Frequency response of Valencia oranges to selective harvesting by vibration

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Abstract

Citrus mechanical harvesting has been investigated since the 1960's. Even though mechanical harvesting could significantly lower production costs, the implementation by the private sector has been slow. The current harvesting technologies detach the fruits with trunk, canopy or branch vibration. For late-season sweet orange varieties which simultaneously bear mature fruit, immature fruitlets and flowers shaker harvesting decreases the subsequent year's yield. This study, investigated the frequency response of mature fruits and immature fruitlets to determine the optimum frequency range for an efficient and selective harvest. Laboratory vibration transmission tests were conducted with 14 branches bearing 76 mature fruits and 151 immature 'Valencia' fruitlets. The fruit and branch response to the forced vibration was measured by several sets of five triaxial accelerometers with a dynamic signal analyser. Three frequency ranges with the highest vibration transmission values were identified for mechanical harvesting lower than 10 Hz. The first frequency range (1.5-2.5 Hz) corresponded best with the most efficient vibration transmission, involving more than 90% of fruit. The second frequency range (4.5-5 Hz) successfully discriminated between mature fruit and immature fruitlets. In this frequency range, 53.4% of mature fruit amplified the acceleration a mean value of 2.2 times, while only 7.3% of immature fruitlets amplified the acceleration with a mean value of 4.4 times. The lowest third frequency range had a vibration transmission value of 7-8 Hz. The frequency response of mature citrus fruits, and their markedly higher fruit mass, were significant factors in efficient selective mechanical harvesting.

Keywords: *Citrus sinensis* (L.) Osbeck, mechanical harvesting, canopy shaker, trunk shaker, acceleration transmissibility

1. Introduction

Although currently commercially available harvesting systems could increase labour productivity by 5 to 15 times and reduce the cost of harvesting up to 50% (Brown, 2005) widespread mechanical harvesting of oranges for juice production has not been widely adapted. As with all tree crops, when developing mechanical harvesting for juice oranges the goals are, in order, producing marketable fruit, preserving long term tree health, reducing harvesting costs and maintaining economically feasible annual yields. Generally, development of a mechanical harvesting program includes simultaneous adaptation of the tree canopies to facilitate more efficient harvesting and investigation of abscission agents.

Earlier citrus mechanical harvesting trials have identified multiple obstacles. Among these problems are yield reduction the subsequent season (F. M. Roka, Burns, & Buker, 2005); the industry wide devastation by Huanglongbing (HLB) (F.M. Roka, House, & R. Mosley, 2014); lack of an effective abscission agent (Burns, Buker Iii, & Roka, 2005); existing orchards and trees poorly adapted for mechanical harvesting (Brown, 2005); and in Spain, multi-use orchards which harvest oranges for fresh fruit or juice markets depending on the current season's market prices (Moreno, Torregrosa, Moltó, & Chueca, 2015).

All citrus mass harvester technologies detach the fruits by applying energy to the tree as forced vibration (Sanders, 2005). The dynamic response of the tree and fruits depend upon the parameters of the vibration (S Castro-Garcia, Blanco-Roldan, Gil-Ribes, & Aguera-Vega, 2008). The frequency of excitation vibration can be generated in multiple ways, all of which affect transmission within the tree. The vibration can be produced by the rotation of an eccentric mass, a drum with sticks, the deflectors of a fan or a crankshaft-rod device (Whitney, 1977; Whitney & Sumner, 1977). This force vibration is applied to the tree with a constant stroke or amplitude and frequency which is difficult to modify without additional engineering. As a result, the vibration at a given excitation frequency value is transmitted by the trunk through main branches to bearing branches where it detaches the fruit. The percentage of fruit removed also depends on the fruit detachment force and mass (Sumner & Coppock, 1982), canopy position (He et al., 2013) and duration or number of vibration events (Blanco-Roldán, Gil-Ribes, Kourba, & Castro-García, 2009). There are multiple reports of citrus mechanical harvesting trials in the literature (supplementary material). However, the different machines, climates, cultivars, orchard management systems and experimental designs make comparisons or generalizations difficult.

