

Effects of 2,4-DP (2,4-dichlorophenoxypropionic acid) plant growth regulator on fruit size and yield of Valencia oranges (*Citrus sinensis* Osb.)

B Yıldırım^{a*}, T Yeşiloğlu^a, M İncesu^a, MU Kamiloğlu^b, B Çimen^a and Ş Tamer^c

^aCukurova University, Agriculture Faculty, Department of Horticulture, Adana, Turkey; ^bMustafa Kemal University, Agriculture Faculty, Department of Horticulture, Antakya, Turkey; ^cSumitomo Corporation Foreign Trade Corporation, Istanbul, Turkey

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The Valencia orange is a high-quality fruit grown in Turkey; however, small fruit sizes and high fruit discard percentages are common in Valencia oranges. Small fruit size is the main factor limiting the marketing of Valencia oranges; thus, synthetic auxins are commonly used to enhance the size of citrus fruit. The objective of the present study was to observe the effects of 2,4-dichlorophenoxypropionic acid (2,4-DP) on the fruit size, yield and quality of Valencia oranges from 29-year-old trees budded on sour orange rootstock in Adana, Turkey during 2005–06. Three concentrations (50, 100 and 150 ppm) of 2,4-DP were applied during the June drop, when the mean fruit diameter was 13–15 mm. The results indicated that the application of 2,4-DP increased the fruit size of Valencia oranges without reducing yield. The application had a significant effect on fruit yield. Compared with the control trees, applications of 2,4-DP increased the number of large, commercially valuable Valencia oranges (75–80 mm). Moreover, an increase in the concentration of 2,4-DP increased the yield and weight of the fruits. As a result, fruit retention was highest in trees sprayed with 150 ppm 2,4-DP. Except for the titratable acid content (TA), which increased with an increase in the 2,4-DP concentration, the internal characteristics of the fruit were not affected by treatment with 2,4-DP. Thus, the results of the present study revealed that 2,4-DP can be used to improve the fruit size of Valencia fruitlets during the June drop.

Keywords: auxin; fruit quality; Valencia orange; yield; plant growth regulators

Introduction

Due to the steady increase in citrus production in Turkey, 3,220,450 million tons of citrus fruits were produced in 2008. Of the citrus produced in Turkey, 1,535,800 tons were oranges (FAO 2009). The main varieties of oranges (*Citrus sinensis*) grown in Turkey are the common oranges, ‘Valencia’ (about 20% of area of plantings) and ‘Shamouti’ and the navel oranges including ‘Washington’, ‘Navelina’, Navelate and Lanelate (greater than 50%) (Tuzcu et al. 2001). Valencia is a late-ripening sweet orange cultivar with high fruit quality; however, small

fruit size is a common problem in Valencia oranges. Moreover, small fruit size and creasing are the main factors limiting the sales of Valencia oranges; thus, large Valencia fruit brings higher prices in the export market (Greenberg et al. 1996). Consumers prefer large fruits; thus, there is a significant price difference between large and small fruits (Agustí et al. 1994; Guardiola & García Luis 2000; Erner et al. 2004).

In terms of determining profitability, fruit size in citrus fruit has become as important as the yield. This phenomenon is readily apparent

*Corresponding author. Email: bilgeyil@cu.edu.tr

for small mandarin fruits, as well as lemons, sweet oranges and large grapefruit species (Guardiola & García Luis 2000).

Fruit size is affected by many factors including irrigation management, soil type, rootstock and ecological variables, which cannot be controlled by the producer. Moreover, fruit size is inversely proportional to yield and fruit number (Guardiola 1997). Bevington (2003) demonstrated that region, cultivar, rootstock, soil type, microecology and plant age affect fruit size. The availability of carbohydrates (increases fruit size), flower intensity (decreases fruit size), competition between flowers/fruitlets (decreases fruit size) and abiotic stresses (decrease fruit size) are the most important factors affecting the final fruit size of citrus fruits (Guardiola et al. 1982; Patrick 1993; Agustí et al. 1995; Goldschmidt & Koch et al. 1996; El-Otmani et al. 2000).

Cultural treatments such as pruning, irrigation and fertilization can be optimized to increase fruit size. For instance, techniques such as girdling (Cohen 1984) and thinning (Hirose 1981; Wheaton 1981; Zaragoza et al. 1992; Guardiola & García Luis 2000) are used in citrus production to increase fruit size.

