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Mechanical mandarin thinning related to fruitlet developing stage

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Abstract: Mandarin thinning is done by hand, increasing labor cost and raising total crop production costs. Mechanical thinning has been tested in peaches and other fruits. To achieve the maximum efficiency thinning requires to be applied at a specific stage of vegetative development. In this research study the mechanical thinning of mandarin branches during the different fruit developing stages has been assessed using a vibratory laboratory device (amplitudes 0.015 m and 0.030 mm and frequencies 34.8 Hz and 37.8 Hz). Branches with flower buds, flowers, small green fruits and medium green fruits were tested during 12 weeks and two different seasons. It was possible to detach mechanically flower buds, flowers and green fruits using different combinations of amplitudes and frequencies. Removal percentage decreased when increasing retention traction force, according to a logarithmic regression model. During fruit setting (weeks 5, 6 and 7) removal percentage was higher, when the retention force is very low. The first weeks just after the natural thinning could be consider the adequate time for a mechanical thinning operation.

Keywords: mandarin thinning, fruitlet, developing stage

1. Introduction

Fruit thinning is the removal of certain flowers or fruitlets in order to improve fruit yield and quality and return bloom for the following year [1]. There are three methods for thinning: hand, mechanical and chemical. Hand thinning is not often applied as a commercial cultural practice in citriculture due to the high cost [2].

Different studies confirmed the effect of chemical thinning agents (synthetic auxins) on mandarin thinning ([3], [4]). However, many chemicals are being released by the chemical companies [1] and other thinning method could be assessed.

Mechanical thinning has been tested in peaches using inertial trunk shakers and electromagnetic shakers ([5], [6]). Besides, in stone fruits and pome fruits, flower and fruit thinning has been studied using drum shakers ([7], [8], [9]). The studies proved that mechanical thinning save time and reduce thinning cost.

In order to design a useful mechanical branch shaker thinning device for citrus fruits, defining the adequate vibration frequency and amplitude is necessary. However, during field shaking tests many non-controlled factors are affecting the results.

[10] designed a laboratory electromagnetic shaker to determine adequate frequency and amplitude when detaching cherry coffee. A metallic device was fitted to the shaker to hold the coffee branches during the vibration tests.

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[11] used a laboratory unidirectional vibratory device to vibrate mandarin branches in order to assess the adequate frequency, amplitude and time for mechanical harvest reducing the experimental field non-controlled factors.

[12] assessed frequency response of late-season 'Valencia' orange to selective harvesting by vibration using a laboratory unidirectional magnetic shaker. The excitation signal used was a random noise with frequencies from 0 to 60 Hz, and a total duration of 60 s. A set of 5 piezoelectric triaxial accelerometers was used to determine acceleration characteristics.

To achieve the maximum efficiency of the crop management practices they require to be applied at a specific stage of vegetative development [13]. In the citrus thinning operation this factor is crucial.

The objective of the present study was to assess citrus mechanical thinning according to fruit developing stage using a laboratory device.

2. Materials and methods

The branches were selected and collected from an orchard of 'Clemenrubi' mandarin located in Sagunto (Valencia, Spain, Google maps coordinates: 39.645122, -0.303941). During 2017 season every week, during 12 consecutive weeks, between 8 and 20 branches were selected and tested. Branches with flower buds, flowers, small green fruits and medium green fruits, from phenological stage number 56 to phenological stage number 72 were tested, based on the BBCH scale [14], Table 1.

Table 1. Frequency, amplitude and phonological stage according to the week of the test.

