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Hand-held mechanical device improves thinning efficiency of peach trees

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Abstract

The objective of this study was to evaluate the effect of mechanical-manual thinning (MmT) at different developmental stages in the thinning efficiency and productive performance of 'Sensação' peach trees. The experiment was performed during the 2013 and 2014 growing seasons, in a commercial orchard located in Morro Redondo (RS), Brazil. Plant material consisted of 7-year-old peach trees grafted on Capdeboscq rootstock and trained as an open-vase system. The experiment was arranged as a randomized block design, with five three-trees replications. In order to reduce the effect of personal experience, the treatments and measurements were applied by the same person in a set of replications throughout the experiment. Treatments consisted of: control I [without thinning (WT)]; control II [hand thinning (HT) 40 days after full bloom (40 DAFB)]; MmT at full bloom (FB): 50% of open flowers; MmT at the end of bloom (EB): 80-100% of open flowers; MmT at petal fall (PF); and MmT at the green fruit (GF) stage (fruit with ~1 cm of diameter). The MmT was performed using a hand-held portable device. The parameters assessed were: percentage of thinning, fruit set, thinning time, work economy, production per tree, fruit mass, estimated yield and fruit size distribution. The use of the MmT at the stages tested reduces thinning time of 'Sensação' peach trees, resulting in labor saving, as well as increases the percentage of fruit in category (CAT) 1. The MmT when performed at GF results in a higher percentage of thinning. The treatment MmT at FB increases the average fruit mass.

Keywords: *Prunus persica* (L. Batsch), mechanical-manual device, thinning time, labor saving, follow-up thinning, yield.

Introduction

Stone fruit usually shows profuse flowering and fruit set, resulting in excessive fruit load that trees cannot support, producing fruit of low commercial value (Costa et al., 2005). In this sense, the thinning of flowers and fruit is one of the standard practices used by growers aiming to adjust crop load in order to increase fruit size and quality, reduce alternate bearing, and improve selling price (Byers et al., 2003). Thinning in peach trees are generally performed manually and although it is a practice that results in several benefits, is delicate and requires high labor input in a short window of time, increasing production costs (Costa and Vizzotto, 2000).
The cost of thinning in peach trees represents around one third of the total costs with hand labor in a season and could take up to 150 h man^{-1} ha^{-1}, depending on tree vigor, age, size, flowering abundance, and cultivar (Lichou et al., 1997; Taheri et al., 2012). Satisfactory results from thinning are directly related with the precocity this is performed (Miller et al., 2011). According to Byers et al. (2003), thinning during flowering can increase the yield and fruit size from 7 to 30% when compared with HT performed between 40 and 50 DAFB. Due to the high costs and low availability of hand labor currently observed in orchards around the world, several alternative studies have been carried out with mechanical and chemical thinning. The main objective of these studies were to reduce the time required for hand thinning or even replace its need (McArtney et al., 2012). Mechanical thinning is a technique of physical action that immediately causes visible effects, allowing the reproducibility of execution, thus it is less variable and more predictable than chemical thinning. The first mechanical thinning experiments used inertial trunk shakers (Powell et al., 1975), but they often caused uneven or excessive fruit thinning. Mechanical methods for flower and fruit thinning use flexible wires, rubber straps or strings that are moved over and through the trees in a tractor platform known as "Darwin String Thinner". These kinds of equipment usually transfer less energy to the tree than trunk shakers. Martin

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et al. (2010) and Schupp et al. (2008) tested a tractor string equipment for thinning after flowering which reduced up to 91 % and 63% the crop load of the trees, respectively, relative to HT, whereas when a follow-up hand thinning was performed, crop load was reduced up to 81% and 54 %, respectively. However, fruit diameter did not differ among treatments with this method. Tractor platforms for thinning show better results in orchards previously designed for mechanization, where the objective is building a fruiting wall (Baugher et al., 2010; Schupp and Baugher, 2011; Hehnen et al., 2012).