Alternatively, synthetic auxins can be applied to increase fruit size (Wheaton 1981; Gallasch 1988; Guardiola et al. 1988). Applying synthetic auxins during the cell division stage of fruit development significantly reduces the number of fruits and increases the final fruit size by reducing the competition for carbohydrates between fruitlets (Agustí et al. 1995). Synthetic auxins such as 2,4-dichlorophenoxy acetic acid (2,4-D), 2,4,5-trichlorophenoxy acetic acid (2,4,5-T), naphthalene acetic acid (NAA) and 2,4-dichlorophenoxypropionic acid (2,4-DP) have been shown to increase fruit size (Stewart et al. 1952; El-Zeftawi 1976; Guardiola et al. 1988; El-Otmani et al. 1993; Agustí et al. 1994).

In this study, the effects of 2,4-DP on fruit size and yield of Valencia oranges was investigated.

Materials and methods

The experiments were conducted on 29-year-old Valencia orange trees planted on sour orange rootstock at 7×7 m intervals at the Research Station of Çukurova University, Agricultural Faculty Citrus Experiment Station, Adana (latitude $35^{\circ} 23' N$; longitude $36^{\circ} 50' E$; altitude 27 m) during 2005 and 2006. The trees were managed and selected for uniformity and crop load. In the experimental area, the soil was a clay loam (55% clay, 22% silt and 23% sand containing 11% CaCO_3), and the soil pH was between 7.20 and 7.29 at a depth of 0–90 cm. The trial was organized in a randomized complete block design with nine replicates for each treatment. The trees were pruned annually after harvest and irrigated weekly from May to October. Pest populations were controlled with a recommended pest management programme.

2,4-DP (Citrimax, 50 g of dichlorophenoxypropionic acid per L) was applied to the entire tree at concentrations of 50, 100 and 150 ppm. At the time of application, the diameters of 70 randomly selected fruitlets were measured. Treatments were performed 8 weeks after anthesis during physiological fruit drop, when the mean fruit diameter was 13–15 mm. Treatments were applied with a high-pressure handgun sprayer to the entire tree, and each tree received 10 L of the 2,4-DP solution, depending on the size of the tree.

The fruit was harvested from 2005 to 2006 at the optimal harvest time (in March). The yield per tree (kg/tree) was obtained by weighing the harvested fruit. A random sample of 25 fruits from each tree was collected to analyse the quality of the fruit. In addition, fruits from each of the plots were weighed to determine the average fruit size. The fruit was sized at the equatorial diameter and graded according to the following commercial size classes: > 79 mm (class 1), 75–79 mm (class 2), 70–74 mm (class 3), 65–69 mm (class 4) and < 65 mm (class 5) (Anonymous 2009).

To determine the fruit retention rate, the number of flowers, fruitlets and fruits were

recorded during full blossom, fruitlet abscission (a couple of weeks after bloom), the June drop and pre-harvest drop. The observations were made on four randomly selected branches from the four quadrants (north, south, east and west) of every tree.

The fruit rind thickness was measured with a digital caliper (Mitutoyo CD-15CPX, Mitutoyo America Corporation, USA). Using a standard juicer, 25 fruits were weighed and juiced. The juice was weighed and expressed as a percentage of the total fruit weight. The total soluble solids (TSS) content was determined with a portable refractometer (FG-103/113, Soif Ltd., China) using a few drops of juice. The total acidity (TA) of the juice was determined by titration with 0.1 N sodium hydroxide (NaOH) using phenolphthalein as the indicator. The concentration of ascorbic acid was obtained according to the method of Pearson (1970) using a Shimadzu UV-1208 (Shimadzu Scientific Instruments, Japan) spectrophotometer. The method was based on the oxidation of ascorbic acid with 2,6 dichlorophenol indophenol. The reading on the standard curve indicated the ascorbic acid content, and the concentration of ascorbic acid was read at 520 nm.

Data were subjected to ANOVA and were analysed using SAS statistical software (SAS 9). To compare the means, a Tukey's HSD test was performed to determine if the differences between treatments were significant at a confidence level of $P < 0.05$.

