Effect of 2,4-D and CPPU on Triploid Watermelon Production and Quality

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Abstract. Pollination is one problem with intensive seedless watermelon (Citrullus lanatus Thunb.) production under unfavorable environmental conditions (low solar radiation and temperature) due to the lowered activity of pollinating insects, such as the bee (Apis mellifera L.). An alternative to overcome these problems is the use of plant growth regulators. For this reason, experiments were conducted for 2 years in plastic greenhouses in the fields of Almeria, southwestern Spain, to evaluate the production and quality of ‘Reina de corazones’ triploid watermelon grafted onto RS841 rootstock (Cucurbita maxima × Cucurbita moschata). Two phytoregulators were used for the development of the ovary: 1-(2-chloro-4-pyridyl)-3-phenylurea (CPPU) and 2,4-dichlorophenoxyacetic acid (2,4-D). Concentrations of CPPU evaluated were 50, 100, 150, and 200 mg L⁻¹. An application of 0.6 mL was applied to each ovary in addition to 4, 6, 8, or 12 mg L⁻¹ of 2,4-D to the foliar mass at a proportion of 1000 L ha⁻¹. Results showed that the production and number of fruit obtained with CPPU treatments were similar to what is obtained by using bees for fruit pollination. Maximum production was achieved at concentrations of 100–200 mg L⁻¹. Average production was 32% to 83% higher than results from 2,4-D at 8 mg L⁻¹. The number of fruit per plant was 33% to 35% higher as well. In the first assay, a positive correlation was also observed between production and CPPU concentration. CPPU treatments had a lower accumulation of sugars than those with 2,4-D; nevertheless, both treatments showed values of commercially acceptable soluble solids.

In recent years, the cultivation of triploid watermelon in Almeria has increased significantly. The annual increase in surface area expanded to this crop has been maintained (Fig. 1). The efficacy of grafting to control soil-borne diseases (Fusarium oxysporum f. sp. niveum) is one of the main causes of this increase. Another reason for this growth is the introduction of triploid varieties, giving rise to seedless fruit, which is increasingly valued in European Union markets. In 2005, the surface area cultivated under plastic houses in Almeria was 6000 ha. For triploid watermelon production, the female flower should be pollinated by pollen from a diploid (2n) cultivar to obtain fruit. Early production of watermelon in plastic houses is transplanted between the months of November and February in Almeria, using between 25% and 40% of the pollinating diploid variety. This fact implies the harvest of at least 25% of seed-bearing fruit, which is less valued by the market, so that the producer receives a lower price for it (Camacho and Fernandez, 2000).

Pollination is the main problem in the production of watermelon in plastic houses due to the limited activity of bees (Apis mellifera) when climatic conditions are unfavorable, such as insufficient solar radiation and temperature (Camacho and Fernandez, 2000; Hayata and Niimi, 1995; Hayata et al., 2000). Under such conditions, pollinator activity is slow and anther dehiscence is inhibited (Hayata et al., 1995; Tsukahara, 1988). It is of utmost importance in watermelon pollination that at least 1000 grains of pollen be regularly deposited on the three stigma lobes to obtain uniform fruit. Because pollen grain produces pollen tubes with descending growth and reduced lateral movement, an insufficient quantity of pollen on the stigma lobe gives rise to asymmetrical fruit. Therefore, saturation becomes an important consideration in insect pollination because uniform fruit must be obtained (McGregor, 1976).

When climatic conditions are unfavorable, flower abortion becomes a serious problem in the commercial production of cucurbits, in spite of artificial pollination (Yu, 1999). Fruit set in melon, watermelon, cucumber, and Chinese white-flowered gourd (Lagenaria leucantha) decreases in such unfavorable climatic conditions as low temperatures and cloudy or rainy days (Hayata et al., 2000, 2001; Ogawa et al., 1977; Yu, 1999). Under unfavorable climatic conditions, watermelon fruit set is a serious problem, which is not completely solved by using artificial pollination or increasing the number of bee hives (Camacho and Fernandez, 2000).

Triploid cultivars are difficult to manage, so fruit set is more susceptible to low temperatures and other environmental stresses than in diploid cultivars (Miguel et al., 2004). Diploid cultivars require the visit of at least 6–8 bees for good fruit set (Adlerz, 1966; Stanghellini et al., 1997). The number of bee visits required for triploid cultivar fruit set, where the relationship of univiable pollen in the crop is at least 2:1, has not yet been determined (Stanghellini et al., 2002). Reduced fruit set in triploid watermelon crops is sometimes the consequence of inadequate plant distribution during transplanting, or it might also be associated with synchronization errors between the maturity of the diploid pollen and the triploid ovary (Camacho et al., 2003; Miguel et al., 2001b).