		2017						2018			
Date	**Week**	**Frequency (Hz)**	**Amplitude (mm)**	**Phenological stage**	**Nº**	**Date**	**Week**	**Frequency (Hz)**	**Amplitude (mm)**	**Phenological stage**	**Nº**
10-mar	0	7/10,5/13/13,7/34,8	15/30/120	56 Flower bud	9						
23-mar	1	11,2/13,4/34,1/35,2/41	15/30	56 Flower bud	9						
30-mar	2	23,2/34,8/37,8	15/30	59 Hollow flower bud	9						
06-abr	3	23,2/34,8	15/30	65 Flower	8						
12-abr	4	34,8	15/30	67 Withered flower	8						
19-abr	5	34,8/37,8	15/30	71 Fruit setting	11						
26-abr	6	34,8/37,8	15/30	72 Green fruit	14						
04-may	7	34,8/37,8	15/30	72 Green fruit	16						
10-may	8	34,8/37,8	15/30	72 Green fruit	20						
17-may	9	34,8/37,8	15/30	72 Green fruit	16						
24-may	10	34,8/37,8	15/30	72 Green fruit	16	23-may	1	18,9/37,8	30	72 Green fruit	12
31-may	11	34,8/37,8	15/30	72 Green fruit	16	30-may	2	18,9/37,8	30	72 Green fruit	14
						06-jun	3	18,9/37,8	30	72 Green fruit	14
						13-jun	4	18,9/37,8	30	72 Green fruit	12
						21-jun	5	18,9/37,8	30	72 Green fruit	12
						27-jun	6	18,9/37,8	30	72 Green fruit	12
						04-jul	7	18,9/37,8	30	72 Green fruit	14
						11-jul	8	18,9/37,8	30	72 Green fruit	14

During 2018 season every week, during 8 consecutive weeks, between 12 and 14 branches were selected and tested. In this second season small green fruits, medium green fruits and high size green fruits (phonological stage number 72) were tested, stating the test later than the previous season (week 1 from 2018 season was related to week 10 from 2017 season.

A modified laboratory unidirectional vibratory device was used to vibrate the mandarin branches based on the one developed by [11]. A connecting rod converts the rotational motion from an electric motor (0.75 kW, ABB-M1001, www.news.abb.com) into linear motion to vibrate the branch, Figure 1. A frequency converter is used to vary the vibration frequency from 4.5 Hz to 40 Hz. The vibration amplitude is modified from 0.015 m to 0.18 m by placing the connecting rod into the different disc holes (A). The branch is located in a vertical downward position (B).

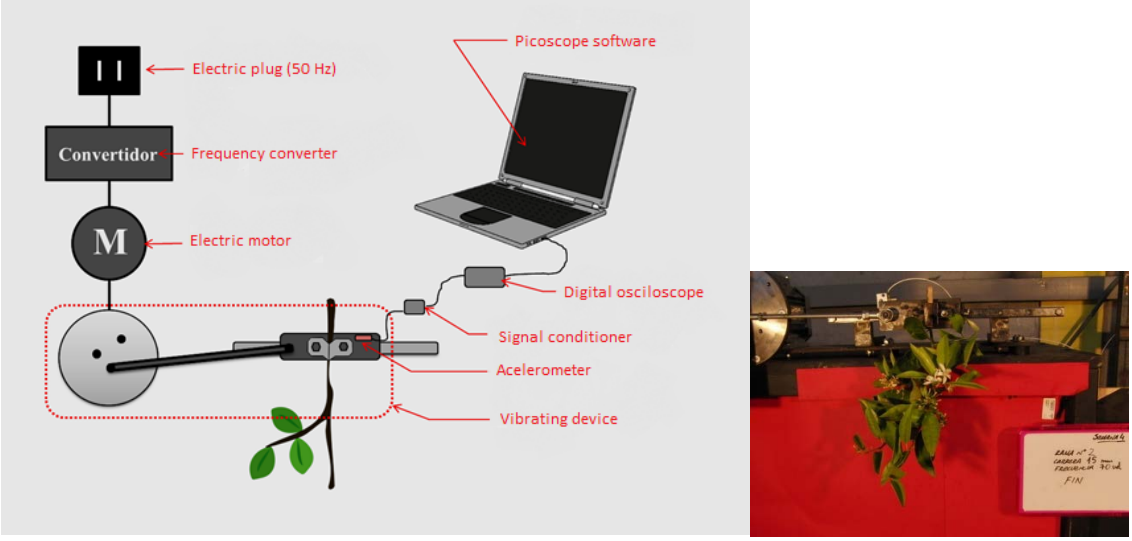

Figure 1. The laboratory unidirectional vibratory device.

Frequencies and accelerations applied were calculated using a triaxial accelerometer (Kistler type 8763A500; range ± 500 G; sensitivity 10 mV G−1; mass 3.3 g; mini cube design 0.01 m length; www.kistler.com) and a high speed camera (Casio EXF1, www.exililm.com) at 300 frames/s.

