Removal of the Most Developed Flowers Influences Fruit Set, Quality, and Yield of Apple Clusters

Carlos Miranda,1 Luis G. Santesteban, and José B. Royo
Departamento de Producción Agraria, Sección de Fruticultura y Viticultura, Universidad Pública de Navarra, Campus de Arrosadia, 31006 Pamplona, Spain

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Abstract. The apical or king (K) flower in the apple (Malus ×domestica L. Borkh.) cluster usually develops and blooms first and also has a greater sink potential. For this reason, resources are primarily used by the K fruit, and this is also one of the reasons why most thinning practices tend to favor K fruit set. However, it is not always possible to retain the K flower and remove the lateral ones. This study was undertaken to determine if the removal of the most developed flowers in the cluster influences yield or quality compared to that obtained in a whole cluster. The treatments were made in ‘Golden Delicious’ and ‘Royal Gala’ apple cultivars, within a wide range of flower densities for each cultivar. The factor tested was the intensity of flower removal (FRI); the treatments consisted in removing one, two, or three flowers in each cluster. Flower density was used as a covariate in an analysis of covariance to account for differences in flower densities in response to FRI treatments. In all experiments the covariate was not significant; therefore FRI effect was not affected by flower density. ‘Golden Delicious’ and ‘Royal Gala’ had similar responses to flower removal, so that when at least three flowers in a cluster remained, fruit set and cluster yield were similar to whole clusters. Only when two or fewer poorly developed flowers remained after FRI treatments, yield was reduced by as much as 25%. Fruit from FRI clusters were even heavier than those from whole clusters, due to reduced competition among the fruit, so that the growth potential of fruit from the first and second lateral flowers was similar to clusters with K fruit, in clusters where the K flower had been removed.

The apical or king (K) flower in the apple (Malus × domestica L. Borkh.) cluster usually develops and blooms first, followed by the lateral (L) flowers, which bloom in sequence (Dennis, 1986). The K flower has a greater number of cells and better vascular development (Westwood et al., 1967), as well as a greater sink potential, so resources are primarily used by the K fruit, which reduces the set and size of the nearest L fruit (Black et al., 2000; Ferree et al., 2000; Goffinet et al., 1996; Koike and Ono, 1998). K flower dominance, however, is not the same for all cultivars. In ‘Delicious’, ‘Jonagold’ and ‘Golden’ the K flower produces noticeably larger fruit than do the L flowers, whereas in ‘McIntosh’, ‘Empire’ and ‘Gala’ the difference is much less pronounced (Dennis, 1986, 2003; Ferree et al., 2000). As apple production and international trade have increased and customers have become more particular, prices for small and medium-sized fruit have remained constant or declined (Dennis, 2000). Normally, too many flowers per tree set fruit, so a reduction in the number of fruit per tree by thinning is necessary and, both for good return bloom and fruit development, the earlier the thinning takes place, the more beneficial its effect is. Most blossom thinning practices tend to take advantage of the greater potential in the size of the K flowers, and favor K fruit set to L fruit set when possible. This is one of the reasons why the application of caustic blossom thinners is recommended at the stage when, in most clusters, only the K flower is open and pollenized, or at most, only one L flower is open but not fertilized, i.e., at full bloom (Fallahi and Willemesen, 2002). At this stage, the other L flowers are at the ‘popcorn’ stage, or slightly (but not completely) open and hopefully not fertilized, so that these caustic thinners damage anthers, stigmata, styles, or pollen tubes (Bound and Jones, 1997; Byers and Lyons, 1985; Fallahi and Willemesen, 2002), preventing their fertilization. The flowers already fertilized are unaffected and continue their development. However, it is not always possible to retain the K flower and remove the L ones. Caustic thinner effects rely on the random fact that a particular flower was hit by any droplet. Mechanical thinning machines, such as those proposed for thinning the ‘fruit wall’ training system (Masseon, 2002), often damage or cut only the biggest and most developed flowers, i.e., the K and first L flowers. And finally, spring frosts of moderate intensity will only kill the most developed flowers in the cluster, because flower development is associated with a progressive increase in the vulnerability to low temperatures (Baldini, 1992; Westwood, 1993). Few studies have included the removal of the K flower in their treatments when comparing set or growth ability of the different flower positions within the cluster. When ‘Empire’ apple clusters were hand-thinned leaving a single fruit of known position within the cluster, there were no statistical differences among flower positions in fruit weight, fruit size or seed count at harvest (Goffinet et al., 1996). Ferree et al. (2001) found similar results for other commercially important cultivars as ‘Jonagold’, ‘Braeburn’, ‘Fuji’, ‘Royal Gala’, ‘Golden Delicious’ and ‘Red Chief Delicious’, and concluded that early thinning allows the most mature L flowers to achieve an equal size to that of the K flowers. In the same study, Ferree et al. (2001) also hand-thinned clusters to pairs of K+L and L+L, and found that the advantage of K flower in attracting assimilates to enable the set, was not always evident when intra-spar competition existed. The authors are unaware of any studies which compare the set or yield of whole apple clusters with the obtained for thinned clusters in which only the K flower has been removed, or in which more than two L flowers are left alone in the cluster.