Results

Effect on yield and fruit retention rate (%)

A foliar application of 2,4-DP had a significant effect on the yield of Valencia oranges (Fig. 1) in both seasons. Treatment with 2,4-DP led to an increase in the yield of fruit; however, the yield obtained in the second season was lower than that of the first season. As shown in Fig. 1, in both seasons and years, the highest fruit yield per tree was obtained from trees treated with 150 ppm 2,4-DP, followed by 100 ppm 2,4-DP.

In the first season, the lowest fruit yield was obtained from untreated trees and trees treated with 50 ppm 2,4-DP. Moreover, in the second season and mean of the years, the lowest yield was obtained from untreated trees.

The effects of 2,4-DP on the fruit retention rate (%) were statistically significant in 2006; however, in 2005, significant differences in the fruit retention rate were not observed (Fig. 2). As shown in Fig. 2, the application of 2,4-DP led to an increase in the fruit retention rate. Specifically, the application of 150 ppm 2,4-DP resulted in high fruit retention rates in both seasons. Thus, 2,4-DP did not have a thinning effect on the trees, and an increase in the fruit retention rate was observed.

Effect on fruit weight and fruit diameter distribution at maturity

The statistical analysis revealed that the average fruit weight was significantly different among treatments in both years (Table 1). In 2005 and 2006, the highest fruit weight was obtained from trees treated with 150 ppm 2,4-DP, followed by 100 ppm and 50 ppm 2,4-DP. The lowest fruit weight was observed in the untreated trees. The results indicated that an increase in the concentration of 2,4-DP increased the weight of retained fruits in both years. In 2005, trees treated with 150 ppm displayed the highest fruit weight, followed by 100 ppm and 50 ppm of 2,4-DP. In 2006, the highest fruit weight was observed from 150 ppm and 100 ppm treatments. The lowest fruit weight was obtained from the control trees.

Except during the second season, the application of 2,4-DP to the entire tree significantly increased the diameter of Valencia oranges (Table 1). In 2005, the maximum increase in the diameter of the fruits was obtained from trees treated with 150 ppm 2,4-DP during physiological drop, followed by 50 ppm and 100 ppm 2,4-DP. According to results obtained in this study, the largest fruit diameters were obtained from trees treated with 150 ppm 2,4-DP, followed 100 ppm and 50 ppm 2,4-DP.

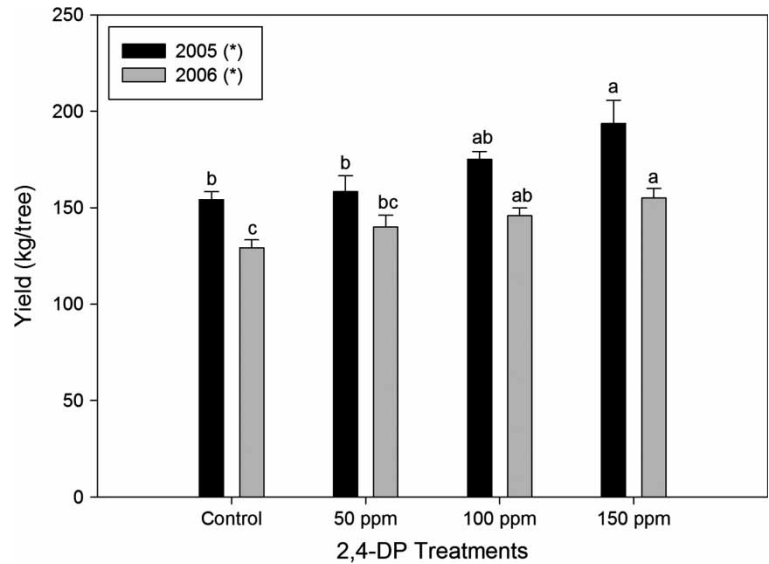


Figure 1 The effect of the 2,4-DP concentration on the yield of Valencia oranges. Columns of each series (2005, 2006) with different letters are significant at a confidence level of 0.05 regarding Tukey’s HSD test and bars indicate the standart errors of means. 156 × 124 mm (300 × 300 DPI).

Specifically, an increase of 1.79–3.71 mm was obtained when trees were treated with 2,4-DP.