The first two weeks from 2017 season, a broad range of frequencies were tested in order to determine the most adequate conditions to detach flower buds. After the first two weeks, two amplitudes (0.015 m and 0.030 mm) and two frequencies (34.8 Hz and 37.8 Hz) were tested.

Physical characteristics, mass, maximum equatorial diameter and retention traction force, of the flower buds, flowers and green fruits were measured during the 12 weeks.

A high-speed color video camera (Casio EXF1, www.exilim.com) was used to record the branch movements at 300 photographs per second.

A universal test machine (Ibertest, www.ibertestint.com) was used to measure the retention traction force, Figure 2. The branch sample was located upside down grabbed by the traction clamp at the lower part (Figure 2, A) and the flower bud, flower (Figure 2, B) or green fruit (Figure 3) was grab by the gripper devise.

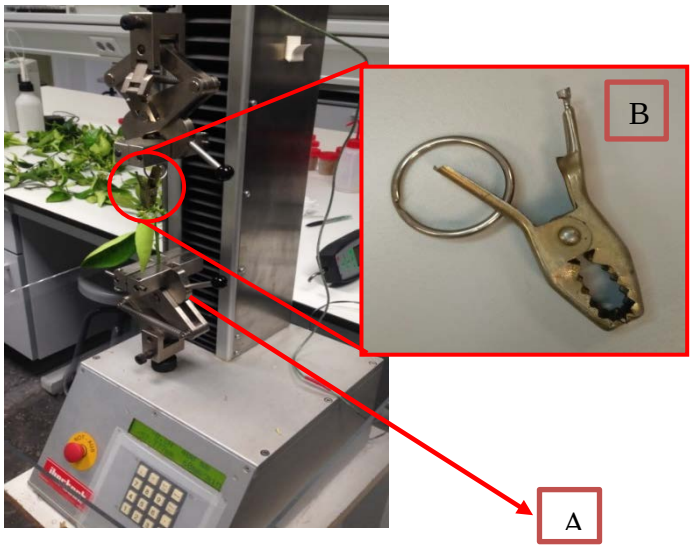

Figure 2. Universal test machine used for the traction retention force test and the gripper device for flower buds and flowers.

Figure 3. The gripper device used for green fruits.

Removal percentage during 10 seconds vibration of flower buds, flowers, small green fruits and medium green fruits were measured.

3. Results

3.1. Physical parameters development according to time

When studying mass, diameter and removal traction force from 2017 and 2018 seasons, it was confirmed that green fruits (phenological stage 72) from the first week in 2018 did not correspond to those from week 10 from 2018. Green fruits from week 1 of 2018 season were similar to those from week between 6 and 7 from 2017 season. This fact could be due to the differences in the two seasons and also to the different procedure followed to choose the branches.

Diameter, mass and retention force development during the phonological stage development is shown in Figure 4.

Until the week 3 (flower buds, and withered flower buds, phenological stages 56-59, diameter of the flower buds and flowers is very low. From the week 4 to the week 8, the diameters are lower than 4.2 mm. This initial phase of the fruitlet growth is related to the increase in the pericarp thickness several weeks after the petal fall [15]. From week 8 a high increase of the green fruit diameter is registered. Related to the second phase of the fruitlet growth with a cell enlargement, the vacuolisation of the juice sacs and an increase in the size of the locules.

Related to mass, it is lower than 1.2 g until week 8, when a drastic change in the mass of the green fruits is produced.

Retention force evolution is very similar to mass. However, retention force is one week ahead of the mass, starting the drastic increment in the seventh week.