Plant bioregulators are an alternative to natural pollination in numerous crops. Parthenocarpy, the development of the ovary into fruit without fertilization or seed formation, is an alternative route for achieving fruit set and normal fruit development (Lukyanenko, 1991). Various research papers have shown that the application of plant growth regulators such as auxins, gibberellins, and cytokinins can improve fruit set and development: 1-(2-chloro-4-pyridyl)-3-phenylurea (CPPU) and gibberellic acid (GA₃) in grape (Retamales et al., 1995); CPPU in kiwi (Antognozzi et al., 1996; Lewis et al., 1996); naphthalene acetic acid (NAA) and phenothiol in loquat (Amoros et al., 2004); and CPPU, 2,4-dichlorophenoxyacetic acid (2,4-D), and benzyl adenine (BA) in apple (Costa et al., 2004; Greene, 2001; Percy et al., 1998; Tartarini et al., 1993).

Applying plant growth regulators has been studied in cucurbit crops: CPPU, BA, and 2,4-dichlorophenoxyacetic acid (2,4-CPA) in Chinese watermelon (Hayata et al., 2002; Li et al., 2002); CPPU in Chinese white-flowered gourd (L. leucantha) (Yu et al., 2001); CPPU, BA, 4-CPA, and GA₃ in cucumber (Kim et al., 1992); BA and CPPU in watermelon (Hayata and Niimi, 1995; Hayata et al., 1995); and 2,4-D in watermelon (Camacho et al., 2003; Miguel et al., 1999). NAA, 2-CPA, and BA were the most effective. Although ineffective at low temperatures, 2-CPA and BA are normally used (Hayata et al., 2000). CPPU is a new plant growth regulator that promotes fruit set and growth under unfavorable conditions for pollination and fertilization (Hayata et al., 2002).

CPPU and 2,4-D plant growth regulators were tested in outdoor watermelon crops in Valencia (eastern Spain). Fruit set and development of triploid watermelon grafted onto Shintoza (Cucurbita maxima × Cucurbita moschata) was improved by the application of 8 and 100 mg L⁻¹ of 2,4-D and CPPU.

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The test lot had a surface area of 896 and 504 m², respectively, for the first and second years. The number of plants per elemental lot was 8 or 6, planted at a density of 0.25 plants/m².

Plant growth regulator evaluated. The products used for fruit set were Sitofex (liquid formulation of BASF, Limburgerhof, Germany) and Antidrop (Agrodan), which contain synthetic phytohormones. The concentration of Sitofex was 1% (w/v) CPPU, from the cytokinin group. The concentration of Antidrop, of the auxin group, was 3.2% (w/v) 2,4-D amino salt. Treatments were defined by the concentrations of the a.i.: 4, 6, 8, and 12 mg L⁻¹ of 2,4-D and 50, 100, 150, and 200 mg L⁻¹ of CPPU. In the second-year trial, the 50 mg L⁻¹ CPPU treatment was not done but was replaced with a 150 mg L⁻¹ CPPU treatment, due to adjustments for obtaining more uniform quality parameters after seeing first-year results. A surfactant (alkyl polyglycol at 20% w/v S.L. Mojante Inagra at a concentration of 50 mL·L⁻¹ of the commercial product) and a foliar fertilizer (20% to 27.8% SC. Goemar BM86 seaweed from Aragonesa at a 200 mL·L⁻¹ concentration of the commercial product) were added to the various 2,4-D solutions. They were applied on the entire foliar mass 51 d after transplant (dat) in the first year of the experiment and 59 dat in the second year, at a proportion of 1000 L·ha⁻¹, by means of a backpack sprayer. CPPU treatments were carried out at 51 and 59 dat the first year and in the second year, every 4 d starting from 44 dat until five applications were made. The applicator was a manual nebulizer regulated to apply only 0.6 mL of solution on each ovary. Both types of phytoregulators were applied when the petals were fully opened.

Plastic houses where the tests were conducted were sealed to prevent entry by outside pollinators. Only triploid watermelon was planted for both experiments with the aim of eliminating diploid watermelon pollen in the plant vicinity. Table 1 summarizes the phytoregulators and concentrations used.

**Materials and Methods**

**Plant material.** Experiments were conducted during two crop cycles (spring of 2003 and 2004), in the plastic house horticultural production area of Almeria. The plant material used was watermelon (Citrullus lanatus cv. Reina de corazones), of uniform performance, productive, striped rind, and slightly oblong (Maroto et al., 2002), grafted onto ‘RS841’ rootstock (C. maxima × C. moschata). It was transplanted into modified soil, locally known as “suelo arenado” (sand-covered soil) with 8.7 pH and 3.62% organic material content. An Almeria-type, “raspa y amagado” (covered skeleton structure), commercial plastic house was used, with an 800-gauge wide trithermal polyethylene covering and zenith and lateral antiaphid, 40-mesh ventilation. Fertilization was applied by fertigation with an automatic head. Quantities of N, P₂O₅, and K₂O equivalent to 200, 150, and 350 kg·ha⁻¹, respectively, were distributed according to crop phenological stage and as recommended by Camacho and Fernandez (2000).