Tractor-driven platforms are usually expansive, reason why they are little used by small growers. An alternative strategy for mechanical thinning is the use of hand-held portable equipment, which uses batteries as energy source, thus allowing more work flexibility. Due to its manual characteristic, they allow thinning regardless training system and are more accessible to small growers. These equipment are currently being widely used, mainly in Europe. Martin et al. (2010) in Murcia, Spain, evaluated different hand-held thinning equipment. They observed that, in general, all devices tested reduced the time necessary for thinning from 46 to 90% and the harvest load 38%, while fruit size increased 47% in comparison to trees not thinned. In the same study, no differences among treatments were found for production per tree. Glozer and Hasey (2006) reported that the use of a hand-held thinning equipment reduced time needed for thinning from 30 to 41%.

Considering the reduced availability and high costs of hand labor, the lack of peach orchards designed for mechanization, and the scarcity of information about mechanical thinning in Brazil, studies about this subject are of major importance as means to improve the development peach industry. The objective of this study was, therefore, to evaluate the effect of mechanical-manual thinning at different developmental stages in the thinning efficiency and productive performance of 'Sensação' peach trees.

Results

Percentage of thinning, thinning time, time for follow-up hand thinning, and labor saving

The greatest percentage of thinning was found with MmT at GF, differing of the other treatments in both growing seasons (2013 and 2014). In the growing season of 2013, all treatments showed differences relative to HT, while in 2014 only the MmT at GF showed significant differences compared to HT (Table 1). In the growing season of 2013, the MmT at GF needed more thinning time relative to the other MmT treatments. On the other hand, in 2014 no differences were found among MmT treatments. However, all of them significantly reduced the time necessary for thinning relative to HT. The time necessary for follow-up HT (s tree^{-1}) did not differ among MmT treatments in both growing seasons (Table 1). Considering the total thinning time per tree, the MmT at EB required the lowest time, not differing of MmT at PF and FB (Table 1). Relative to HT, the total thinning time per tree was lower in all MmT treatments. In the growing season of 2014, the results were similar to the previous season, except that the total thinning time per tree did not differ among MmT treatments (Table 1). The parameter labor saving (%), did not differ among MmT treatments in both growing seasons. However, all MmT treatments significantly reduced the labor needed for thinning relative to HT (Table 1).

Fruit set and number of fruit removed on follow-up hand thinning

In the growing season of 2013, the lowest fruit set was observed in the MmT at GF, while in 2014 no differences were observed between the MmT treatments. When each MmT treatment was compared to control I (WT), all of them showed lower fruit set in both growing seasons (Table 2). Regarding the number of fruit removed in the follow-up HT, significant differences were not observed between the MmT treatments in 2013. On the other hand, in 2014, the MmT at PF and GF resulted in the lowest number of fruit removed, differing only of MmT at FB (Table 2).

Number of fruit per tree, fruit mass, production per tree, and estimated yield

In 2013, the MmT at GF showed the lowest final number of fruit per tree, differing of the other MmT treatments, while in 2014 it differed only of MmT at FB (Table 2). The lowest average fruit mass (g), considering the MmT treatments, was observed with MmT at GF in both growing seasons, but in 2014 it differed only of MmT at FB. Compared to control I (WT) fruit from all MmT treatments showed greater mass, in both seasons. Regarding the comparison with control II, in 2013 all treatments, but MmT at GF, showed greater fruit mass, while in 2014 this result was observed only with MmT at FB (Table 2). Regarding the production per tree, the comparison among the MmT showed similar behavior of average fruit mass in 2013, where the MmT at GF showed the lowest value. In 2014, the MmT at FB was responsible for the greater production per tree (Table 2). In comparison to control I (WT), only the MmT at GF was different in 2013, showing lower production per tree and in 2014, besides this treatment, the MmT at PF also showed lower production per tree than control I (WT). Considering the comparison of MmT with control II (HT) in 2013, significant differences were not found. However, in 2014, the MmT at FB and PF obtained greater production per tree compared to control II (HT) (Table 2). Production per tree of trees treated with these MmT was increased 15.75 kg and 6.76 kg, respectively, relative to control II (HT). The estimated yield (ton ha^{-1}), showed similar behavior as production per tree.