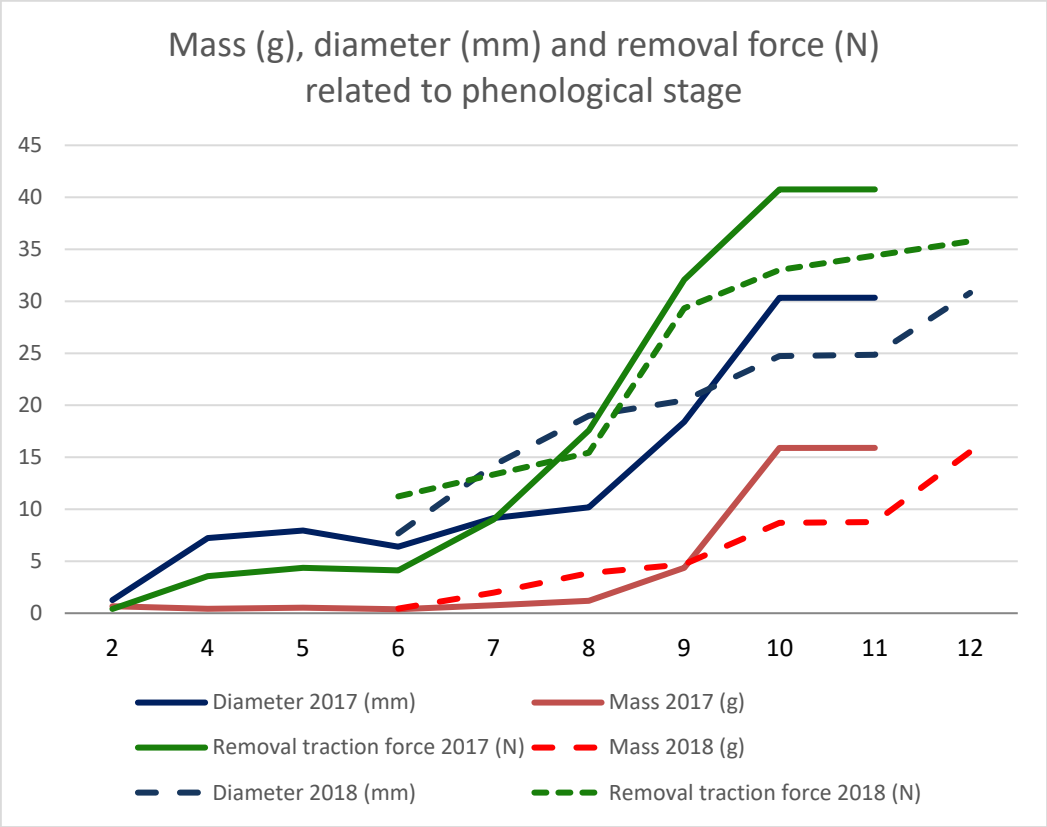

Figure 4. Mass (g), equatorial diameter (mm) and retention removal force (N) of the flower buds, flowers and green fruits according to the weeks in 2017 and 2018 seasons.

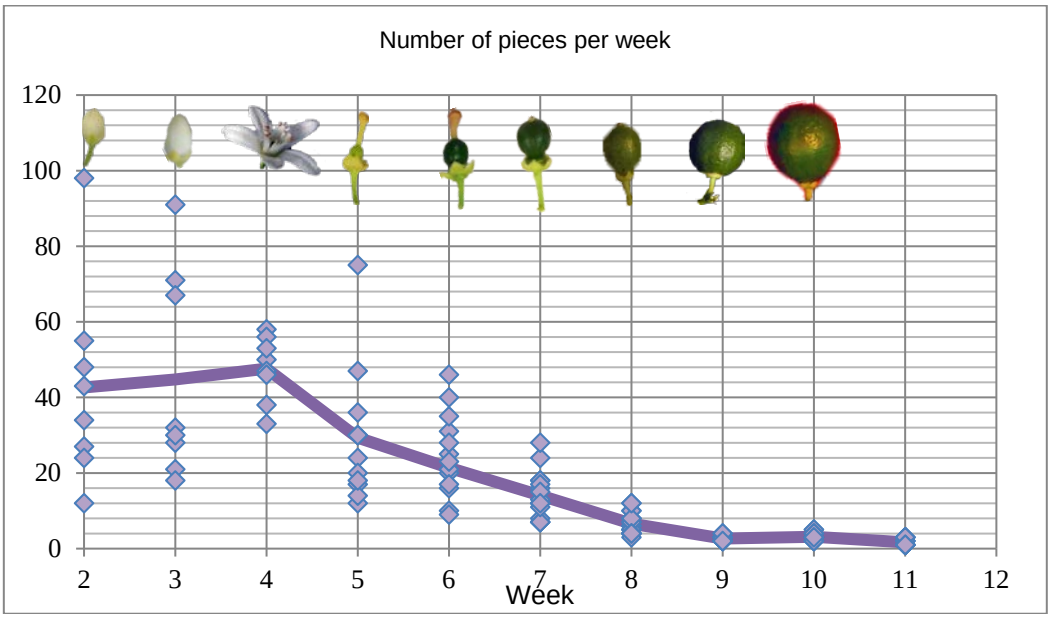

Figure 5. Number of pieces (flower buds, flowers or fruits) according to the week.