The current study was undertaken to determine whether the removal of the most developed flowers in the cluster at ‘first bloom’ influences the yield or quality of the apple fruit. The treatments were performed under a wide range of flower densities. The cultivars ‘Golden Delicious’ and ‘Royal Gala’, which are widely grown in Spain (Iglesias et al., 2000; Prognosfruit, 1999) were evaluated in this study.

Materials and methods

Treatments. The research was conducted in 1999 and 2000 using four commercial orchards in full production, one per cultivar and year, located in Alfaro (Lat. 42.11° N, Long. 1.45° W, altitude 300 m), in the mid-Ebro river valley. The cultivars studied were ‘Golden Delicious’ and ‘Royal Gala’, both grafted on M9 and planted in 1992. All the orchards had 4 rows of ‘Golden Delicious’ per row of ‘Royal Gala’. In both years the weather was favorable for pollination, and yields were the usual for the tree sizes and bud loads.

At first bloom stage, 60 trees (1999) or 45 trees (2000) were selected and their sizes (i.e., TCA) and flower densities (FD, number of flower clusters per square centimeter TCA) were recorded (Table 1). Fifty flower clusters with five flowers on 2- to 3-year-old wood situated in one uniform limb per tree were tagged. The following flower removal (FRI) treatments were applied to tagged clusters in 15 trees each: 1) K flower removed (Kr); 2) K and first L flowers removed (K1Lr, performed only in 1999); 3) K, first and second L flowers removed (K2Lr); and 4) no hand thinning (NT, control treatment). As a result, the number of flowers remaining after treatments was 4 for Kr, 3 for K1Lr, and 2 for K2Lr. The L flowers removed were always those closest to reaching anthesis. About 25 d after full bloom (DAFB), when K fruit diameter was 10 to 12 mm, chemical thinning with NAA at 12.5 mg·L–1 was performed in the entire orchard, using a commercial airblast sprayer. No further thinning (manual or chemical) was performed. The experiment had a completely randomized design, with four thinning intensities in 1999 and three in 2000. As the purpose of this study was to evaluate the influence of FRI under a
wide range of flower densities, the latter varied greatly within each treatment, so it was included in the design as a covariate.

**Data collection.** About 25 DAFB, just before chemical thinning was performed, the fruit cluster number and the number of fruit per cluster were counted on tagged clusters for each treatment and control. This procedure was repeated at harvest and the maximum equatorial diameter of each fruit was also measured. Harvest maturity was determined by the starch-iodine test on 50 randomly chosen fruit in the orchard, taken from trees adjacent to those used for the trial. Harvest took place when the average starch conversion stage reached the type 6 in the 1 to 10 CTIFL starch conversion scale (Vaysse, 2002). For each tree, 5 to 10 fruit were randomly taken, and fruit weight, seed number, maximum equatorial diameter, and height were measured. From the data collected, cluster set (%) at 25 DAFB and at harvest, number of fruit per cluster at 25 DAFB and at harvest, fruit shape (as diameter/height ratio), fruit weight (g), cluster weight (g) and yield per cluster at full bloom (YCB, g) were calculated. YCB stands for the ratio between the sum of the yields obtained in the tagged clusters with fruit at harvest, and the 50 clusters tagged at full bloom.