Fruit size distribution according to categories

The parameter percentage of fruit according the fruit size category (CAT) showed significant interaction with treatment (Table 3). Considering the treatments in each CAT in 2013, it was observed that control I (WT) showed the greater percentage of fruit in CAT 4 while in the CAT 3 no differences were found among treatments. On the other hand, all treatments showed greater fruit in CAT 1 and 2 than control I (WT). Considering the factor category within the treatment control I (WT), the greatest percentage of fruit was found in CAT 4, while the opposite was observed for the other treatments, i.e., the greater percentage of fruit were classified as CAT 1 (Table 3). Regarding the growing season of 2014, considering the levels of treatment in the CAT 4, the greatest percentage of fruit was observed in control I (WT), while in CAT 3 and 2 significant differences were not found.

Table 1. Thinning, thinning time, time of follow-up hand thinning, total thinning time, and labor saving of 'Sensação' peach trees submitted to mechanical-manual fruit thinning (MmT) at different developmental stages and control II (hand thinning; HT), in the growing seasons of 2013 and 2014.

Treatments	Thinning (%)	Thinning time (s tree^{-1})	Time of follow-up hand thinning (s tree^{-1})	Total thinning time (s tree^{-1})	Labor saving (%)
			2013		
Control II (HT)	50.19	913.80	---	913.80	---
MmT (FB)	57.21 b$^{1\alpha}$	278.00 b$^{\alpha}$	206.00^{ns}	484.00 ab$^{\alpha}$	47.04^{ns}
MmT(EB)	55.66 b$^{\alpha}$	291.60 b$^{\alpha}$	182.00	473.60 b$^{\alpha}$	48.18
MmT (PF)	56.34 b$^{\alpha}$	283.60 b$^{\alpha}$	202.00	485.60 ab$^{\alpha}$	46.87
MmT (GF)	61.06 a$^{\alpha}$	338.00 a$^{\alpha}$	200.00	538.00 a$^{\alpha}$	41.15
			2014		
Control II (HT)	56.32	1017.00	---	1017.00	---
MmT (FB)	55.71 b	334.00 $^{\alpha}$	240.20^{ns}	574.20 $^{\alpha}$	49.55^{ns}
MmT(EB)	56.11 b	353.40 $^{\alpha}$	257.00	610.40 $^{\alpha}$	39.99
MmT (PF)	55.99 b	352.80 $^{\alpha}$	236.80	589.60 $^{\alpha}$	41.43
MmT (GF)	60.85 a$^{\alpha}$	357.20 $^{\alpha}$	205.40	562.60 $^{\alpha}$	44.69

[1]Means followed by the same lower-case letters in the column are not different according to Waller-Duncan's test ($p \le 0.05$), within MmT treatments. $^{\alpha}$significant differences between each MmT treatment and control II (HT) by Dunnett's test (p≤0,05). ns: not significant; FB: full-bloom; EB: end of bloom; PF: petal fall; GF: green fruit.

Table 2. Fruit set, number of fruit thinned, final number of fruit per tree, average fruit mass, production and, estimated yield of 'Sensação' peach trees submitted to mechanical-manual fruit thinning (MmT) at different developmental stages, besides de control I (without thinning; WT) and control II (hand thinning; HT), in the growing seasons of 2013 and 2014.

Treatments	Fruit set (%)	N^{o} fruit thinned (n^{o} tree^{-1})	Final fruit number (n^{o} tree^{-1})	Average fruit mass (g)	Production (kg tree^{-1})	Estimated yield (ton ha^{-1})
			2013			
Control I (WT)	46.82	---	525.6	68.30	35.90	47.85
Control II (HT)	---	543.6	237.8	131.60	31.29	41.71
MmT (FB)	23.22 a^{1}*	150.8 a$^{\alpha}$	261.0 a*	149.63 a*$^{\alpha}$	39.05 a	52.05 a
MmT(EB)	23.41 a*	119.0 a$^{\alpha}$	247.4 a*	147.20 a*$^{\alpha}$	36.41 a	48.53 a
MmT (PF)	21.88 a*	150.0 a$^{\alpha}$	266.0 a*	143.09 a*$^{\alpha}$	38.06 a	50.73 a
MmT (GF)	18.67 b*	173.4 a$^{\alpha}$	170.0 b*$^{\alpha}$	133.32 b*	22.66 b*	30.20 b*
			2014			
Control I (WT)	52.06	---	574.5	75.64	43.45	57.65
Control II (HT)	---	605.8	265.4	113.80	30.20	40.25
MmT (FB)	23.62 a*	210.0 a$^{\alpha}$	315.0 a*$^{\alpha}$	145.90 a*$^{\alpha}$	45.95 a$^{\alpha}$	61.25 a$^{\alpha}$
MmT(EB)	20.25 a*	163.8 ab$^{\alpha}$	279.4 ab*	132.30 ab*	36.96 b$^{\alpha}$	49.26 b$^{\alpha}$
MmT (PF)	20.38 a*	134.2 b$^{\alpha}$	272.6 ab*	131.40 ab*	35.81 bc*	47.73 bc*
MmT (GF)	23.36 a*	128.4 b$^{\alpha}$	260.4 b*	121.80 b*	31.71 c*	42.27 c*