The number of pieces registered along the weeks reduced drastically after the week number 7, related to the natural thinning of the tree in 2017 season, Figure 5.

3.2. Removal percentage according to vibration amplitude and frequency

Both vibrating parameters, amplitude and frequency and development time (week), significantly affected removal percentage, Table 2.

Table 2. Variance analysis of the effect of the factors frequency, week and amplitude on the variable removal percentage for 2017 and 2018 seasons.

2017 season					
Source	**Square Sum**	**df**	**Average Square**	**F-value**	**P-value**
PRINCIPAL EFFECT					
A:Frequency	3843.15	1	3843.15	4.69	0.0322
B:Week	20297.2	9	2255.24	2.75	0.0057
C:Amplitude	50585.4	1	50585.4	61.77	0.0000
RESIDUES	100733	123	818.967		
TOTAL (CORRECTED)	171463	134			
2018 season					
Source	**Square Sum**	**df**	**Average Square**	**F-value**	**P-value**
PRINCIPAL EFFECT					
A:Frequency	48810.0	1	48810.0	113.11	0.0000
B:Week	9798.8	6	1633.13	3.78	0.0022
RESIDUES	35384.3	82	431.516		
TOTAL (CORRECTED)	93993.1	89			

Despite the small difference between the two frequencies studied in 2017, the average removal percentage when vibrating with a 34.8 Hz frequency was around 33% compared to nearly 48% when vibrating with 37.8 Hz frequency. In 2018 the differences in removal percentage between the two vibrating frequencies was very significant as it was expected, 11.1% for 18.9 Hz and 57.21 % for 37.8 Hz, with 30 mm amplitude in both cases.

The removal percentage when using the 30 mm amplitude was always higher than the removal percentage when using 15 mm amplitude, Figure. When using 30 mm amplitude the removal percentages were always very high, more than 30 %. It could be more interesting using the 15 m frequency. However, it is important to remark that the removal percentages are considered when vibrating during 10 seconds. A sorter vibration with 30 mm could be acceptable.

During the weeks 2 and 3, phenological stages 56, 59 and 65, the removal percentages increases, being possible to remove flower buds, hollow flower buds and small flowers with the frequencies and amplitudes studied.

Removal percentages in the week 4 (withered flower stage, phenological stage 67) are reduced. This could be due to the increment of the air resistance when vibrating related to the opening of the petals.

