**THE INHIBITION OF FLOWER BUD DIFFERENTIATION IN ‘CRIMSON
GOLD’ NECTARINE WITH GA₃ AS AN ALTERNATIVE TO HAND THINNING.**

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Abstract

The reduction of flower bud density by gibberellin sprays, to adjust the cropping level, is a novel approach to fruit thinning of peach and nectarine. A linear reduction in the number of flowers developed per unit of shoot length was found following the spray application of increasing concentrations of GA₃, in the nectarine cultivar Crimson Gold. These reductions in flower number led to reductions in yield at harvest, and increases in mean fruit weight. Flowering was slightly delayed by the GA₃ treatments, but no differences in ripening were detected at harvest, this depending rather on fruit size. The yield obtained by the application of 200 mg L⁻¹ GA₃ corresponded to that obtained with a very good thinning level, as established by hand thinning. No secondary effects on vegetative growth followed either the application of GA₃ or the reductions in crop load by means of hand thinning. Decreasing crop-loads have resulted in an increase in fruit size and an advance of fruit ripening, measured by greater levels of soluble solids and lower flesh firmness. A good commercial quality fruit size was obtained for crop-loads of 300 fruits per tree or less.

Key-words: peach, nectarine, gibberellins, flower density, cropping, fruit quality.

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1. Introduction.

The increasing demand by the markets for high quality fruit is making the control of fruit tree crop load an unavoidable operation in orchard management. Chemical fruit thinning of peach and nectarine (*Prunus persica* (L.) Batsch) generally fails due to a variety of causes, some of a physiological nature, and some environmental, and so most fruit growers, in many areas, still rely on hand thinning. However, alternatives to hand thinning are being sought as hand labour costs are continually increasing, and the availability of skilled workers is becoming increasingly rare.

Gibberellins are known to inhibit flower initiation in *Prunus* species (Bradley and Crane, 1960), and, thus, reductions in flower initiation were proposed years ago, as a possible alternative to traditional fruit thinning strategies (Corgan and Windmayer, 1971; Clanet *et al.*, 1979). Experiments carried out by Taylor and Geisler-Taylor (1998) showed that flower inhibition in short or long shoots of peach depended upon the date of GA₃ spray, or the concentration applied, and that it also was cultivar dependent. Also, Byers *et al.*, (1990) found differences in flower distribution that led them to suggest that early sprays of GA₃ could be used for selective thinning in cultivars in which fruits grown on them are particularly small. However, early applications of GA₃ to 'Redhaven' trees affected negatively fruit growth during the current growing season, producing a yield of poor quality (Monge *et al.*, 1994).

The application of GA₃ later in the growing season may be an approach of great interest for cultivars grown in areas with low risk of spring frost, and particularly for the very early ripening varieties, as treatment application could be performed after yield harvest, thus avoiding problems of residues on marketable fruits.

'Crimson Gold' is a very early nectarine cultivar, which yields small fruits unless heavily thinned, for which the use of chemical thinning agents is desirable. The application

of gibberellins to reduce flower density, and consequently crop-loads, is, then of great interest.

Several experiments were carried out in this nectarine cultivar, to test the effectiveness of GA₃ on the reduction of flowering, and hence on yield and fruit size, and to establish the optimum level of thinning to produce high quality fruit.

2. Materials and methods

The experiments were carried out in a commercial orchard of the ALM Group located in Sástago (Spain), along the Ebro Valley. The trees of the nectarine cv. 'Crimson Gold' grafted on peach seedling rootstock, were nine-years-old at the start of the experiments, and were shaped as central leaders. The orchard was subjected to the usual cultural practices of the area, including hand thinning, drip fertigation, and summer pruning.

Experiment 1 was a preliminary trial designed to evaluate the effects of a wide range of concentrations of GA₃ (Berelex, Zeneca) on crop yield and fruit quality. The trees were treated on 18 July 1997 with 0 (control), 50 100, 200 and 400 mg L⁻¹ GA₃. The treatments were applied in randomized blocks with 4 replications, using a tree as experimental unit. At the start of the experiment, on 8 July, the trees had an averaged trunk-cross-sectional area (TCSA) of 100.2 ± 13.9 cm². A small sprayer was used to apply the GA₃ treatments and the trees were sprayed to dripping point, using an average of 3.9 ± 0.5 L of solution per tree. Regression analysis of data against GA₃ concentration was made.

