Feasibility of peach bloom thinning with hand-held mechanical devices

B. Martin-Gorriz[1], A. Torregrosa[2], J. García Brunton[3]

[1]Universidad Politécnica de Cartagena. Dpto Ingeniería Alimentos y Equipamiento Agrícola. Paseo Alfonso XIII, nº 48. 30203 Cartagena (Spain). E-Mail: b.martin@upct.es

[2]Universitat Politècnica de València. Dpto Ingeniería Rural y Agroalimentaria. Valencia (Spain).

[3]Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario. Murcia (Spain).

Abstract:

The use of hand-held mechanical devices to thin blooms of peach trees trained into the "free Italian vase" form was studied. Three devices were tested, and no differences were found among them in terms of thinning time and number of fruits per cm^2 of trunk cross-sectional area (TCSA) at harvesting. Thinning, by hand or mechanically, reduced the yield per tree by 26% to 33% with respect to not thinning; however, thinning increased the fruit size. In both years, the yields of fruit >67 mm in the thinned trees ranged from 40.4 to 53.4 kg $tree^{-1}$, respectively, whereas in the un-thinned trees, it was 25.1 and 18.2 kg $tree^{-1}$ in 2009 and 2010, respectively. Hand thinning took 385 h ha^{-1}, and mechanical thinning reduced this time by 89%. The cost of hand thinning was 4.8 € $tree^{-1}$, whereas the cost of mechanical thinning ranged from 0.4 to 1.1 € $tree^{-1}$. The economic study showed that the total yield value was similar with hand and mechanical thinning, but the cost of mechanical thinning was only 10-18% that of hand thinning.

Keywords: Mechanical thinning; Branch brusher; Peach; Fruit; Harvest; *Prunus Persica;* Hand-held thinners.

1. Introduction

The plentiful blooms of peach trees produce an excessive number of small fruits with low market value. The usual way to reduce the excess of flowers or green fruits is to thin them by hand. In Murcia (Spain), farmers try to leave fruits 8-10 cm apart on the tree, allowing the fruit to get to a marketable size. Thinning is done from bloom until 40-60 days after full bloom (DAFB) (Costa and Vizzotto, 2000). In early cultivars and in those destined for the fresh market, the most appropriate time to thin is at the bloom appearance to obtain the full development of the fruit. Bloom thinning reduces the early competition between fruits and usually increases fruit size. Byers and Lyons (1985), report increases of 20 to 30% in fruit size thinning at bloom in comparison with thinning 40 to 50 DAFB. However, in places with frost risks, thinning is done when the risk is over, and by then, the fruits are usually developed. In any case, thinning must be done before the hardening of the fruit stone.

Some researchers recommend eliminating 50-60% of the flowers by mechanical thinning (Schupp et al., 2008), just as in hand thinning (Myers et al., 2002). The optimum level of crop load, which is usually expressed as the number of fruits per unit of branch length or the number of fruits per trunk cross-sectional area (TCSA), differs for each cultivar and may also change slightly for the same cultivar when grown at different sites (Miranda and Royo, 2003).

The economic profit obtained with thinning is due to the higher price that the bigger fruits usually get, but this higher price must compensate for the total yield reduction of the tree. It is necessary to reach the optimum point between size increase and yield reduction that achieves the maximum net value of the crop (Myers et al., 2002). That optimum point depends on cultural practices as well as biological, environmental, and economical factors, particularly the cultivar, time of thinning, fruit size at the time of thinning, tree nutrition, economic value of different sized fruit and cost of labour. Scott and Rasmussem (1990) developed a mathematical model to optimize the thinning intensity in peaches using easily measurable parameters. Mathematical models are useful tools for optimizing thinning, but the parameters must be obtained for any particular agricultural situation.

In Murcia (Spain), the three most labour-consuming tasks in peach cultivation are pruning, thinning and harvesting, which represent 22%, 32% and 45% of the total time, respectively (Garcia, 2007; Torregrosa et al., 2008). At present, thinning is done by hand. The time required to thin a tree depends on its size, the amount of fruit to be thinned and, above all, the final use of the peaches (fresh market or industry). The time required for hand thinning ranges from 302 h ha^{-1} to 444 h ha^{-1} for peach and nectarine trees (Garcia, 2007).