**Statistical analyses.** The data were analyzed with SPSS’s GLM procedure. The effect of flower density was evaluated with an analysis of covariance. The approach for determining the form of the covariate part of the model was the one suggested by Field (2000) and Litell et al. (1996), where flower density was included in the model as the covariate. First, the hypothesis that all slopes are equal was tested by including in the model terms for the main effect (FRI) and the interaction of the main effect with the covariate (flower density). When the interaction term with the covariate was not significant at the 5% level, an equal slopes model was evaluated by including in the model the covariate and the main effect. When the covariate was significant, the least square means, adjusted for the covariate, was estimated and compared with the probability of the difference adjusted with the Bonferroni correction. When the covariate was not significant, an analysis of variance was performed and the least squares means were compared with Tukey’s test. Percentage values were arc-sin transformed before statistical analysis. The data for each tree was averaged before being subjected to the analysis. To determine fruit weight a regression analysis was performed for each FRI treatment between the diameter and the weight of the sampled fruit by fitting curvilinear estimation models with the Curvilinear Regression Procedure of SPSS.

**Results**

The FRI treatments did not significantly affect seed number or fruit shape in any of the cultivars and years tested (data not shown).

**Golden Delicious** 1999. The interaction between FRI and flower density was nonsignificant for any of the studied variables, so a common slopes model was evaluated with an analysis of covariance (Table 2). The covariate (flower density) was significant in all cases except for the number of fruit per cluster at 25 DAFB, seed number and fruit shape. At 25 DAFB (just prior to NAA application), cluster set for Kr and K1Lr treatments was similar to that for control, whereas K2Lr had about 14% less cluster set. However, cluster set at harvest was similar for all treatments and control. All treatments had at 25 DAFB less fruit than control, ranging from 0.5 less for K1Lr to 1.2 less for K2Lr. At harvest, Kr clusters bore a similar number of fruit to control, whereas both K1Lr and K2Lr treatments bore about 0.25 less fruit than control. FRI treatments did not significantly affect fruit weight. Cluster yield was similar for K1Lr and K2Lr treatments, and 36 g lower than for the other treatments. YCB was significantly lower than control only for K2Lr treatment.

**Royal Gala** 2000. As with Royal Gala (1999), the interaction between FRI and flower density was nonsignificant for any of the studied variables, so the common slopes model was evaluated with analysis of covariance (Table 3). The covariate was significant only for the number of fruit/cluster at 25 DAFB, and for fruit weight. At chemical thinning time, cluster set for K1Lr treatment was significantly similar to that for control, whereas K2Lr had about 9% less cluster set. However, cluster set at harvest was similar for all treatments and control. All variables, so the common slopes model was evaluated with analysis of covariance (Table 3). The covariate was significant only for the number of fruit/cluster at 25 DAFB, and for fruit weight. At chemical thinning time, cluster set for K1Lr treatment was significantly similar to that for control, whereas K2Lr had about 9% less cluster set. However, cluster set at harvest was similar for all treatments and control. All

| Cultivar      | Year | PD | TT   | Tree size (cm² TCA) | No. flower buds/cm² TCA |
|---------------|------|----|------|---------------------|-------------------------|
|               |      |    |      | Mean (±SD) Min Max  | Mean (±SD) Min Max        |
| Golden Delicious | 1999 | 9  | NT   | 125 ± 18 94 165    | 3.8 ± 2.1 1.2 9.8        |
|               |      |    | Kr   | 126 ± 17 92 163    | 3.5 ± 2.3 1.2 13.0       |
|               |      |    | K1Lr | 126 ± 19 91 160    | 3.5 ± 2.3 1.2 13.0       |
|               |      |    | K2Lr | 126 ± 16 93 162    | 3.5 ± 2.3 1.2 13.0       |
|               | 2000 | 9  | NT   | 126 ± 7 110 139    | 6.6 ± 1.6 2.8 10.2       |
|               |      |    | K1Lr | 125 ± 6 110 135    | 6.2 ± 2.2 2.6 10.3       |
|               |      |    | K2Lr | 133 ± 7 117 142    | 6.2 ± 1.8 3.3 10.1       |
| Royal Gala    | 1999 | 6  | NT   | 66 ± 8 48 82       | 5.0 ± 2.5 1.4 12.2       |
|               |      |    | Kr   | 63 ± 7 47 77       | 4.8 ± 2.0 1.4 9.6        |
|               |      |    | K1Lr | 63 ± 9 45 82       | 4.8 ± 1.9 1.4 9.4        |
|               |      |    | K2Lr | 63 ± 7 48 78       | 4.7 ± 2.0 1.4 9.7        |
|               | 2000 | 6  | NT   | 40 ± 7 32 53       | 9.6 ± 5.4 5.1 27.6       |
|               |      |    | K1Lr | 36 ± 6 37 47       | 9.9 ± 6.1 5.2 24.2       |
|               |      |    | K2Lr | 37 ± 6 35 49       | 9.9 ± 6.5 5.1 29.2       |