Experiment 2 was designed following the results of the preliminary trial, to test different concentrations of GA₃: i.e. 50, 100, 200 and 300 mg L⁻¹ sprayed on 21 July 1998, and these were compared to untreated controls and to untreated trees which were hand

1 thinned on 14 April 1999. The trees were sprayed with the same machine as in the previous
2 experiment, and an average of 2.1 ± 0.5 L of solution were used, a smaller quantity than in
3 the previous experiment as summer pruning had already been done. Fruits were hand-
4 thinned to the level of crop-load commercially applied in the farm, and on the date of
5 thinning they measured an average diameter of 11.4 ± 0.9 mm. The trees at the start of the
6 experiment, on 19 July 1998, had a mean TCSA of 108.7 ± 11.6 cm². The experiment was
7 designed as randomized blocks with 4 replications, being a tree the experimental unit. Data
8 were analyzed by ANOVA, and when results were significant, means were compared with
9 Duncan's multiple range test. When appropriate, regression analysis was made against
10 crop-load level, GA₃ concentration, or other parameters.

11 Experiment 3 was designed to study the competing relationships among fruits, to
12 determine the crop load level needed to obtain high quality fruit. Trees, of an average
13 trunk-cross-sectional area of 132.0 ± 19.2 cm², were hand-thinned to three levels of
14 cropping: heavy thinning, medium thinning and left unthinned, to produce a full crop.
15 Hand thinning was applied on 14 April 1999. The experiment was designed as randomized
16 blocks with 5 replications, and a tree was the experimental unit. Regression analysis of
17 data was made against the number of fruits produced by the tree.

18 In experiment 2, 10 long shoots and 10 fruiting spurs were tagged at bloom, and the
19 number of flower buds and length recorded to evaluate flower density. Fruitlet counts were
20 made in these same shoots in different dates along the growing season (7 April, 3 May, 20
21 May, and 8 June, corresponding to 29, 51, 72 and 95 days after full bloom) to determine
22 fruit set evolution.

23 All fruits were harvested on one occasion in each experiment. In experiment 1,
24 yield was collected on 2 July 1998, in experiment 2, on the 18 June, 1999, and in the third
25 trial, on 15 June, 1999. Data on total yield and number of fruits were recorded, and the

mean fruit weight calculated from them. In experiments 2 and 3, random samples of 10 fruits from three blocks of treatments were collected to carry out tests of the pH of the juice, soluble solids with a hand refractometer, and flesh firmness with an Effeggi penetrometer on two opposite sides of the fruit. Also, the length and diameter of fruits were measured, and the L/D ratio worked out from them.

Evaluation of vegetative growth was made in experiments 2 and 3, by measuring trunk girths at about 20 cm above the union, both at the start and at the end of the experiment, from which the trunk-cross-sectional areas (TCSA) were calculated. In experiment 2, trunk girths were also measured in the winter 1998-99. Besides, 10 shoots were cut at the end of October, after leaf fall, to measure their length. In experiment 2, the length of 10 long shoots, and 10 fruiting spurs were also recorded in the spring of 1999 at bloom time.

3. Results

Experiment 1.- The weather during the winter 1997-1998 was most unusual in the area, with heavy fog and very low temperatures in February, and warm weather and some frosts in March, which resulted in a very irregular flowering, with the bloom period extended along a very long time, which made very difficult the evaluation of bloom density. However, at harvest (Figure 1), the recording of the yield and the number of fruits grown per tree showed a significant decrease as the concentration of GA₃ applied increased following a quadratic pattern ($R^2 = 0.520$; $P \leq 0.01$; and $R^2 = 0.497$; $P \leq 0.01$ respectively). On the contrary, the mean weight of fruits increased following a quadratic pattern ($R^2 = 0.480$; $P \leq 0.01$) with the concentration of gibberellin applied in the previous year, with a maximum value around 250 mg/L GA₃.

(Insert Figure 1)

Experiment 2.- A second experiment was designed in 1998-1999 to confirm the results obtained, and to have a close look at the fruit development process.

At bloom, in the spring of 1999, the trees that were sprayed with GA₃ flowered later, and the flowers were more elongated than those left untreated. Besides, a decrease in bloom density was recorded in the trees treated with GA₃, this effect increasing with the concentration. Regression analysis of the number of flowers per unit of shoot length against the concentration of GA₃ applied showed a linear decrease both in long shoots ($r = -0.895$; $P \leq 0.01$) and in fruiting spurs ($r = -0.488$; $P \leq 0.05$) (Figure 2).