Randomized complete-block design was used with four repetitions the first year and with three in the second year. In both cases, the \( y_{ij} = \mu + \tau_i + \beta_j + \epsilon_{ij} \) linear additive model was followed, where \( i = 1, 2, \ldots, 6 \) for both assays; \( j = 1, 2, 3, 4 \) for the first season; and \( j = 1, 2, 3 \) for the second season.

![Fig. 1. Almeria watermelon area (*CVVV new virus detected in the area).](Image)
Results

Production. CPPU applied to the ovary at anthesis and 2,4-D applied by spraying the leaves promoted growth of fruit from unpollinated triploid watermelon flowers in crops in plastic houses. The effects of various treatments and concentrations of 2,4-D and CPPU on watermelon production in both experiments are shown on Tables 2 and 3. Total production from both experiments was greater in blocks treated with CPPU than in those treated with 2,4-D, as is shown in Tables 8 and 9. But the differences between CPPU and 2,4-D were insignificant for concentration, except for 12 mg L⁻¹. The lowest production values were from blocks treated with 12 mg L⁻¹ of 2,4-D.

Quality parameters. Results from the analysis of quality parameters are shown on Tables 4, 5, 6, 7, 10, 11, 12, and 13. There were significant differences in the soluble solids content among treatments in the first experiment but not in the second one. Soluble solids contents always had higher values than the minimum acceptable market values for all watermelons (8 °Brix).

Average pH values of fruit at harvest were between 5.37 ± 0.18 and 5.14 ± 0.12 for the first and second experiments, respectively. There were statistically significant differences among average pH only in the first study, with a 5.23–5.60 and 5.04–5.29 pH interval for fruit from the first and second experiments. Pulp firmness values varied from 2.53 to 3.15 kg cm⁻² and 1.96 to 2.22 kg cm⁻² for the first and second experiments, respectively, with average values of 2.88 ± 0.31 and 2.07 ± 0.13 kg cm⁻².

Results from size of the pistil scar showed statistically significant differences between 2,4-D and CPPU, with lower values corresponding to CPPU. Measurement averages were 14.21 and 12.60 mm for 2,4-D and CPPU, respectively, in the first experiment and 20.97 and 12.97 mm for 2,4-D and CPPU in the second experiment. Average rind thickness measurements oscillated between 16.88 ± 1.71 and 14.51 ± 1.55 mm for the first and second assays, respectively. There were statistically significant differences between some 2,4-D treatments and CPPU treatments.

There were no statistically significant differences between values from the LP/TP relationship (longitudinal perimeter/transverse perimeter) because the fruit is oblong in shape.

Table 2. Effect of 2,4-D and CPPU concentration on production and on main yield components in Reina de corazones cv. triploid watermelon; first experiment (Spring 2003).∗

| Treatment and concn (mg L⁻¹) | Total production (kg m⁻²) | kg/plant | Fruit/plant | Avg fruit wt (kg) |
|-----------------------------|---------------------------|----------|-------------|-------------------|
| CPPU                        |                           |          |             |                   |
| 200                         | 9.6 ab                    | 38.6 a   | 7.1 a       | 5.5 ab            |
| 100                         | 9.3 ab                    | 37.1 ab  | 7.1 a       | 5.0 ab            |
| 50                          | 8.4 ab                    | 33.8 ab  | 6.4 a       | 5.3 ab            |
| 2,4-D                       |                           |          |             |                   |
| 12                          | 2.1 d                     | 8.4 d    | 2.1 c       | 4.1 c             |
| 8                           | 7.4 abc                   | 29.5 abc | 5.1 ab      | 5.8 a             |
| 6                           | 6.4 bc                    | 25.5 bc  | 5.5 a       | 4.6 bc            |
| 4                           | 6.9 abc                   | 27.6 abc | 5.1 ab      | 5.4 ab            |

∗Different letters mean significant differences, at P < 0.05. Untreated control groups were unproductive and therefore are not shown in the table.

