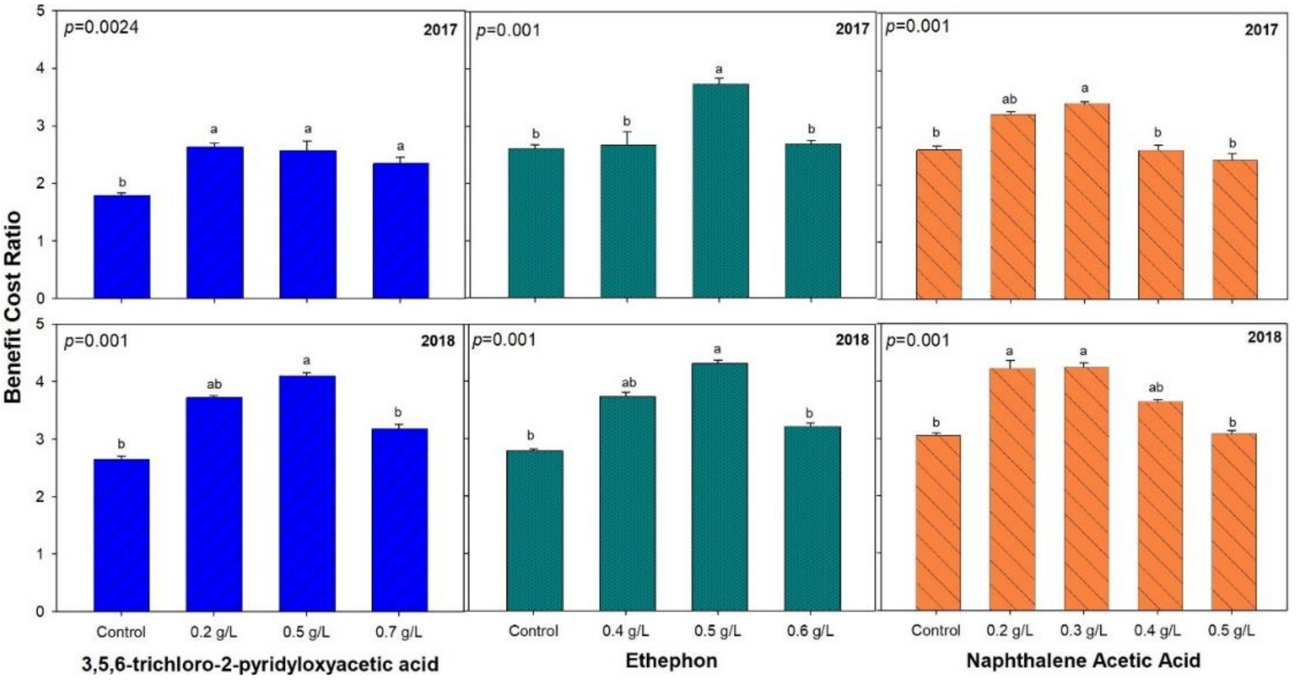

Fig. 3. Fruit cost-benefit ratio of 'Kinnow' mandarin (*Citrus reticulata* Blanco) exposed to different chemical treatments in the 2017/18 and 2018/19 growing seasons. Different lowercase letters indicate significant differences at 5% probability.

Discussion

Fruit thinning is a commercial practice in citrus and other fruit orchards to reduce crop load, optimize fruit size, improve color, shape, and quality, maintain tree growth, structure, and maximize crop value, as well as promote blooming to keep the alternate bearing cycle (Cong *et al*., 2022). Treatment with fruit thinning chemicals has been a viable method used for over 50 years and has given promising results for regulating crop load, promoting the return of flowering, and reducing the cost of hand-thinning in some fruit species (Williams, 1994; Dennis, 2000). Thinning chemicals indirectly affect the growth rate, reduce the number of fruits/tree, and promote abscission, reducing the competition for carbohydrates, leading to large fruit (Agustí *et al*., 1996; Yasmeen *et al*., 2021; Adhikary *et al*., 2022).

Fruit size is an essential parameter of quality in citrus fruit because consumers prefer large fruit, resulting in a clear distinction in the market price between small and large fruit. The profitability of citrus fruit also depends on the fruit size and yield. Chemical fruit thinning helps in abscission layer development and improves the nutrient availability of the remaining fruit, increasing the final size (Struckmeyer & Roberts, 1950). This was evident in this study, with the application of 3,5,6-TPA (0.5 gL^{-1}), ethephon (0.4 gL^{-1}), and NAA (0.2 gL^{-1}) yielding larger fruit than control. Previous studies corroborated our results, such as Muller (1995), which indicated that 3, 5, 6-TPA applications significantly enhanced ‘Navelate’ orange fruit standard size. Hilgeman & Dunlap, (1964) found that fruit thinning by NAA improved the ‘Kinnow’ mandarin fruit size in an Arizonan study. Furthermore, Hutton (1992) improved the fruit size of Late Valencia oranges with ethephon fruit-thinning sprays.