(Insert Figure 2)

Fruit set, evaluated in different dates along the growing season, showed a similar pattern for all treatments in long shoots (Figure 3) except for the hand thinned trees which showed lower values from the date of thinning onwards. In fruiting spurs, the pattern was similar (data not shown).

(Insert Figure 3)

At harvest, yield in trees decreased linearly with the concentration of GA₃ applied being those of trees treated with 200 and 300 mg L⁻¹ similar to those hand-thinned ($r = -0.673$; $P \leq 0.01$). The number of fruits collected per tree followed a similar pattern ($r = -0.678$; $P \leq 0.001$), while the mean fruit weight increased ($r = 0.696$; $P \leq 0.001$) (Figure 4).

(Insert Figure 4)

No significant differences on fruit quality were observed among treatments, as evaluated in terms of fruit shape (L/D ratio), flesh firmness, and pH of the juice (Table 1). However, the soluble solids content of the fruits increased linearly with the concentration of GA₃ applied to the trees ($r = 0.622$; $P \leq 0.05$). The soluble solids content of the fruits was also negatively correlated with the number of fruits grown per tree ($r = -0.712$; $P \leq$

0.01), and positively correlated with the mean weight of fruits ($r = 0.922$; $P \leq 0.001$) (Figure 5).

(Insert Table 1 & Figure 5)

During 1998, from the date of treatment application (end of July) until winter, vegetative growth, measured by the relative increase in TCSA, increased linearly with increasing concentrations of GA₃ ($r = 0.959$; $P \leq 0.001$) (Figure 6). On the contrary, shoot extension growth was not affected by the gibberellin treatments (Table 2). During 1999, tree growth as measured by the TCSA increment or by shoot extension growth, was similar for all the treatments applied.

(Insert Figure 6 and Table 2)

Experiment 3.- The three thinning levels resulted, at harvest, in different yields, and number of the fruits produced by the trees (Table 3), although, the final crop was greater in the trees subjected to the heavy thinning level than in those medium thinned. This was due to a greater increase in the weight of fruits in the heavy-thinned trees than in those moderately thinned.

(Insert Table 3)

Regression analysis of data against the number of fruits per tree showed a linear increase in yield ($r = 0.947$; $P \leq 0.001$) with increasing crop loads, and a curvilinear pattern of decrease in mean fruit weight as the number of fruits produced per tree increased ($r = -0.937$; $P \leq 0.001$) (Figure 7). The measurement of the length and diameter of fruits showed no variations in the ratio between them (data not shown).

(Insert Figure 7)

The analysis of different parameters to evaluate fruit maturity showed that the soluble solids content of fruits decreased linearly with increasing crop-loads ($r = -0.751$; $P \leq 0.05$). The soluble solids content was also correlated with the mean fruit weight ($r =$

0.921; $P \leq 0.001$) (Figure 8). Fruit firmness was also correlated with the number of fruits yielded by the trees ($r = 0.721$; $P \leq 0.05$) (Figure 9). On the contrary, no significant correlation's were found among the juice pH and the number of fruits harvested or the mean fruit weight.

(Insert Figures 8 & 9)

The level of thinning did not affect vegetative growth, as the length of shoots did not vary, and the relative increase in TCSA was similar for all the three treatments (data not shown).

4. Discussion

The application of GA₃ to the trees during the summer (experiments 1 and 2) resulted in the reduction of cropping in two consecutive years in the nectarine cultivar Crimson Gold. This has also been found in peach and other *Prunus* species by different workers (Clanet *et al.*, 1979, Southwick *et al.*, 1995; 1997). Taylor and Geisler-Taylor (1998) found that GA₃ sprays to 'Redhaven' and 'Cresthaven' peaches was far more effective when applied in May or June than later in the summer. In the experiment here reported, sprays were applied after fruit harvest, avoiding this effect and the possibility of GA₃ residues in the fruit, and were effective enough as to avoid any extra hand thinning.

In Crimson Gold, the reduction in the number of flower buds developing per shoot was related to the concentration of GA₃, following a linear trend. This pattern has occurred at the same level both in long shoot and in fruiting spurs, as the regression lines had the same slope.

Fruit set in the GA₃ sprayed trees was slightly greater than that in the controls, as found by Edgerton (1966). At harvest, the yield and the number of fruits produced per tree followed the same pattern as that found for flower density. The opposite trend was

1 observed for the size of fruits. The yield, number of fruits produced, and mean size of
2 fruits from trees treated with 300 mg L⁻¹ were similar to those from the hand thinned trees.
3 However, comparing these with data from experiment 3, it can be observed that the
4 thinning levels in the experiment 2 were heavier, for which the application with 200 mg L⁻¹
5 of GA₃ could be considered as the best to apply to obtain a crop of good quality fruit.