Table 3. Effect of 2,4-D and CPPU concentration on production and on main yield components in Reina de corazones cv. triploid watermelon; second experiment (Spring 2004).∗

| Treatment and concn (mg L⁻¹) | Total production (kg m⁻²) | kg/plant | Fruit/plant | Avg fruit wt (kg) |
|-----------------------------|---------------------------|----------|-------------|-------------------|
| CPPU                        |                           |          |             |                   |
| 200                         | 9.1 b                     | 38.2 a   | 8.5 a       | 4.5 a             |
| 150                         | 8.5 a                     | 36.0 a   | 8.0 a       | 4.5 a             |
| 100                         | 9.8 a                     | 39.3 a   | 8.8 a       | 4.5 a             |
| 2,4-D                       |                           |          |             |                   |
| 12                          | 5.3 b                     | 21.3 b   | 3.9 b       | 5.4 a             |
| 8                           | 5.4 b                     | 23.1 b   | 4.3 b       | 5.4 a             |
| 6                           | 5.1 b                     | 20.4 b   | 3.7 b       | 5.6 a             |
| 4                           | 3.5 b                     | 13.8 b   | 3.0 b       | 4.6 a             |

∗Different letters mean significant differences, at P < 0.05.

Table 4. Effect of 2,4-D and CPPU concentration on total soluble solids content, pH, pulp firmness, and pistil scar size in Reina de corazones cv. triploid watermelon; first experiment (Spring 2003).∗

| Treatment and concn (mg L⁻¹) | °Brix | pH  | Pulp firmness (kg cm⁻²) | Pistil scar (mm) |
|-----------------------------|-------|-----|------------------------|------------------|
| CPPU                        |       |     |                        |                  |
| 200                         | 9.2 c | 5.2 c | 3.0 abc                | 13.9 bc          |
| 100                         | 10.1 b| 5.4 bc| 2.6 cd                 | 11.8 cd          |
| 50                          | 10.7 ab| 5.3 c | 2.8 bcd                | 12.1 cd          |
| 2,4-D                       |       |     |                        |                  |
| 12                          | 10.8 ab| 5.4 bc| 3.0 ab                 | 11.2 d           |
| 8                           | 11.0 a| 5.4 b | 3.1 abc                | 16.6 a           |
| 6                           | 10.6 ab| 5.3 bc| 2.5 d                  | 14.4 ab          |
| 4                           | 11.0 a| 5.6 a | 3.2 ab                 | 14.6 ab          |

∗Different letters mean significant differences, at P < 0.05.

Table 5. Effect of 2,4-D and CPPU concentration on total soluble solids content, pH, pulp firmness, and pistil scar size in Reina de corazones cv. triploid watermelon; second experiment (Spring 2004).∗

| Treatment and concn (mg L⁻¹) | °Brix | pH  | Pulp firmness (kg cm⁻²) | Pistil scar (mm) |
|-----------------------------|-------|-----|------------------------|------------------|
| CPPU                        |       |     |                        |                  |
| 200                         | 10.8 a| 5.0 a | 2.1 ab                 | 12.7 cd          |
| 150                         | 10.5 a| 5.0 a | 2.2 a                  | 14.7 c           |
| 100                         | 10.8 a| 5.1 a | 2.0 b                  | 11.5 d           |
| 2,4-D                       |       |     |                        |                  |
| 12                          | 10.2 a| 5.2 a | 2.0 ab                 | 21.5 ab          |
| 8                           | 10.6 a| 5.2 a | 2.1 ab                 | 23.1 a           |
| 6                           | 10.3 a| 5.3 a | 2.0 ab                 | 20.4 ab          |
| 4                           | 10.7 a| 5.1 a | 2.1 ab                 | 18.9 b           |

∗Different letters mean significant differences, at P < 0.05.

Temperature and relative humidity. Climatic unfavorable conditions for fruit set were detected during both years’ assays. Temperature and relative humidity showed important oscillations during fruit set time (Fig. 2).

Discussion

Production. In the first experiment, except for treatment with 12 mg L⁻¹ of 2,4-D, average production corresponding to CPPU treatments exceeded those with 2,4-D by 32.5%. A positive relationship was also observed between total production and CPPU concentration; that is, the greater the concentration, the higher the production. A maximum value was obtained at 200 mg L⁻¹ of CPPU, contrary to what happened with the highest concentration of 2,4-D.
Table 6. Effect of 2,4-D and CPPU concentration on rind thickness, longitudinal perimeter (LP), transverse perimeter (TP), and LP/TP relationship in Reina de corazones cv. triploid watermelon; first experiment (Spring 2003).x

| Treatment and conc (mg L⁻¹) | Rind thickness (mm) | LP (cm) | TP (cm) | LP/TP |
|-----------------------------|---------------------|---------|---------|-------|
| CPPU 200                    | 16.4 ab             | 71.5 a  | 65.1 a  | 1.1 a |
| 100                         | 15.3 b              | 69.3 a  | 63.8 ab | 1.1 a |
| 50                          | 16.0 ab             | 71.6 a  | 63.7 ab | 1.1 a |
| 2,4-D 12                    | 16.7 ab             | 63.4 b  | 58.7 c  | 1.1 a |
| 8                           | 16.7 ab             | 72.9 a  | 66.0 c  | 1.1 a |
| 6                           | 18.2 a              | 68.5 a  | 59.9 bc | 1.1 a |
| 4                           | 18.7 a              | 68.7 a  | 61.7 abc| 1.1 a |

*Different letters mean significant differences, at P < 0.05.