The commercial mechanical tractor-driven thinning equipment already existing requires hedge-trained trees (Baugher et al., 2010; Schupp et al., 2008), but in Murcia, the most common training system is the “free Italian vase”, where that equipment cannot work appropriately. Thus, hand-held devices were chosen because they can be used in any training system (Martin et al., 2010).

Mechanical thinning devices usually reduce the thinning time but are not able to keep a high uniformity of distances between fruits (Martin et al., 2010; Rosa et al., 2008; Schupp et al., 2008). However, some researchers have demonstrated that it is possible to obtain peaches of marketable sizes without a uniform separation between fruits. According to Marini and Sowers (1994), if peaches are thinned non-uniformly throughout the canopy, the lack of thinning individual shoots will be partially compensated by the adequate thinning of most of the tree. Miranda and Royo (2002) concluded that fruit distribution on the shoot had little or no influence over either final diameter or yield.

As hand thinning is an intensive task that must be done within a short period of time by trained workers at a high economic cost, the objective of this study was to determine if hand-held mechanical devices used at bloom are an alternative to traditional hand thinning in “free Italian vase” peach trees. The parameters for analysis were thinning time, crop load, fruit size and economic value of marketable fruit for the fresh market.

2. Materials and Methods

2.1 Treatments

The research was conducted in 2009 and 2010 on a peach (*Prunus persica* L. Batsch, cv *Carson*) orchard located in Caravaca (Murcia, Spain). The trees were 8 years old and planted in a frame with 5 m between rows and 3 m spacing within rows. The trees measured 3 m in diameter and were 3.5 m tall. The average trunk height was 0.60 m, and the average trunk diameter was 0.14 m. The main branches were 1.7–2.1 m long and formed 140–160º angles with the trunk. The secondary branches were 0.8–1.3 m long and formed 80–120º angles with the trunk. The trees were trained to a “free Italian vase” shape and were hand-pruned.

The following treatments were used:

1. Hand thinning: the treatment control. The thinning was done by workers who eliminated green fruits from all the branches on the tree (with or without ladders), leaving one fruit approximately every 10 cm, which is adequate to thin peaches for the fresh market.

2. Device A: electric hand-held fruit remover (Volpi, Davide e Luigi Volpi S.p.A. Casalromano, Italy). This device was 2.5 m long and weighed 2 kg. It had a head with six rotating fingers (Fig. 1) and was powered by a 12 V electric motor that operated at two fixed speeds, 714 and 833 rev min^{-1}. After preliminary tests, 714 rev min^{-1} was determined to be the most suitable speed for thinning. Electricity was supplied by a 12 V, 75 Ah car battery, which remained on the ground, and a 15-m long electric extension cord.

3. Device B: electric hand-held fruit thinner prototype (Spanish patent, ES20091448). This thinner had a rotating cylinder with 10 flexible cords, placed at the top of a pole 2 m in length (Fig. 2). A 12 V DC motor, 0.12 kW, moved the cylinder. Although the speed was variable, it was set to 250 rev min^{-1}. Electricity was supplied by a 12 V, 75 Ah car battery, which remained on the ground, and a 15 m long electric extension cord.

4. Device C: electric hand-held flower thinner (Electrocoup. Infaco S.A. Cahuzac sur Vere, France). This device was 2.0 m long and weighed 2 kg. It had a rotary head with a four-finger comb that operated at 770 rev min^{-1} (Fig. 3). Powered by a 48 V electric motor, it was equipped with a portable battery bag, which facilitated worker mobility in the field.

5. Un-thinned: this treatment was used as a reference to determine the number and size of fruits produced by un-thinned trees and also to measure the thinning intensity.

The experiment was designed as a randomised block, divided into 5 plots; each plot had 3 trees (replicates) in 2009 and 6 trees in 2010.

2.2. Data collection

In 2009, the flowers were thinned on March 21, 6 DAFB with devices A, B and C. The green fruits were thinned by hand (control) on May 7, 62 DAFB. In 2010, the flowers were thinned on March 26 (6 DAFB), and the green fruits were thinned on May 11 (53

DAFB). The hand thinning was done, both years, on the same dates as the whole commercial orchard.