[1]Means followed by the same lower-case letters in the column are not different according to Waller-Duncan's test ($p \le 0.05$), within MmT treatments. *significant differences between each MmT treatment and control I (WT) by Dunnett's test (p≤0,05) $^{\alpha}$significant differences between each MmT treatment and control II (HT) by Dunnett's test (p≤0,05). ns: not significant; FB: full bloom; EB: end of bloom; PF: petal fall; GF: green fruit.

Table 3. Percentage of fruit in the categories I, II, II, and IV of 'Sensação' peach trees submitted to mechanical-manual fruit thinning (MmT) at different developmental stages, besides control I (without thinning; WT) and control II (hand thinning; HT), in the growing seasons of 2013 and 2014.

Treatments	Fruit category (%)			
	IV (45 < 55 mm)	III (55 < 60 mm)	II (60 < 65 mm)	I (> 65 mm)
		2013		
Control I (WT)	69.13 aA*	29.61B	1.26 bC	0.00 bC
Control II (HT)	0.67 b D	9.58 C	29.07 aB	60.68 aA
MmT (FB)	0.42 b D	7.02 C	23.26 aB	69.29 aA
MmT(EB)	0.00 bC	3.89C	18.23 aB	77.87 aA
MmT (PF)	0.00 bC	4.85 C	22.74 aB	72.41 aA
MmT (GF)	0.00 b C	4.97 C	33.34 aB	61.69 aA
		2014		
Control I (WT)	49.55 aA	32.48AB	17.46BC	0.52 cC
Control II (HT)	0.56 b B	18.02 B	16.32 B	65.11 abA
MmT (FB)	0.00 bB	0.00 B	13.00B	87.00 aA
MmT(EB)	1.11b B	3.13 B	13.33B	82.43 aA
MmT (PF)	0.00 bB	12.80 B	24.77 B	62.43 abA
MmT (GF)	0.00 bC	18.95 BC	33.20 AB	47.85 bA

*Means followed by the same lower-case letters in the column and upper-case in the row are not different according to Waller-Duncan's test ($p \le 0.05$). FB: full bloom; EB: end of bloom; PF: petal fall; GF: green fruit.

In CAT 1, the treatments MmT at FB and EB showed greater percentage of fruit than control I (WT) and MmT at GF. Regarding the categories within each treatment level, in control I (WT) the greatest percentage of fruit was observed in CAT 4, which did not differ of CAT 3. For the other treatments the percentage of fruit in CAT 1 was greater than the other categories, except the MmT at GF, where the percentage of fruit in CAT 1 was superior only to CAT 3 and 4 (Table 3).

Discussion

Overall, our results show that the percentage of thinning was increased by MmT treatments relative to standard HT, and more markedly when performed at GF stage. On the contrary, thinning time was reduced by MmT. Similar results were found in studies with 'Cresthaven' (Marini, 2002) and 'Carson' (Martin-Gorriz et al., 2010; Martin-Gorriz et al., 2011) peaches, where the mechanical and mechanical-manual thinning of flowers and fruit resulted in an economy of time of 88% and 54%, respectively, compared to HT. The parameter time necessary for follow-up HT (s $tree^{-1}$) did not differ among MmT treatments in both growing seasons (Table 1).