Table 7. Effect of 2,4-D and CPPU concentration on rind thickness, longitudinal perimeter (LP), transverse perimeter (TP), and LP/TP relationship in Reina de corazones cv. triploid watermelon; second experiment (Spring 2004).x

| Treatment and conc (mg L⁻¹) | Rind thickness (mm) | LP (cm) | TP (cm) | LP/TP |
|-----------------------------|---------------------|---------|---------|-------|
| CPPU 200                    | 13.6 b              | 70.5 a  | 66.6 a  | 1.1 a |
| 150                         | 13.7 b              | 69.9 a  | 65.8 a  | 1.1 a |
| 100                         | 14.0 b              | 71.5 a  | 67.9 a  | 1.1 a |
| 2,4-D 12                    | 16.7 a              | 73.2 a  | 69.2 a  | 1.1 a |
| 8                           | 14.8 b              | 70.9 a  | 68.0 a  | 1.0 a |
| 6                           | 14.9 b              | 71.6 a  | 67.6 a  | 1.1 a |
| 4                           | 14.0 b              | 70.8 a  | 67.3 a  | 1.0 a |

*Different letters mean significant differences, at P < 0.05.

Table 8. Effect of 2,4-D and CPPU treatment on production and on main yield components in Reina de corazones cv. triploid watermelon; first experiment (Spring 2003).x

| Treatment | Total production (kg m⁻²) | kg/plant | Fruit/plant (kg) | Avg fruit wt (kg) |
|-----------|---------------------------|----------|-----------------|-----------------|
| CPPU      | 9.1 a                     | 36.5 a   | 6.9 a           | 5.3 a           |
| 2,4-D     | 5.7 b                     | 22.8 b   | 4.5 b           | 5.0 a           |

*Different letters mean significant differences, at P < 0.05.

Table 9. Effect of 2,4-D and CPPU treatment on production and on main yield components in Reina de corazones cv. triploid watermelon; second experiment (Spring 2004).x

| Treatment | Total production (kg m⁻²) | kg/plant | Fruit/plant (kg) | Avg fruit wt (kg) |
|-----------|---------------------------|----------|-----------------|-----------------|
| CPPU      | 9.3 a                     | 38.0 a   | 8.5 a           | 4.5 a           |
| 2,4-D     | 4.8 b                     | 19.7 b   | 3.7 b           | 5.3 a           |

*Different letters mean significant differences, at P < 0.05.

Table 10. Effect of 2,4-D and CPPU treatment on total soluble solids content, pH, pulp firmness, and size of pistil scar in Reina de corazones cv. triploid watermelon; first experiment (Spring 2003).x

| Treatment | °Brix | pH | Pulp firmness (kg cm⁻²) | Pistil scar (mm) |
|-----------|-------|----|------------------------|-----------------|
| CPPU      | 10.0 a| 5.3 a| 2.8 a                  | 12.6 b          |
| 2,4-D     | 10.9 a| 5.4 a| 3.1 a                  | 15.2 a          |

*Different letters mean significant differences, at P < 0.05.

Table 11. Effect of 2,4-D and CPPU treatment on total soluble solids content, pH, pulp firmness, and size of pistil scar in Reina de corazones cv. triploid watermelon; second experiment (Spring 2004).x

| Treatment | °Brix | pH | Pulp firmness (kg cm⁻²) | Pistil scar (mm) |
|-----------|-------|----|------------------------|-----------------|
| CPPU      | 10.7 a| 5.0 a| 2.1 a                  | 13.0 b          |
| 2,4-D     | 10.5 a| 5.2 a| 2.1 a                  | 21.0 a          |

*Different letters mean significant differences, at P < 0.05.

Results from CPPU treatments are similar to those observed by Camacho and Fernandez (2000) in 1996 and 1997, respectively, for the same cultivar and stock, using bees for pollination. On the other hand, production was significantly affected by treatments. This performance is similar to what Camacho et al. (2003) obtained with ‘Sweet Marvel’ diploid watermelon grafted onto ‘RS841’ (C. maxima × C. moschata) in plastic houses.

In the second experiment, although it lacks a linear relationship between concentrations of CPPU and production values, the production values are still higher than those obtained with 2,4-D applications, as was observed in the first experiment.

Other researchers have reported linear performance between CPPU concentration and fruit weight (Greene, 2001), although in the case of Greene (2001) it was due to the fruit thinning effect incited by various CPPU concentrations.