Each year, the fruit was harvested on three dates. In 2009, it was harvested at 130, 136 and 140 DAFB (July 14th, 20th and 24th); in 2010, it was harvested at 125, 130 and 134 DAFB (July 21st, 26th and 30th). Only firm, ripe fruits (based on the ground colour) were harvested on the first two dates, and all the remaining fruits were harvested on the last date.

On the first thinning day of 2009 and 2010, the trunk diameter of each tree was measured at 30 cm above the ground to calculate the TCSA. In 2010, the thinning intensity was determined by measuring on each tree the length of two scaffolds and the distance between flowers before and after each thinning treatment.

On each harvest date, several parameters were analysed: (i) the fruit harvested from each tree was weighed using an electronic balance with a resolution of 50 g to determine the yield per tree (kg tree^{-1}) and yield efficiency (kg cm^{-2} TCSA), (ii) the number of fruits per tree (no. fruit tree^{-1}) was counted, and the fruit load (no. fruit cm^{-2} TCSA) was calculated, (iii) the fruit mass (g fruit^{-1}) was obtained indirectly by dividing the yield per tree by the number of fruits, (iv) the fruit size category (% no. fruit tree^{-1} and kg tree^{-1}) was obtained from a sample of 150 fruits per tree. It was measured using electronic calliper with 0.1 mm resolution. The collected fruits were divided into four categories based on their diameters: first category, fruits over 67 mm; second category, fruits 61-67 mm; third category, fruits 56-61 mm; and fourth category, fruits under 56 mm.

Thinning operations were recorded with a camcorder, and the time required to thin each tree was measured to calculate the thinning costs.

To evaluate quality parameters, on each harvest date, a sample of 100 fruits was taken. Several parameters were analysed: (i) the pulp firmness was measured by means of a Magness-Taylor style penetrometer probe (Fruit Pressure Tester, FT-327, Facchini SRL, Alfonsine, Italy) equipped with an 8-mm-diameter probe (section 50 mm^2), (ii) the total content of soluble solids in the fruits was determined from juice samples using a hand refractometer (Atago Pocket Pal-1, Atago Co. Ltd., Tokyo, Japan), (iii) the level of acidity was obtained by neutralising 1.5 mL of the squeezed, spin-dried and filtered juice with 0.1 N NaOH, using a digital pH meter (Crison pH Burette 24, Crison Instruments S.A., Barcelona, Spain). The results were expressed in terms of the dominant acid as grams of malic acid per litre (g malic acid L^{-1}).

The data were analysed using a one-way analysis of variance, and the mean difference between treatments was separated by the least significant difference (Tukey HSD test) test at $P < 0.05$. The Statgraphics Plus 5.1 software was used to run the analysis.

The economic profit of the thinning treatments was calculated considering the yield (kg $tree^{-1}$) of fruits with diameters > 56 mm because this is the minimum size to be considered in the category “extra” according to CEE directive 3596/90, Ministerio de Agricultura, Pesca y Alimentación, (1995). The three categories based on their diameters were: over 67 mm, 61-67 mm, and 56-61 mm. The price of the peaches (€ kg^{-1}) by categories (Table 1) was obtained from the wholesale weekly prices received by producers in the field (personal communication). The thinning cost (€ $tree^{-1}$) was subtracted from the production value (€ $tree^{-1}$) to obtain the net margin.

The economic costs for the mechanical devices were calculated following ASAE D497.5 (2006) and ASAE EP496.3 (2006). The following parameters were used: a machine life of 5 years or 1200 h, an annual usage of 240 h, an interest rate of 7%, a salvage value of 12% of the purchase price, storage at 0.75% of the purchase price and cumulative repair and maintenance costs at 82% of the purchase price. The hand-labour cost was 8.22 € h^{-1}, including taxes. All prices were standard for the year 2010.

Three economic scenarios were analysed: (i) fruits of all three categories have commercial value, (ii) only fruits of the 1st to 2nd categories have commercial value and (iii) only the fruits of the largest size category have commercial value.

3. Results

3.1. Effect of thinning on distance between flowers or green fruits

Scaffold length was similar in all treatments. The mean distance between flowers prior to thinning was 2.3 cm (treatment 5, Table 2). Hand thinning produced the highest separation between fruits, 10.1 cm. The mean distance between flowers thinned by the three mechanical devices (treatments 2, 3 and 4) did not differ significantly between them, ranging from 5.2 to 6.9 cm.