1PD = tree spacing (m²/tree).
2TT = thinning treatments in which, respectively, none (control, NT), the king flower (Kr), K and the first lateral flower (K1Lr), or king flower and both the first and second laterals (K2Lr) were cut at full bloom stage.
3TCA = trunk cross-sectional area (cm²).

Table 1. Mean (±SD), maximum (max) and minimum (min) values for the main agronomical characteristics of the ‘Golden Delicious’ and ‘Royal Gala’ apple orchards under study.

At 25 DAFB (just before NAA application), cluster set for K1Lr treatment was similar to that for control, whereas K2Lr had about 12% less cluster set. However, cluster set at harvest was similar for all treatments and control. Clusters with flowers removed bore at 25 DAFB about 1.2 less fruit than control, for both FRI intensities, whereas at harvest they bore only 0.17 to 0.23 less fruit. Fruit weight for treatments was higher than for control. Cluster yield for K2Lr treatment was significantly lower than control, whereas YCB did not differ significantly from control for both treatments.
Discussion

Results from different cultivars and years differed slightly, but overall responses were fairly consistent. In all experiments the covariate, flower density, was generally significant in cluster set, fruit per cluster number, fruit size and yield. These results imply greater competition for resources between developing fruit as the flower density increases, right from the first stages of development, as commonly known and widely reported in previous research (Dennis, 1986; Knight, 1980; Miranda and Royo, 2004; Stover, 2000).

Table 4 summarizes the results from the previous Tables to provide a brief overview of them. The Table depicts the maximum effects (positives, negatives, or nonsignificant) that were obtained with the removal of the most developed flowers in the cluster (as many as three in some cases).

![Table 4](image)

*YCB = yield per flower cluster at full bloom; ratio of total yield in tagged clusters and number of tagged clusters at full bloom.

1DAFB = days after full bloom.  
2Thinning treatments in which, respectively, none (control, NT), the king flower (Kr), K and the first lateral flower (K1Lr), or king flower and both the first and second lateral flowers (K2Lr) were cut at full bloom stage.  
3Least adjusted means adjusted for the covariate within columns followed by the same letter do not differ at 5% level, by Tukey’s test with Bonferroni correction.

Table 3. The effect of thinning the most developed flowers in the cluster on set, fruit characteristics and yield for ‘Royal Gala’ apple. When the covariate, flower density (FD) was significant, values in the same column are least squared means adjusted for the covariate. When the covariate was not significant, values in the same column are least squared means.

![Table 3](image)

*YCB = yield per flower cluster at full bloom; ratio of total yield in tagged clusters and number of tagged clusters at full bloom.

1DAFB = days after full bloom.  
2Thinning treatments in which, respectively, none (control, NT), the king flower (Kr), K and the first lateral flower (K1Lr), or king flower and both the first and second lateral flowers (K2Lr) were cut at full bloom stage.  
3Least adjusted means adjusted for the covariate within columns followed by the same letter do not differ at 5% level, by Tukey’s test with Bonferroni correction.

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Table 4. Summary of maximum responses to removal of flowers from apple flower clusters.

| Observation          | Golden Delicious | Royal Gala |
|----------------------|------------------|------------|
|                      | 1999             | 2000       | 1999       | 2000       |
| Cluster set          |                  |            |            |            |
| 25 DAFB              | –                | –          | –          | –          |
| Harvest              | NS               | NS         | NS         | NS         |
| Fruit/cluster (no.)  |                  |            |            |            |
| 25 DAFB              | –                | –          | –          | –          |
| Harvest              | NS               | NS         | NS         | NS         |
| Seed/fruit           |                  |            |            |            |
| L/D ratio            | NS               | NS         | NS         | NS         |
| Fruit weight (g)     | NS               | +          | +          | +          |
| Yield/cluster        |                  |            |            |            |
| Bearing clusters     | –                | –          | –          | –          |
| All clusters (YCB)   | –                | (NS)       | –          | –          |

*NS* Nonsignificant, (−−) negative effect, (−→) highly negative effect, (++) positive effect.