In the results presented herein, a fruit set (expressed as harvested fruit compared with treated flowers) of 85.0%, 69.76%, and 78.70% was obtained in the second experiment for CPPU concentrations of 100, 150, and 200 mg L⁻¹, respectively. Incidence of split fruit was, respectively, 4.84%, 8.24%, and 9.14% of the flowers treated per plant. Low concentrations of CPPU applications increased the number of split fruit in seedling-bearing as well as in seedless melon (Cucumis melo). CPPU had a great effect on seedling-bearing fruit set. In seedless melons, CPPU induced 100% fruit set with parthenocarpic development when 10 mg L⁻¹ was applied. Lower concentrations were much less effective (Hayata et al., 2000). The effects of CPPU in watermelon fruit set under unfavorable crop conditions were reported by Hayata et al. (1995). They obtained 26.9%, 65.05%, and 89.5% fruit set in manual pollination with 20 and 200 mg L⁻¹ of CPPU, respectively.

The number of fruit per plant performed similarly to production. The strong correlation (r = 0.93) shown by these parameters (Fig. 3) in both seasons explains this performance and simultaneously corroborates the observations of Camacho and Fernandez (2000), in that the number of fruit per plant is the yield component with the greatest effect on productivity. Thus, production values expressed in kg m⁻² or in kg/plant for both seasons reflect the number of fruit set.

On the other hand, comparing these results with those obtained from assays conducted in Almeria by Camacho et al. (2003), fruit set in the 2002–2003 season for 50, 100, and 200 mg L⁻¹ of CPPU surpassed the number of fruit set from the ‘Sweet Marvel’ diploid cultivar by 130%, 55%, and 48%, respectively, for these same concentrations. These percentages are even higher when considering the number of fruit set from the 2003–2004 season for concentrations of 100 and 200 mg L⁻¹ of CPPU.

Also, when compared with results from the Community of Valencia (eastern Spain), the number of fruit set with 50 and 100 mg L⁻¹ of CPPU, as well as with 4 and 8 mg L⁻¹ of 2,4-D in the 2002–2003 season, exceeded the values obtained by Miguel et al. (2003a, 2003b) by 100% for these concentrations in the same cultivar–stock combination in the same year.

Because the number of fruit set is one of the components directly influencing...
production, several researchers have tried to explain what happens in the fruit before and after this process. Talon et al. (1990) studied hormonal changes associated with fruit set and development in mandarins. Their results suggest that the fruit set potential in parthenocarpic fruit is mainly affected by their hormonal state during the late stages of cellular division and the early stages of cellular growth. Hayata et al. (2002) later affirmed that CPPU application and pollination cause high contents of indoleacetic acid (IAA) and low contents of abscisic acid (ABA) during the first stages of fruit development. These situations can be closely related to fruit set and growth, as observed in the experiments described in this article.

**Quality parameters.** Tables 4 and 5 show the values for content of solids (°Brix), degree of acidity (pH), and fruit firmness. All °Brix values were within acceptable commercial requirements and were similar to those obtained by Camacho and Fernandez (2000) for the same cultivar and stock. Nevertheless, CPPU treatments showed lower °Brix values compared with 2,4-D treatments. Similarly, an inverse relationship was also observed between CPPU concentration and °Brix; that is to say, the greater the CPPU concentration, the lower the soluble solids content. Similar results were obtained in various grapevine cultivars: ‘Kings Ruby’ (El-Hammady et al., 2000), ‘Perlette’ and ‘Italia’ (Ezzahouani, 2000), ‘Tas-A-Ganesh’ (Bhujbal et al., 2002), and ‘Campbell Early’ (Kim et al., 2002). Hayata et al. (2000) reported that high CPPU concentrations applied to muskmelon crops reduced sucrose levels in the placenta of seedless fruit, indicating that such concentrations play a very important role in sugar accumulation during the late stages of development. In addition, Hayata et al. (2001) concluded that levels of sucrose synthase activity are closely related to sugar accumulation in seedless, parthenocarpic muskmelon.

With the increase in CPPU concentration, pH values decreased, as did °Brix, an observation reported by Ezzahouani (2000) in grapevine varieties with and without seeds. The combination of °Brix and pH values from this research indicate that, as the CPPU concentration increases, fruit ripening is delayed. NeSmith (2002) reached similar results with blueberry (Vaccinium ashei R.) as did Retamales et al. (1995) with ‘Thompson Seedless’ grape.

Pulp firmness values are higher with CPPU treatments (2.61–2.95 kg cm⁻²) than those measured by Camacho and Fernandez (2000), which could be an effect of the °Brix and pH values shown, with repercussions of a delay in ripening.