3.2. Thinning time and thinning efficiency

The mechanical devices reduced the thinning time by 92% in 2009 and 86% in 2010 compared to hand thinning (Table 3). Within each year, there were no significant differences between mechanical treatments; in 2009, the thinning time was 2.4-3.0 min tree^{-1}, and in 2010 it was 4.1-5.8 min tree^{-1}. In 2010 thinning with the three devices used more time than in 2009. The tree size was similar, but the operators were different, and the use of these devices is strongly dependent on the operator skill.

In 2010, the thinning time was higher than in 2009 and, consequently, the fruit load was lower (2.7 fruit cm^{-2} TCSA in 2010 and 4.8 fruits cm^{-2} TCSA in 2009). This correlation was not obtained in the hand-thinning treatment, which gave a similar fruit load in both years (3.8 fruits cm^{-2} TCSA in 2009 and 3.1 fruits cm^{-2} TCSA in 2010).

On average for both years, mechanical thinning reduced by 48% the number of fruits cm^{-2} TCSA, while hand thinning diminished it by 53%. In 2010, there were no significant differences between the four thinning techniques. In 2009, thinning with devices A and C resulted in a higher fruit load (5.6-4.9 fruit cm^{-2} TCSA).

3.3. Optimizing crop load

The more fruits per tree, the lower the average weight per fruit (Myers et al., 2002). Our experiments provided similar results; the highest fruit load (7.5-7.3 fruits cm^{-2} TCSA) and the lowest fruit size (98-108 g fruit^{-1}) were obtained from unthinned trees (Table 3).

A regression analysis between the average weight of the fruits (g fruit^{-1}) and the fruit load (no. fruit cm^{-2} TCSA) was performed on the data from the years 2009 and 2010, yielding a high correlation (Fig. 4). The best adjusting model was of the type:

$$\mathbf{y = 1/(a + b*x^2)} \qquad (1)$$

Where, **y** is the mean fruit size (g fruit^{-1}), and **x** is the fruit load (no. fruit cm^{-2} TCSA).

Also, there was a high correlation between yield efficiency (kg cm^{-2} TCSA) and fruit load (no. fruit cm^{-2} TCSA) in 2009 and 2010 (Fig. 5). The best adjusting model was of the type:

$$\mathbf{y = exp(a + b/x)} \qquad (2)$$

Where **y** is the mean fruit size (kg cm^{-2} TCSA) and **x** is the fruit load (no. fruit cm^{-2} TCSA).

3.4. Fruit per tree, yield and fruit size category

In 2009, unthinned trees produced 1115 peaches per tree. Treatments 1 and 3 had lower fruit densities of 534 and 512 fruits per tree, respectively (Table 4). In treatments 2 and 4, significantly more fruits were harvested: 656 and 609, respectively. However, these differences in fruit load were not significantly reflected in the yield by tree (kg $tree^{-1}$), with the only exception that unthinned trees that yielded more than all the other treatments. The percentage of fruits in the top size category (>76 mm) was similar for all the treatments (46% on average), with the exception of unthinned treatment (15%). The combined weight of the fruits in this category was also higher in the thinned trees (on average, 48.3 kg $tree^{-1}$) than in the unthinned (25.1 kg $tree^{-1}$).

In 2009, the thinned trees had 52% as many fruits as the un-thinned trees. In 2010, this percentage decreased to 41%; therefore, the thinning intensity was higher in 2010 than in 2009. In 2010, there were no significant differences among treatments 1 through 4 in either the number of fruits per tree or the yield.

In summary, in both years, the results obtained in treatments 1 through 4 (mechanical devices and control) were similar in terms of the fruit load (597 fruit $tree^{-1}$) and yield (77 kg $tree^{-1}$) as well as the percentage of fruits in the top two categories (81% of fruits >61 mm in diameter). The unthinned trees produced more fruits (1069 fruit $tree^{-1}$) and a greater yield (109 kg $tree^{-1}$) but a lower percentage of bigger fruits (only 50% of fruits >61 mm in diameter). In terms of the yield of the superior categories of fruits (>61 mm), the differences were less notable: 68.35 kg $tree^{-1}$ on average for treatments 1 to 4 versus 67.1 kg $tree^{-1}$ for treatment 5.