Fig. 3 shows the effects of 2,4-DP treatments on the distribution of the crop within commercial fruit size classes. The results indicated that the frequency distribution of the fruit shifted toward larger sizes when the trees were treated with 2,4-DP. In 2005, the highest

percentage of large, commercially valuable Valencia fruits (>80 mm and 75.00–79.99 mm, class 1 and 2, respectively) was obtained from trees with treated 150 ppm 2,4-DP, followed by 50 ppm and 100 ppm 2,4-DP. In 2006, the percentage of large fruits (fruit sizes >80 mm) increased substantially on trees treated with 100 ppm 2,4-DP. Moreover,

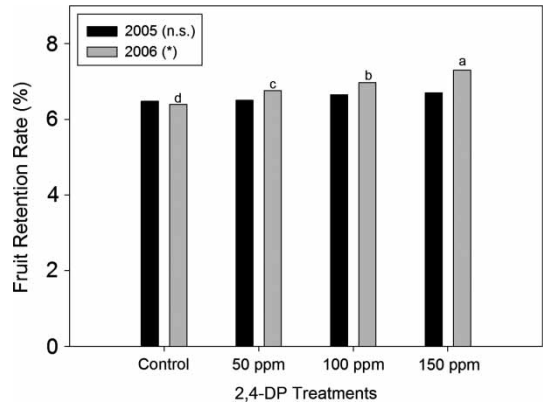


Figure 2 The effects of 2,4-DP on the fruit retention rate of Valencia oranges. Differences between the means were analyzed by conducting a Tukey’s HSD test. The percentages were analyzed after arc-sin transformation. n.s.: not significant; *: significant at a confidence level of 0.05. 147 × 114 mm (300 × 300 DPI).

Table 1 Effects of 2,4-DP on the fruit characteristics of Valencia oranges.

Treatment	Fruit weight (g)	Fruit diameter (mm)	Rind thickness (mm)	Juice content (%)	TSS (%)	TA (%)	TSS/TA	Ascorbic acid (mg/100 g)
2005								
50 ppm	197.22 b ¹	74.26 b	5.41 a	45.40	10.40	1.61 c	6.47 a	55.79 b
100 ppm	198.66 b	73.01 bc	5.56 a	45.29	10.20	1.77 b	5.77 b	63.15 ab
150 ppm	211.00 a	76.60 a	5.71 a	46.65	10.04	1.87 a	5.38 b	55.47 b
Control	184.27 c	71.19 c	4.61 b	46.35	10.75	1.55 c	6.97 a	64.96 a
Prob > F	0.0014** ²	0.0026*	0.0024**	0.8150	0.1374	<.0001**	<.0001**	0.0471*
2006								
50 ppm	151.58 b	68.10	5.32	43.80	10.52 a	1.30	8.17	41.11
100 ppm	171.49 a	68.74	5.51	44.30	10.00 ab	1.25	8.04	43.92
150 ppm	172.83 a	70.02	5.71	46.50	10.40 a	1.31	8.03	44.00
Control	151.14 b	67.78	5.51	44.82	9.68 b	1.21	8.02	41.50
Prob > F	0.0043**	0.0799	0.6664	0.2858	0.0489*	0.5182	0.9903	0.1246

¹Mean separation within columns by Tukey's HSD tests at 0.05.

²**, * Results are statistically significant regarding ANOVA at a confidence level of 0.01 and 0.05, respectively.

compared with the control trees, trees treated with 150 ppm and 100 ppm 2,4-DP produced a higher percentage of class 2 (75.00–79.99 mm) and class 3 fruits (70.00–74.99 mm). Alternatively, the highest percentage of commercially unacceptable fruits (diameter <65 mm) was obtained from the control trees.

Effects on the internal characteristics of fruit

Except for juice content, the application of 2,4-DP had a significant effect on the internal characteristics of the fruit (Table 1) in 2005 and 2006. However, the effects of treatment varied throughout the experimental years, and different treatments showed different effects on fruit