So, the more thinning chemicals applied, the larger the fruit, and the more fruitlets are thinned. However, a negative relationship exists with the yield as this study indicates that increasing the level of different chemical thinning agents increases the fruit thinning percentage but has reduced the final yield. In our study, application of 3, 5, 6-TPA (0.5 gL^{-1}), ethephon (0.5 gL^{-1}), and NAA (0.5 gL^{-1}) resulted in high percentages of fruit thinning. Agustí *et al*., (1996) reported that the number of fruits that reached maturity was decreased by 62.5%. Similarly, Iwahori & Oohata (1976) reported a 30% increase in fruit drop by applying NAA (300 ppm). It was demonstrated by Serciloto *et al*., (2008) and Rivas *et al*., (2011) that mandarin trees’ ideal fruit thinning percentage was 50–60%. NAA decreased the yield by 20–22% in an experiment conducted by Stover *et al*., (2006). Agusti *et al*., (1995) indicated that Maxim (3,5,6-TPA) also decreased the fruit yield when trees were sprayed 12 weeks after flower opening. In the present study, ethephon reduced the yield by 25–40%, similar to Gallasch (1988) findings, which reported that NAA and ethephon treatment on Imperial mandarin trees effectively thinned and reduced the yield by up to 24%.

Fruit size was divided into different classes based on the fruit diameter. The fruit size and the quality increase were directly proportional to the moderate to severe fruit thinning percentages from applying thinning chemicals. Our results were similar to previous findings of Stover *et al*., (2006) and Summers *et al*., (2008) that using thinning chemicals improved the fruit size and quality. The juice weight was also higher for all the treated citrus trees, but the best treatments enhanced the juice weight percentage by 65–70%. Previous studies also recorded a 55–65% increase in fruit juice weight in trees sprayed with fruit thinning chemicals (Josan & Sharma, 1987; Sawale *et al*., 2001; Sajjad *et al*., 2021). Fruit weight was significantly increased by applying fruit thinning chemicals, increasing 130–210 g. This is in accordance with Ortolá *et al*., (1991), who observed a high fruit weight in treated Satsuma mandarin trees.

The total soluble solids ranged between 8 and 12% with different thinning chemicals. Safaei-Nejad *et al*., (2015) reported that 7 treatments increased juice total soluble solids and enhanced fruit growth indices, including fruit weight, volume, diameter, and length, compared with the controls. Yildirim *et al*., (2011) also found high total soluble solids content in the treated plants compared with the control. The titratable acidity was decreased with the fruit thinning percentage increase and ranged from 0.85-2.0%. The TSS: TA ratio is used as the maturity index of the fruit and is associated with ensuring a proper supply of metabolites to the fruit. The TSS: TA ratio is used to check the maturity level of the fruit and ranges from 6 to 12. Galliani *et al*., (1975) evaluated the efficacy of chemical thinning and reported that the fruit acidity had a more positive effect on fruit size, and lower acidity was found in the small fruit. Saleem *et al*., (2008) found that juice acidity was increased with 2,4-D concentration in bloodred oranges. The antioxidant activity of the fruit is affected by flavonoids an essential part of citrus fruit juice (Bocco *et al*., 1998). Polyphenols, including flavonoids, directly influence antioxidant activity. Therefore, a decrease in the phenolic content of juice may also reduce the antioxidant in the fruit (Alothman *et al*., 2009). Ascorbic acid ranged from 40–65 mg 100 g^{-1} fresh weight. Ascorbic acid is an important antioxidant soluble in water and oxidizes rapidly in response to temperature and light (Rapisarda *et al*., 2008; Yang *et al*., 2013). Ascorbic acid is also considered a good indicator of quality parameters (Lee & Coates, 1999).

This study included three fruit thinning chemicals with variable yield per acre for each chemical. The treatments with lower yields resulted in good quality fruit and more income based on the fruit grades. Yildirim *et al*., (2011) reported that the fruit diameter was significantly affected by the application of 3,5,6-TPA, which increased the number of large fruits. A reduction in yield favors a greater fruit size. Fruit thinning with 3,5,6-TPA, ethephon, and NAA increased the income per acre based on the number of Grade A fruit per tree. Our results are in line with those of Gallasch, (1988), who reported results from two thinning experiments with ethephon on mature Imperial mandarin trees in Australia, where small fruit had a meager value of \$5 per package. Duarte *et al*., (1996) undertook research into 2,4-D as a chemical thinner for the ‘Esbel’ clementine and found an increase in yield ranging from 25–38%. Agusti *et al*., (1995) tested several thinning procedures and indicated that chemical fruit thinning increased income by about 30% compared with hand thinning or the control.

Conclusion

The fruit size, quality, and economic return are important parameters for commercial value and consumer satisfaction. Fruit thinning improved the fruit quality, fruit size, and income of citrus growers. This study reported that chemical thinning applications during the early fruit developmental stage (after June drop) induced fruit drop and caused fruit thinning. It is well-known that in the case of fruit drop, the development of subsequent fruit becomes healthier, leading to enhanced sizing potential and quality of fruit. The ‘Kinnow’ trees with no fruit thinning (control) yielded poor-quality grade C fruit than trees that had been thinned with different chemicals. However, among the different fruit thinning chemicals, 0.5 gL^{-1} ethephon or 0.6 gL^{-1} 3,5,6-TPA gave the best results with double income per acre. NAA (0.2 or 0.3 gL^{-1}) also improved the cost-benefit ratio. Moreover, fruit thinning by applying different chemicals regulates alternate bearing in ‘Kinnow’ trees, maintains the balanced distribution of carbohydrates supply to fruit, and enhances the growers' profitability.

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