**Conclusions**

The results presented herein allow the affirmation that—in the place where these experiments were conducted—the production obtained with CPPU is similar to that obtained by using pollinator insects. CPPU
treatments in all concentrations surpass those with 2,4-D, reaching maximum production between 100 and 200 mg L⁻¹. Production and average number of fruit with CPPU treatments exceeded that obtained with 2,4-D by 32.5% and 35%, respectively. All treatments showed +Brix values that surpassed the required commercial minimum. However, those corresponding to CPPU showed less sugar accumulation compared with 2,4-D.

**Literature Cited**

Adler, W.C. 1966. Honey bee visit numbers and watermelon pollination. J. Econ. Entomol. 59:28–30.

Amoros, A., P. Zapata, M.A. Petrol, M.A. Botella, M.S. Almansa, and M. Serrano. 2004. Role of naphthalene acetic acid and phenothiol treatments on increasing fruit size and advancing fruit maturity in loquat. Scientia Hort. 102:387–398.

Antongnnozzi, E., A. Battistelli, F. Famanii, S. Moscatello, F. Stanica, and A. Tombesi. 1996. Influence of CPPU on carbohydrate accumulation and metabolism in fruits of Actinidia delicosa (A. Chev.). Scientia Hort. 65:37–47.

Bhujbal, B., D. Ranawade, and K. Jagtap. 2002. Effects of CPPU on quality of grapes cv. Tas.AgAnesh. J. Maharashtra Agr. Univ. 27:13–14.

Camacho, F. and E.J. Fernandez. 2000. El cultivo de sandia apierna inyectada, bajo invernadero, en el litoral mediterráneo español. Ed. Caja Rural de Almería.

Camacho, F., E.J. Fernandez, and M. Pérez. 2003. Greenhouse production of diploid watermelon without biological pollination: effects of 2,4-D and CPPU on yield and seedless fruit induction. Acta Hort. 614:145–148.

Costa, G., F. Bucchi, M. Montefiori, A.M. Bregoli, and L. Corelli Grappadelli. 2004. Thinning activity and fruit quality of Gala and Fuji apple varieties as affected by cytokinins. Acta Hort. 653:107–113 (Proc. 9th Intl. Symp. Plant Bio-regulators in Fruit Prod.).

El-Hammady, A.M., A.D. Shaltout, N. Abdel-Hamid, and M. El-Sayed. 2000. Effect of sitoflex (CPPU) and shoulder thinning on yield and quality of King’s Ruby grapes. Arab Univ. J. Agr. Sci. 8:735–754.

Ezzahouani, A. 2000. Effect of forchlorfenuron (CPPU) and girdling on table grape cultivars ‘Perlette’ and ‘Italia’. J. Int. Sci. Vigne Vin 34:57–60.

Greene, D.G. 2001. CPPU influences fruit quality and abscission of ‘McIntosh’ apples. HortScience 36:1292–1295.

Hayata, Y., X.X. Li, D. Kishimoto, and Y. Osajima. 2001. p-CPA enhances growth and quality of muskmelon fruits. Plant Growth Regulat. 36:13–18.

Hayata, Y., X.X. Li, and Y. Osajima. 2002. Pollination and CPPU treatment increase endogenous IAA and decrease endogenous ABA in muskmelons during early development. J. Amer. Soc. Hort. Sci. 127:908–911.

Hayata, Y. and Y. Niimi. 1995. Synthetic cytokinin 1-(2-chloro-4-pyridyl)-3-phenylurea (CPPU) promotes fruit set and induces parthenocarpy in watermelon. J. Amer. Soc. Hort. Sci. 120:997–1000.

Hayata, Y., Y. Niimi, and N. Iwasaki. 1995. Inducing parthenocarpic fruit of watermelon with plant bioregulators. Acta Hort. 394:235–240.

Hayata, Y., Y. Niimi, K. Inoue, and S. Kondo. 2000. CPPU and BA, with and without pollination, affect set, growth and quality of muskmelon fruit. HortScience 35:868–870.

Kim, I.L., Y.L. Piao, Y.S. Hwang, and J. Lee. 2002. Effects of synthetic cytokinin, thidiazuron on berry size and quality of ‘Campbell Early’ (Ficus labruscana) grapes. J. Korean Soc. Hort. Sci. 43:457–461.

Kim, I.S., H. Okubo, and K. Fukuoka. 1992. Endogenous levels of IAA in relation to parthenocarpy in cucumber (Cucumis sativus L.). Scientia Hort. 52:1–8.

Lewis, D.H., G.K. Hopping, and P.E. Jameson. 1996. Cytokinins and fruit development in the kiwifruit (Actinidia delicosa). II. Effects of reduced pollination and CPPU application. Physiol. Plant. 98:187–195.

Li, X.X., Y. Hayata, and Y. Osajima. 2002. p-CPA increases the endogenous IAA content of parthenocarpic muskmelon fruit. Plant Growth Regulat. 37:99–103.