3.5. Physical-chemical properties of fruits

The fruit quality was evaluated at each harvest date. The average firmness was similar in both years, 36.08 N and 36.09 N, in 2009 and 2010 respectively. There were no significant differences in firmness between harvesting data in each year. The acidity increased with harvest date both years, but the differences were not significant, 5.57 g malic acid L-1 in 2009 and 5.51 g malic acid L-1 in 2010). The soluble solids content was 9.65º Brix in 2009 and 10.96º Brix in 2010. In both years, soluble solids content was always higher on the first harvest date, although the differences were significant only in 2009.

The acid increase and the sugars decrease in the former harvesting dates can be explained by the selective manual harvesting. In the first dates, workers take only the biggest and more colored fruits, meanwhile in the last, they take all the remnant fruits of the tree, with independence of its maturity stage.

3.6. Economic value by marketable fruits, cost of thinning and net value of peach fruits

Hand thinning was the technique with the lowest hourly cost (8.22 € h^{-1}) (Table 5). Mechanical techniques had a higher hourly cost due mainly to the purchase price of the device. Thinning with mechanical devices took 9.93 € h^{-1}, 9.41 € h^{-1} and 11.5 € h^{-1} for devices A, B and C, respectively. Despite these higher hourly costs, the great time savings of 91-93% in 2009 and 83-88% in 2010 with the mechanical devices (Table 3) lowered the total thinning cost with mechanical devices to 90% and 82% of the cost of thinning by hand in 2009 and 2010, respectively (Table 6). The thinning costs were 4.8 € $tree^{-1}$ for hand thinning compared to 0.7 € $tree^{-1}$ on average for the mechanical treatments.

There were no significant differences among the treatments in the economic value of the peach crops in both years (Table 6). Although by categories, treatments 1 through 4 fetched more money (€ $tree^{-1}$) in the two superior fruit size categories, and treatment 5 (not thinned) obtained a higher value in the inferior size category (56-60 mm).

The net value (€ $tree^{-1}$) was similar for all the treatments (Table 6), but, sometimes, as in the years with an excess of fruit on the markets, farmers have difficulty selling the inferior categories of fruits. To analyze this possibility, three hypothesis were studied:

(i) the three categories are all accepted by the market, (ii) only the two top categories are accepted and (iii) only the fruits of the first category can be sold (Fig. 6). In the first case (i), all the treatments, including not thinning, yield a similar net value. However, in scenarios (ii) and (iii), not thinning had the lowest net value, and there were no clear differences between the other treatments.

4. Discussion

4.1. Hand thinning vs. not thinning

Hand thinning reduced the number of fruits 50% and yield 29 % on average for both years. In the other hand, fruit size increased 56% and also the proportion of top size fruits. As farmers in Spain, usually do not produce peaches exclusively for processing, if not that they try to sell part or the total production for the fresh market, they thin all the trees as for fresh. But this practice, can lead to an over-thinning and so, to a minor profitability.

The total net value (€ $tree^{-1}$) depends on the yield and price of fruits within the different size categories. Usually, farmers receive higher prices for the higher categories, and these higher prices compensate for the total yield reduction. In 2009 and 2010, yields were reduced 25% and 32% by hand thinning compared to not thinning, but there were no significant differences in the total net value (Table 6). Hand thinning had a cost of 4.8 and 4.7 € $tree^{-1}$ (around 10% of the gross value) that can reduce the net value of thinned peaches to below the value of peaches from unthinned trees, but the differences are small (41.39 € $tree^{-1}$ versus 47.81 € $tree^{-1}$ in 2009 and 46.32 $tree^{-1}$ versus 47.73 € $tree^{-1}$ in 2010). On the other hand, hand thinning makes peach marketing easy, even in the more unfavourable scenarios, like when only the higher size categories are marketable. The net economic values for the top category of fruits (>67 mm) was 13 and 7 € $tree^{-1}$ in unthinned trees versus 27 and 24 € $tree^{-1}$ in hand-thinned trees in 2009 and 2010, respectively (Fig. 6).