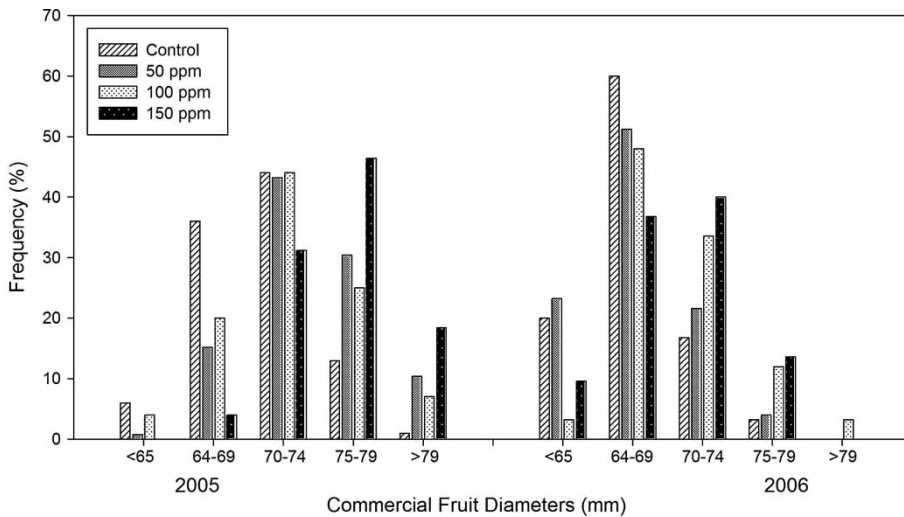


Figure 3 Frequency distribution of the diameter of Valencia oranges at harvest. 201 × 116 mm (300 × 300 DPI).

quality. In 2005, the application of 2,4-DP significantly affected the rind thickness, titratable acid (TA) content, TSS/TA ratio and vitamin C content; however, significant differences in the juice content and TSS content were not observed. Compared with the control fruit, fruit obtained from trees treated with 2,4-DP possessed a thicker rind, and an increase in the concentration of 2,4-DP increased the average fruit weight. Oranges containing the highest acid content were obtained from trees treated with 150 ppm 2,4-DP, followed by 100 ppm 2,4-DP. In comparison, the control trees and trees treated with 50 ppm 2,4-DP presented the lowest acid content. The TSS/TA ratio was significantly affected by the application of 2,4-DP, and the highest ratio was obtained in control trees and trees treated with 50 ppm 2,4-DP. In contrast, the lowest TSS/TA ratio was observed in trees treated with 100 ppm and 150 ppm 2,4-DP. The vitamin C content in the juice varied between applications. The maximum vitamin C content was observed in the control trees, followed by trees treated with 100 ppm 2,4-DP. In comparison, the lowest concentrations of vitamin C were obtained from trees treated with 150 ppm and 50 ppm 2,4-DP.

Except for TSS, significant differences in the internal quality of fruit were not observed between applications in 2006 (Table 1). Compared with the control trees, the application of 2,4-DP increased the TSS. The highest TSS content was obtained from fruit derived from trees treated with 50 ppm and 150 ppm 2,4-DP, followed by 100 ppm 2,4-DP. The lowest TSS was determined in the control trees. The TA was not affected by the application of 2,4-DP, and significant differences in the TSS/TA ratio between treatments were not observed. The rind thickness, juice content and vitamin C content of the fruits were similar, and significant differences among treatments were not observed.

Discussion

According to the results obtained in this study, the application of 2,4-DP increased the fruit

yield (kg/tree). The time and rate of 2,4-DP application had a positive effect on the yield, and a reduction in fruit yield was not observed. Similar results were obtained by Chao et al. (2004), who studied Fina Sodea clementine mandarins, and found that a post-bloom application of 2,4-D (2,4-Dichlorophenoxyacetic acid) significantly increased the yield. Similarly, a significant increase in the fruit number per tree of Valencia and Shamouti oranges was obtained when 2,4-D (20 ppm) was applied 6–8 weeks after full bloom (Erner et al. 1993) and 2,4-DP application increased total yield of Valencia orange (Greenberg et al. 1996).

The application of 2,4-DP significantly improved the fruit retention rate. Specifically, trees treated with 2,4-DP displayed significantly higher fruit retention rates than the control trees, and thinning effects were not observed. The results obtained in the present study are in concordance with those of Saraswathi et al. (2003), who demonstrated that the highest fruit retention rate was obtained (28.32%) from trees treated with 20 ppm 2,4-D. In comparison, the fruit retention rate of the control trees in the aforementioned study was only 20.32%. In a previous study, the application of 2,4-D (15 mg L^{-1}) delayed the abscission of navel oranges (Stewart & Klotz 1947). Moreover, foliar applications of 2,4-DP significantly reduced abscission in mature Washington navel sweet oranges (Agustí et al. 2006).