MmT treatments reduced approximately 50% the labor needed for thinning, similarly as observed by Martin-Gorriz et al. (2012) in a study with the cultivar 'Carson', using a mechanical-manual device specific for fruit thinning. Using this device, they needed from 120 to 198 seconds per tree, while for HT 1500 to 1962 seconds per tree were necessary. The economy of time provided by the mechanical device ranged from 87 to 93%, allowing the thinning of an average of 23 trees h^{-1}. According to the same authors, when performing the follow-up HT after mechanical thinning, an average of 318 to 668 seconds per tree was necessary. Compared to HT a reduction of 46 to 82% was observed. The authors emphasize that the results were positive because the reduction in the costs relative to HT and the possibility of performing the thinning of fruit, timing when freezing events are reduced in the region where the study was performed.

The final outcome of mechanical thinning is removing fruit without reducing yield to non-economic levels, or similar to standard HT. In our study, MmT at GF reduced the yield relative to HT and the other MmT treatments, but in 2014 it was similar to standard HT. Similarly, Martin-Gorriz et al. (2011) in a study with the peach cultivar 'Carson' testing three equipment for MmT of flowers and fruit, reported that they did not affect yield and did not differ among them, as well as in comparison with HT. In our study, the only exception was the control I (without thinning) which resulted in greater yield than the other treatments in 2013, but only to MmT at PF and GF in 2014. This result is likely due the greater crop density, i.e., greater number of fruit (Table 2), as observed by Martin-Gorriz et al. (2012) in 'Carson' peach trees.

By definition, successful thinning reduces crop load and increases fruit size (Martin-Gorriz et al., 2012). Similar results were found in our study were crop load was reduced and fruit size (mass) increased, without negatively affecting production per tree and estimated yield, relative to control I (WT). In fact, when the MmT was performed at FB and EB, despite reducing crop load relative to control I (WT), production per tree and estimated yield were similar to control I (WT) and significantly greater than control II (HT), without negatively affecting fruit size, showing that early thinning increases the potential to achieve high yields with good fruit size. The early thinning (at bloom or soon after pollination) results in larger fruit, indicating that peach fruit growth is source-limited during the early periods of development (Costa and Vizzotto, 2000), which explains the greater fruit mass of fruit from trees of MmT at FB.

Overall, all MmT treatments and HT showed a greater proportion of fruit on CAT 1, which is extremely important because this is one of the main factors determining the final price of the fruit paid by industry and fresh market (Martin et al., 2010).

Materials and Methods

Plant material

The experiment was performed during the growing seasons of 2013 and 2014, in a commercial orchard localized in the municipality of Morro Redondo (RS), Brazil (31°39'55,09''S, 52°34'51,30''W Greenwich and altitude of 245 m). According to the Köppen climatic classification, the region shows a Cfa climate: humid subtropical, average annual precipitation of 1582 mm, annual average temperature of 18.4 °C, annual relative humidity of 78 %, and an average accumulation of 550 chilling hours (bellow 7.2 °C) (Diniz et al., 2003). The soil of the experimental field is a Ultisol.

Plant material consisted of 7-year-old peach trees of cultivar Sensação, grafted onto 'Capdeboscq' rootstock. Trees were trained as an open-vase system, and spaced 5 m between rows and 1.5 within the row, resulting in a planting density of 1333 trees ha^{-1}. Cultural practices during the experiment were similar among treatments and consisted on fertilization based on soil analysis, pest and disease treatments as needed, and weed control.

Experimental design and treatments

The experiment was arranged as a randomized block design, with five replications, each one composed of three trees, where the central one was used for data collection leaving one in each side as border. The trees were selected by uniformity of size and grouped in blocks based on trunk diameter, measured at 20 cm from the ground.

The six treatments tested were: 1) Control I [without thinning (WT)]; 2) Control II [(hand thinning (HT) at 40 days after full bloom (DAFF)]; 3) mechanical-manual thinning (MmT) at full bloom (FB; 50% of flowers at anthesis); 4) MmT at end of bloom (EB; 80-100% of flowers at anthesis; T5) MmT at petal fall (PF) and; 6) MmT of green fruit (GF; with 1 cm of diameter). In all MmT treatments, HT was performed at 40 DAPF to remove remaining unwanted fruit. Since the effect of personal experience may have a great effect on the thinning results, all treatments were applied by two students properly trained. By the time of first treatment (MmT at FB) a group of replications was set for each student: student one worked on replications 1 and 2 and student two on replications 3, 4, and 5. This scheme was kept until throughout the experiment.