4.2. Mechanical thinning vs. hand thinning

In 2010, a similar number of fruits were harvested from mechanically thinned trees (332 to 461 fruit $tree^{-1}$) as in hand-thinned trees (440 fruit $tree^{-1}$) (Table 4). However, when the distance between flowers was measured immediately after thinning, the distance was 10.1 cm in hand-thinned trees and 5.2-6.9 cm in mechanically-thinned trees (Table 2). Thus, more fruits would be expected at harvest from the mechanical treatments. A possible explanation for this discordance is that some flowers were damaged by the mechanical thinning operation, and later, after measuring the distances, they fell. In future studies, the distance measurement must be done some weeks after thinning to avoid this problem.

In 2010, there were no significant differences in fruit load, yield efficiency, mean fruit size, fruit per tree, yield per tree and fruit size category between the hand-thinning and mechanical-thinning treatments (Table 3 and Table 4). In 2009, device B (treatment 3) also gave similar results to hand thinning, but the other two devices showed some differences from hand thinning.

In both years, there were no significant differences in the net value of peaches thinned by hand or by machine (Table 6), nevertheless, hand thinning took 389 and 380 h ha^{-1} versus 31-55 h ha^{-1} for mechanical thinning in 2009 and 2010, respectively. Thus, mechanical thinning increased the working capacity of the operators by 8.9 times, and this provides a great advantage for farmers who need to have to their crops thinned in a short period of time (40-50 days) and have difficulties finding enough manpower. Perhaps, this was the main advantage of the mechanical thinning because there were no significant differences between the net value (€ $tree^{-1}$) resulting from the manual and mechanical thinning treatments (Table 6).

4.3. Strategies for optimizing thinning intensity with hand-held thinners

At thinning time, farmers must take a decision about the final use of its peaches, fresh or processing, because it is related with the desired fruit size. On the other hand, the relationship between yield and fruit size with fruit load can be calculated by regression analysis as showed in figures 4 and 5, so that the farmer will have an idea about the optimum fruit load. Obviously, regression coefficients must be obtained for each crop and its particular conditions.

If the farmer decides to do mechanical thinning with portable devices, a system to control thinning intensity with these devices is to measure the time used to thin each tree, since the thinning intensity is highly dependent on the thinning time (Table 3). The regression analysis of the number of fruits per tree and the thinning time (min $tree^{-1}$) for the devices used (treatments 2-4) in 2009 and 2010 shows a high correlation according to the model:

$$\mathbf{y} = 1064.63 - 277.77*\mathrm{sqrt}(\mathbf{x}) \quad (7)$$

Where **y** is the number of fruits tree^{-1} and **x** is the time of thinning (min tree^{-1}), with a R^2 adjusted = 78 %.

This correlation was not obtained for the hand-thinning treatments, so the use of mechanical devices improved the productivity of thinning.

The main advantage of the hand-held tested thinners, compared with the tractor driven ones, is that the can be used in almost all type of tree conduction, it is not necessary to introduce pruning changes, although short scaffolds will facilitate thinning.

After 5 years of thinning with these equipments, no damages have been noticed in the limbs or in the bark of the young branches. No changes have been appreciated in the return bloom after mechanical thinning.

5. Conclusions

Thinning, either by hand or mechanically, reduced the yield per tree by 30%, but increased the yield of fruits in the highest size category (>67 mm). Moreover, 50% of the fruits from thinned trees were within the highest size category versus 13% of fruits from unthinned trees.

No significant differences were found between the three mechanical thinners tested in terms of the thinning time or the number of fruits per cm^2 TCSA.

In both years, the net economic value of the total yield and also the yield per size category was similar for manual and mechanical thinning, but the thinning time was 385 h ha^{-1} with hand thinning versus 42 h ha^{-1} with mechanical thinning.

Mechanical thinning was 86% cheaper than hand thinning. The thinning cost by tree (€ tree^{-1}) accounted for 10% of the gross value of the peaches for hand thinning and 2% for mechanical thinning.

There is a good correlation between the mechanical thinning time (min tree^{-1}) and the thinning intensity (no. fruits tree^{-1}). As the thinning time is easy to measure, it is a parameter that can be used by workers to govern thinning intensity with hand-held thinners.

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