The results of the present study indicated that the fruit weight of trees treated with 2,4-DP was higher than that of the control. Specifically, an increase in the fruit weight was observed when treatments were applied during natural physiological fruit drop (when the mean fruit diameter was 13–15 mm). The results obtained in the present study are in agreement with those described in a previous report by Greenberg et al. (1996), who studied the effects of 2,4-DP on Valencia oranges. Moreover, the results of the present investigation concur with those of Duarte et al. (1996), who studied Esbal clementine mandarins, and found that the average fruit weight of trees

treated with 2,4-D was greater than that of the control. Moreover, Modise et al. (2009) verified the results of Duarte et al. (1996) and demonstrated that various concentrations of 2,4-D had a significant effect on fruit weight. Several other auxins such as 3,5,6-TPA, GA3 and chelated zinc/GA3 have also been reported to increase the weight of fruit (Agustí et al. 1995, 2001; Abd El-Moneim et al. 2007).

Fruit size is one of the most important factors affecting the marketing of fresh citrus fruits. Thus, synthetic auxins are commonly used to increase the size of fruit for fresh consumption. In the present study, fruit diameter was significantly affected by the application of 2,4-DP. Specifically, treatment with 2,4-DP increased the number of large fruits and reduced the number of fruits with a diameter <65 mm. In previous studies, fruits harvested from trees treated with 2,4-DP were significantly larger than that of the control trees, indicating that the application of 2,4-DP and 2,4-D increased fruit size (Hield & Erickson 1962; El-Otmani et al. 1993; Erner et al. 1993; Agustí et al. 1996; Greenberg et al. 1996; Koch et al. 1996; Gravina et al. 1998; Mesejo et al. 2003; Chao et al. 2004; Erner et al. 2004; Fang et al. 2008). 2,4-DP has given good results in increasing the fruit size of various citrus varieties without any significant thinning effects (Vanniere & Arcuset 1989; Agustí & Almela 1991). Also, according to El-Otmani et al. (1993), 2,4-DP improved fruit size by affecting juice sac development through an enhancement of cell enlargement rather than cell division. Similar results have also been reported for other auxins. For instance, applications of 10–20 ppm 3,5,6-trichloro-2-pyridylloxyacetic acid (3,5,6-TPA) increased the fruit size of Fino lemons (García-Lidón et al. 1992), satsuma mandarins (Agustí et al. 1994) and clementine mandarins (Agustí et al. 1995). In addition, Gravina et al. (1998) demonstrated that treatment with 3,5,6-TPA increased the mean fruit size of Ellendale tangor. Moreover, Summers et al. (2008) found that the application of 3,5,6-TPA (10 mg L⁻¹) to fruit with an

average diameter of 24 mm increased the size of fruit by 6.9–7.4 cm. Similarly, applications of naphthalene acetic acid increased the fruit size of Fino clementine mandarins (van Rensburg et al. 1996) and Valencia oranges (Greenberg et al. 1996).

The average internal characteristics of the fruit were evaluated, including the juice, TSS and vitamin C content, as well as the soluble solid:acid ratio. In general, the results indicated that the characteristics of the peel were not affected by the application of 2,4-DP; however, significant differences in the TA content were observed among treatments. The acidity of the juice was significantly different among treatments, and the TA content of the fruit increased with an increase in the 2,4-DP concentration. These results are in agreement with those obtained by Saleem et al. (2008), who studied Blood Red oranges, and found that the acidity of the juice increased with an increase in 2,4-D concentration. Thus, the aforementioned results indicate that the concentration of 2,4-D should be minimized to improve the quality of fruit. The effects of other synthetic auxins on the TA content have been investigated in previous studies. For instance, the application of 3,4,5-TPA was found to increase the total acid content of Fino clementine mandarins; however, significant differences in the acid concentration were not observed due to an increase in the volume of juice (Agustí et al. 1995). Nevertheless, except for titratable acidity, major internal fruit characteristics were not affected by auxin treatments, as previously observed by other researchers (Coggins 1981; Lima & Davies 1984; Pons et al. 1992; Davies et al. 1999; Agustí 2000; Pozo et al. 2000; Saraswathi et al. 2003; Almeida et al. 2008).

In conclusion, the application of 2,4-DP during the physiological fruit drop (eighth week after full blossom, fruit diameter of 13–15 mm) increased fruit size without significantly changing the yield. Thus, to increase the number of large, commercially valuable fruits, 150 ppm 2,4-DP can be applied to Valencia oranges.

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