The MmT was performed using a hand-held portable device (Carpa Electro total control® - REF 30I31), which consists on a rotary spindle (20 cm long) with flexible rubber rings. This spindle is connected to a 1.8 m long cable that is connected to four portable batteries, enabling amplitude and work mobility. The total device weight is 3.79 kg. Working speed to apply the treatments was 5350 rpm (revolutions per minute).

Measurements

In both growing seasons, thinning treatments were performed in whole trees. In order to determine the percentage of thinning (%) and fruit set (%), the number of flowers (at FB) and fruit was counted in six mixed shoots (25-60 cm long) selected per tree, before and after thinning. The percentage of thinning was calculated using the following formula: [100 - (nº of flowers or fruit after thinning/nº of flowers or fruit before thinning x 100)]. After the natural fruit drop (~40 DAFB), all remaining fruit in the selected shoots were counted to obtain the fruit set (%), according the relationship (nº fruit x 100) / (nº flowers). After that, standard HT was performed in control II (standard HT) and in MmT treatments to remove the excess of fruit in some portions of the tree and adjust the distance between then when necessary (follow-up HT). Standard HT and follow-up HT were performed at 40 DAFB by the two students and scheme previously described, leaving 10 to 15cm between fruit according to shoot vigor. Full bloom occurred in 28 July 2013 and 25 July 2014. The time spent to perform each treatment was recorded with a digital chronometer and expressed as seconds (s) per tree^{-1}

From the time for MmT and time for follow-up HT, the total working time (s tree^{-1}) was calculated. The economy of work (%), was determined from the reduction of time necessary for thinning provided by the MmT + follow-up HT relative to standard HT. The final fruit number per tree (nº tree^{-1}) was determined by counting the number of fruit in each experimental unit before harvest.

Fruit were harvested in 13 November 2013 (109 DAFB) and 10 November 2014 (108 DAFB). For each experimental unit (tree), 50 fruit were randomly sampled. These fruit were then weighed with a digital scale to determine average fruit mass (g), by the relationship fruit mass/fruit number (sample). From this parameter the production per tree (kg tree^{-1}) was calculated, by multiplying the average fruit mass and fruit number per tree. The estimated yield (ton ha^{-1}) was obtained by the relationship between production per tree and number of trees per ha (1333). Fruit size distribution was determined using classification rings according to commercial standards and then classified in the following categories (CAT): CAT IV) 45 < 55 mm, CAT III) 55 < 60 mm, CAT II) 60 < 65 mm, CAT I) > 65 mm, and expressed as the percentage of fruit (%) in each CAT.

Statistical analysis

The statistical analysis were performed using the R software (R Core Team, 2017). The data were analyzed separately for each season (2013 and 2014) regarding the normality by Shapiro-Wilk's test, the homogeneity of variances by Hartley's test and, the independence of residues by graphical analysis. Data expressed as percentage or counts were transformed by arcsin [square root (n + 1)] and square root (n + 1), respectively. Then, the data were submitted to analysis of variance (ANOVA) by F test ($p \leq 0{,}05$), and when significant differences were found, the effects of MmT were compared by Waller-Duncan's test ($p \leq 0{,}05$), and the comparison with the control I and II (WT and standard HT, respectively) performed by Dunnett's test ($p \leq 0{,}05$).

Conclusions

Our results show that the use of a mechanical-manual device at different developmental stages improves thinning efficiency of 'Sensação' peach trees, reducing approximately 50% of labor needed compared to standard hand-thinning. Fruit set is reduced and the percentage of thinning is increased by the mechanical-manual thinning at different developmental stages, without negatively affecting production per tree and estimated yield. The greatest percentage of thinning is obtained when the mechanical-manual treatment is performed at the green fruit stage. Fruit mass is not reduced by any of the MmT compared to hand thinning, while is consistently increased when MmT is performed at full bloom. The percentage of fruit classified as category I is increased when MmT is performed between full bloom and petal fall, as well as traditional hand-thinning.

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