6 Changes in flower development occurred in trees treated with GA₃: flowers were
7 more elongated than those in the untreated trees, and a delay in bloom date was observed
8 as reviewed by Anderson and Seeley (1993). These effects were more evident with the
9 increase in the concentration of GA₃ applied. However, no differences appeared at harvest
10 in fruit shape, or any other fruit quality parameters. In fact, fruit ripening appeared to be far
11 more related to fruit growth, as both the soluble solids content and the flesh firmness were
12 correlated with the size of the fruit. This was confirmed in the experiment 3, where fruits
13 had greater concentration of soluble solids and lesser firmness as their size increased, as a
14 result of the reduction of crop-load by hand-thinning.

15 Generally, an increase in vegetative growth was found following reductions in
16 crop-load in peach and other fruit species (Chalmers and van den Ende, 1975; Blanco *et*
17 *al.*, 1995). DeJong *et al.* (1987) explained this in terms of fruit–shoot competing
18 relationships, these changing as a result of the differences in the dates of maximum growth
19 rate of the fruits. Crimson Gold is a very early cultivar, the fruit being harvested in mid-
20 June, just about the time when the maximum shoot growth rate usually occurs, and
21 consequently, the competition established among vegetative and fruiting organs should be
22 very weak, and so no effect can be recorded.

23 The application of GA₃ to the trees late in July does not affect shoot growth, as
24 their growing period has ended by then. Nevertheless, an effect on total vegetative growth
25 of the canopy was found, as shown by the increase in TCSA. However, in the following

1 year no effects have been recorded, similar to the result obtained when crop-load was
2 altered by hand thinning.

3 The cropping relationships in the nectarine ‘Crimson Gold’, as found in experiment
4 1, followed a pattern similar to other cultivars of peach (Rowe and Johnson, 1992; Blanco
5 *et al.*, 1995). In this experiment, the heaviest level of fruit thinning was lighter than in the
6 experiment reported by these authors, for which the best fitted trend for the yield was
7 linear rather than quadratic. The mean fruit weight followed a curvilinear trend with
8 changes in the number of fruits grown as reported by these workers. From this equation,
9 the optimum crop-loads to produce good quality fruit may be established.

10 The results of these experiments show that GA₃ applied in July to ‘Crimson Gold’
11 nectarine trees can effectively reduce flower density and consequently crop-load to
12 produce high quality fruit without any extra hand thinning. Nevertheless, some authors
13 (Costa, personal communication) claim that in many peach cultivars, the reduction in
14 flower density does not result in greater fruit size at harvest. As they have observed, the
15 distribution of flowers along the fruiting shoots is uneven, and consequently, the fruits
16 yielded do not attain a good commercial size. On the other hand, Royo *et al.* (in
17 preparation) have studied the importance of fruit distribution along the shoots in different
18 peach and nectarine cultivars, and have found that certain cultivars are very sensitive,
19 needing a uniform distribution, while others produce good quality fruit with an uneven
20 distribution of fruits. Consequently, these last cultivars can be thinned by gibberellin
21 application in the previous summer. Crimson Gold appears to be a cultivar that does not
22 need an even distribution of fruits and so, the application of GA₃ may well be a substitute
23 for fruit thinning.

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Table 1

Length diameter ratio (L/D), flesh firmness, soluble solids content and pH of the juice of fruits harvested in 1999 from 'Crimson Gold' nectarine trees, sprayed with different concentrations of GA₃ in the summer of 1998, and compared with untreated and unthinned trees and with untreated and hand thinned trees in the spring of 1999.

Treatments	L/D ratio	Flesh firmness (N)	pH
Unthinned control	1.04	57.5	3.7
50 mg L ⁻¹ GA ₃	1.00	55.3	3.6
100 mg L ⁻¹ GA ₃	1.01	58.4	3.5
200 mg L ⁻¹ GA ₃	1.02	55.1	3.6
400 mg L ⁻¹ GA ₃	1.04	52.6	3.6
Hand thinning	1.02	43.2	3.6
SED ^a	0.027	7.83	0.10

^a) SED: standard error of the difference between two means.