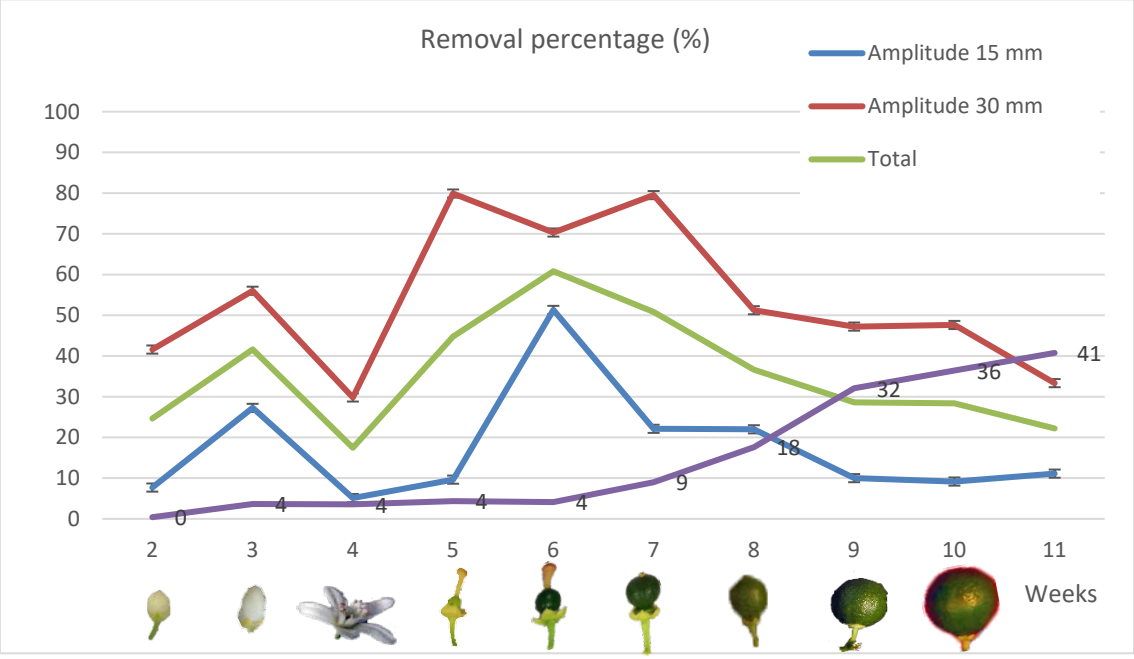

Figure 6: Removal percentage (%) development according to amplitude (15 mm, 30 mm and total) and related to retention traction force (N) for 2017 season.

In 2017, the highest removal percentages are found during the weeks 5, 6 and 7, when the retention force is very low, Figure 6. This tendency is also confirmed in 2018 with a brief delay This period corresponds to the natural thinning. After these weeks, the amount of fruits is naturally drastically reduced (Figure 5) and the retention force increases and the removal percentage decreases. The first weeks just after the natural thinning could be considered adequate for mechanical thinning.

Considering only the green fruits, a logarithmic regression model was found between the removal percentage of the green fruits (%) and the retention traction force (N), with 87.6 % R2, Figure 7, equation [1].

$$\text{Removal percentage (\%)} = 67.5 - 16.1 \ln Ft \quad [1]$$

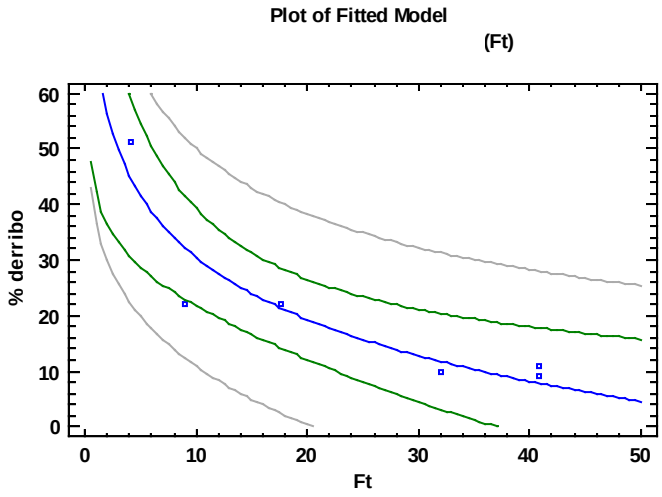

Figure 7. Logarithmic regression model between the removal percentage of the green fruits (%) and the retention removal force (Ft, N).

4. Conclusions

It is possible to detach flower buds, flowers and green fruits using different combinations of amplitudes (30 mm or 15 mm) and frequencies (34.8 and 37.8), under the laboratory conditions studied.

- Amplitude, frequency and phenological stage significantly affect removal percentage.

The removal percentage when using the 30 mm amplitude was always higher (more than 30 %) than the removal percentage when using 15 mm amplitude, with frequencies of 34.8 and 37.8 Hz. The average removal percentage when vibrating with a 34.8 Hz frequency was around 33% compared to nearly 48% when vibrating with 37.8 Hz frequency.

- Equatorial diameter and retention traction force have very low values until the sixth-seventh week (phenological stage 72), when the fruit setting is finishing and a significant change of slope increment is registered. Mass has a similar development with a week delay.
- Removal percentage decreases when increasing retention traction force, according to a logarithmic regression model.
- Removal percentage is higher during the weeks 5, 6 and 7 during fruit setting, when the retention force is very low coinciding with the tree natural thinning. The first weeks just after the natural thinning could be consider the adequate time for a mechanical thinning operation.

5. Acknowledgment

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