Naphthalene acetic acid, when applied at 8 to 14 mm K fruit diameter, compels weaker fruit to abscise, though its mode of action is not completely understood (Dennis, 2002; Wertheim, 2000; Williams and Fallahi, 1999). When clusters bear a high number of fruit, and especially when K fruit is present, intra-spur competition is stronger, so that many of them will be at a disadvantage. Therefore, the NAA thinning effect is greater on trees with stronger competition and higher fruit number per cluster (Black et al., 2000). In our research, more fruit clusters remained at 25 DAFB on the trees from control and K1Lr treatment, and these clusters also had more fruit. Greater NAA thinning effect on these trees with stronger competition will explain why differences in cluster set and fruit number per cluster found at 25 DAFB (just before NAA application) have been reduced, or have even disappeared, at harvest. This means that, although natural behavior at 25 DAFB in thinned clusters from Kr and K1Lr had been poorer than in control clusters, final agronomical behavior was quite similar. NAA thinning effect for control and Kr or K1Lr treatments has not been strong enough to match K2Lr treatment. In conclusion, clusters in which three or four L flowers remain have similar agronomical ability to set than whole clusters, and this ability is only diminished when one or two poorly developed flowers (the most distal in the cluster) remain.

Seed number at harvest and fruit shape in this study were not affected by FRI treatments. This result indicates that clusters bearing only L flowers have a similar ability to be pollinated and form viable seeds than clusters with K flower. Ferree et al. (2001) found similar results for some cultivars, including ‘Royal Gala’. This result reinforces the argument that agronomical behavior for partially deflowered clusters is similar to that of whole clusters.

Fruit weight was similar for all ‘Golden Delicious’ treatments in 1999, whereas in 2000 fruit from FRI treatments was heavier than control. Similar results were found for ‘Royal Gala’. Fruit weight depends on crop load, fruit number per cluster and seed content. Competition among fruit can be due to fruit number on the same spur (intra-spur competition), or to the number of fruit clusters (inter-spur competition); seed content also enhances the fruit competitive ability (Black et al., 2000; Dennis, 1986). In fact, Black et al. (2000) found in ‘Redchief Delicious’ that intra-spur competition, particularly at early stages of development, could have greater influence on final fruit size than inter-spar competition in the same branch. FRI treatments in clusters from K1Lr and K2Lr in 2000 reduced intra-spur competition, so that fruit size was increased with respect to control, whereas in 1999 fruit from all treatments and control had similar fruit size. In Kr and K1Lr treatments this could be due to a similar fruit number per cluster and seed content than control trees. However, although clusters from K2Lr had fewer fruit than the rest, no apparent intra-spur benefits were observed. A whole, these results seem to confirm that the growth potential of fruit from first and second L flowers, in clusters with the K flower removed, is similar to clusters with K fruit retained. When only the third and fourth L flowers remain in the cluster, their fruit have a slightly lower growth potential. Previous research with one-flowered thinned clusters showed that flower position had little influence on shape, size or seed content (Ferree et al., 2000, 2001; Goffinet et al., 1996).

Cluster yield was similar for all treatments and control in 2000 as a consequence of similar fruit size and fruit per cluster number. However, in 1999 clusters from K2Lr treatments yielded less than the rest of the treatments, due to less fruit/cluster number. Similar results were obtained for yield per flower cluster at full bloom. Therefore, the reduced cluster set and growth potential of the fruit from the third or from the fourth L flowers in ‘Golden Delicious’ and ‘Royal Gala’ imply cluster yield reductions up to about 25%. These losses will be found especially when the flower density is low. From the trial results, 25% yield reductions will be expected with two to six L flowers ranging from two to six flower clusters/cm TCA, because in 2000, with higher flower densities, losses were about 10% and not significant. This study was undertaken on well developed spurs from 2 to 3-year-old wood. Similar treatments carried out on lower quality spurs, such as older apical spurs or 1-year-old lateral clusters (Robbie and Atkinson, 1994; Volz et al., 1994) probably had had lower fruit set and fruit weight, at least for the KW2Lr treatment, due to the lower growth potential of the third and fourth L flowers found in this study.

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