1 Table 2

2 Shoot length (cm) of ‘Crimson Gold’ trees treated in the summer of 1998 with different
3 concentrations of GA₃, measured in the winter of 1998 and of 1999.

Treatment	Year	
	1998	1999
Control	63.3	66.0
50 mg/l	61.1	68.9
100 mg/l	55.7	71.5
200 mg/l	63.4	72.4
300 mg/l	60.1	70.6
Hand thinning	--	72.1
SED ^a	5.19	5.78

4

^a SED: standard error of the difference between two means.

1 Table 3

2 Effect of three hand-thinning levels of fruits from ‘Crimson Gold’ nectarine trees on the

3 yield (kg/tree) and the number of fruits harvested per tree^a.

	Level of fruit thinning		
	No thinning	Medium	Heavy
Yield	32.8 ± 4.2	26.2 ± 2.0	27.6 ± 1.4
No. fruits/tree	476.0 ± 97.5	294.8 ± 46.4	282.4 ± 36.0

4

5 ^a Mean ± standard deviation.

6

Fig. 1. Yield, and number of fruits harvested in 1998, and mean fruit weight of 'Crimson Gold' trees treated in the previous summer with different concentrations of GA₃.

Regression equations are:

a: $y = 0.0004 x^2 - 0.2124 x + 35.998$

b: $y = 0.0055 x^2 - 3.0885 x + 468.019$

c: $y = -0.0006 x^2 + 0.2979 x + 78.479$

1

2 Fig. 2.- Effect of different concentrations of GA₃ applied in the previous summer, on the
 3 flower density of long (—●—) and short (—■—) shoots of 'Crimson Gold' nectarine
 4 trees. Each point represents the mean of 4 values. Regressions are:

5 Long shoots: $y = 0.334 - 0.00076 (\pm 0.00009) x$

6 Fruiting spurs: $y = 0.959 - 0.00082 (\pm 0.00035) x$

1
2 Fig. 3.- Fruit set variation along the growing season in long shoots of nectarine trees
3 treated in the previous summer with different concentrations of GA₃. ('Crimson Gold').
4 Each point represents the mean of 4 values. □ Control; ○ 50 mg/l GA₃; Δ 100 mg/l GA₃;
5 ▽ 200 mg/l GA₃; ◇ 300 mg/l GA₃; ■ Hand-thinning.

Fig. 4.- Yield, number of fruits, and mean fruit weight in 1999, of 'Crimson Gold' nectarine trees treated in the previous summer with different concentrations of GA₃, or hand thinned in the spring. Each point represents the mean of 4 values, and bar correspond to hand thinning (H – T) data $\pm$ standard error. Regressions are:

a: $y = 34.11 - 0.067 (\pm 0.018) x$

b: $y = 427.8 - 1.02 (\pm 0.20) x$

c: $y = 78.67 + 0.105 (\pm 0.033) x$

Fig. 5.- Variation of soluble solids content in fruits from 'Crimson Gold' nectarine trees treated with different concentrations of GA₃ in the previous summer according to the GA₃ applied, the number of fruits per tree and the mean fruit weight. Each point of the graph represents the mean of 4 values. Regressions are:

a: $y = 8.05 + 0.005 (\pm 0.0006) x$

b: $y = 9.78 - 0.004 (\pm 0.0011) x$

c: $y = 4.65 + 0.040 (\pm 0.0047) x$

1

2 Fig. 6.- Effects of GA₃ application at the end of July on the relative increase in TCSA of
 3 'Crimson Gold' nectarine trees since then until the winter. Each point represents the mean
 4 of 4 values. Regression is:

5 $y = 3.37 + 0.011 (\pm 0.002) x$

1

2 Fig. 7.- Variation of yield (kg/tree) and mean fruit weight (g) in 'Crimson Gold' nectarine
3 trees carrying different cropping levels. Regressions are:

4 a: $y = 16.951 + 0.033 (\pm 0.003) x$

5 b: $y = 366.76 - 48.23 (\pm 4.99) \ln x$

1
2 Fig. 8.- Soluble solids content (%) variation according to the number of fruits grown per
3 tree (a) or according to the mean fruit weight (b). 'Crimson Gold'. Regressions are:
4 a: $y = 10.24 - 0.004 (\pm 0.0012) x$
5 b: $y = 6.40 + 0.03 (\pm 0.005) x$

Fig. 9.- Flesh firmness (N) variation of fruits from Crimson Gold trees hand thinned to different crop-loads. Regression equation is: $y = 41.1 + 0.066 (\pm 0.0242) x$