Lukyanenko, A.N. 1991. Parthenocarpy in tomato, p. 167–178. In: G. Kallio (ed.). Genetic improvement of tomato, Monographs on Theoretical and Applied Genetics 14. Springer-Verlag, Berlin.

Maroto, J.V., A. Miguel, and F. Pomares. 2002. El cultivo de la sandia. Caja Rural de Valencia. Ediciones Mundi-Prensa.

McGregor, S.E. 1976. Insect pollination of cultivated plants. Agriculture Handbook No. 496. Agricultural Research Service, U.S. Department of Agriculture, Washington, D.C.

Miguel, A., J.V. Maroto, and S. López. 2001a. Triploid seedless watermelon production without pollinators. Effect of the number of sprayed pollen. Acta Hort. 559:135–138.

Miguel, A., J.V. Maroto, and S. López. 2001b. Production of different triploid watermelon cultivars without pollinators. Acta Hort. 559:145–148.

Miguel, A., J.V. Maroto, S. López, J. Verdú, S. García, E. Márquez, and D. Herrans. 1999. Comparision of different concentrations of CPPU in the treatment a flora for the cuaje of sandia triploide with pollinizer, p. 157–159. Memoria de actividades. Resultados de ensayos hortícolas. Consellería de Agricultura, Pesca y Alimentación.

Miguel, A., J.V. Maroto, A. San Bautista, C. Baixauli, V. Cebolla, B. Pascual, S. López, and J.L. Guardiola. 2004. The grafting of triplod watermelon is an advantageous alternative to soil fertilization by methyl bromide for control of Fusarium wilt. Scientia Hort. 103:9–17.

Miguel, A., J.I. Marsal, I. Verdú, J. Garcia, J. Villalba, and V. Bosk. 2003a. Comparación de métodos de cuaje de sandia triploide in invernadero, p. 105–106. In: Memoria de actividades. Resultado de ensayos hortícolas. Consellería de Agricultura, Pesca y Alimentación.

Miguel, A., J.I. Marsal, I. Verdú, J. García, J. Villalba, and V. Bosk. 2003b. Cuaje de sandia triploide sin polinizador in invernadero. Comparación de diferentes concentraciones de 2,4-D en pulvizarización sobre la planta, p. 107–108. In: Memoria de actividades. Resultado de ensayos hortícolas. Consellería de Agricultura, Pesca y Alimentación.

NeSmith, D.S. 2002. Response of rabbiteye blueberry (Vaccinium ashei Reade) to growth regulators CPPU and gibberellic acid. HortScience 37:666–668.

Ogawa, Y., N. Inoue, and S. Auki. 1977. Prominent promotion on the fruit growth in Cucumis sativus L. J. Jpn. Soc. Hort. Sci. 59:597–601.

Percy, A.E., P.E. Jameson, and L.D. Melton. 1998. Expansion during early apple fruit development induced by auxin and N-(2-chloro-4-pyridyl)-N'-phenylurea: effect on cell wall hemicellulose. Plant Growth Regulat. 26:1–6.

Retamales, J., F. Bangert, T. Cooper, and R. Callejas. 1995. Effects of CPPU and GA₃ on fruit quality of Sultana table grape. Acta Hort. 394:149–158.

Stanghellini, M.S., J.T. Ambrose, and J.R. Schultheis. 1997. The effects of honey bee and bumble bee pollination on the fruit set and abortion of cucumber and watermelon. Amer. Bee J. 137:386–391.

Stanghellini, M.S., J.R. Schultheis, and J.T. Ambrose. 2002. Pollen mobilization in selected Curcurbitaceae and the putative effects of pollinator abundance on pollen depletion rates. J. Amer. Soc. Hort. Sci. 127:729–736.

Talon, M., L. Zacarías, and E. Primo-Millo. 1990. Hormonal changes associated with fruit set and development in mandarins differing in their parthenocarpic ability. Physiol. Plant. 79:400–406.

Tartarini, S., S. Sansavini, and M. Ventura. 1993. CPPU control of fruit morphogenesis in apple. Scientia Hort. 53:273–279.

Tsuzuki, A. 1988. Semi-forcing culture in watermelon, p. 194–196. In: The system of agricultural technology: melon and watermelon. Soc. Cult. Agr. Vill. Press, Tokyo (in Japanese).

Yu, J.Q. 1999. Parthenocarpy induced by N-(2-chloro-4-pyrdyl)-N’-phenylurea (CPPU) prevents flower abortion in Chinese white-flowered gourd (Lagenaria leucantha). Environ. Exp. Bot. 42:121–128.

Yu, J.Q., Y. Li, Y.R. Qian, and Z.J. Zhu. 2001. Cell division and cell enlargement in fruit of Lagenaria leucantha as influenced by pollination and plant growth substances. Plant Growth Regulat. 33:117–122.