The popular juice variety, late-season 'Valencia', which simultaneously bears mature fruit, immature fruitlets and flowers presents a particularly difficult problem. Mechanically harvesting the mature fruit often results in a significant decrease in the subsequent year's yield.as the force required to remove the mature fruit often removes the immature fruitlets for the next season's crop. Trials with prototype trunk shakers demonstrated that the combination of specific excitation frequencies combined with prior application of an abscission agent resulted in an efficient harvest of mature fruit without impacting the following season's yield (Burns, Roka, Li, Pozo, & Buker, 2006). Their results suggest an abscission agent is required to increase the percentage of mature fruit removal in late-season oranges with trunk shakers (F. M. Roka et al., 2005), but is unnecessary with canopy contact harvesters. Finally, current citrus mechanical harvesting methods show percentages of mature fruit removal, but most of appear to selectively harvest specific fruit sizes (Sanders, 2005). This size selectivity is an advantage as it can discriminate between mature and immature fruits during late-season orange variety harvesting.

The objective of this study is to determine the frequency response of mature fruit and immature fruitlets under forced vibration within the range of excitation frequencies of the current harvesting technologies in order to develop a more selective mechanical harvesting process.

2. Material and methods

The experimental bearing branches were obtained from a commercial citrus orchard located near the village of Hornachuelos (Cordoba, Spain). The (*Citrus sinensis* (L.) Osbeck cv. "Valencia late") fruit were destined for juice processing. The 10 years old hedgerow orchard was planted in a north-south orientation 3.2 m high and 2.5 m wide rows. Trees were planted at spacing of 3 m in-row and 7 m between rows.

Laboratory tests were carried out with 14 bearing branches cut during last week of July, 2015; all had mature fruit and immature fruitlets but no flowers. Representative branches bearing mature fruit and immature fruitlets were selected from both sides of canopy, from three tree row set. The branches were placed in cold storage at 5°C, HR 95%, with the cut-end of the branch under water, no longer than the 3 days required to complete the tests. During the storage period neither wilting nor loss of turgor was observed on branches, fruits or leaves. The average branch mean length was values 118 cm, weighed 3.1 kg, had a volume of 251.8 L and was 18.5 mm diameter where cut.

For the laboratory tests, the branches were oriented as if still within the tree canopy and secured in a fixed position to facilitate measurement of the dynamic response produced under vibration. The branch excitation was applied by a unidirectional magnetic shake (LDS V406, Nærum, Denmark). The vibration generated was not sufficient to detach the oranges, fruitlets or leaves. The objective was to study the frequency response of the mature fruit and immature fruitlets. In order to avoid resonance phenomena in the branch or in the fastening system, the excitation signal used was a random noise with frequencies from 0 to 60 Hz, for a total duration of 60 s. The response of the branch, mature fruit and immature fruitlets was measured with a set of 5 piezoelectric triaxial accelerometers (PCB 356A32, Depew, NY, U.S.).

The number of mature and immature fruit determined how many sets of measurement were performed on each branch. For each set of measurements, an accelerometer was placed at the point of application of vibration on the branch base. A total of 99 sets of measurements were performed. A dynamic signal analyser with 16 measurement channels (OROS 36 Mobi-Pack, Meylan, France) controlled by vibration software (NVGate v.8, Meylan, France) was used to generate the vibration signal, sensor conditioning, recording and analysis of the acceleration signals. A total of 888 acceleration signals were analysed in a frequency domain with 801 lines of spectral resolution in a frequency range of 0.5 to 40 Hz with 0.5 Hz resolution. The root mean square values of acceleration for each accelerometer axis ($\ddot{x}$, $\ddot{y}$ and $\ddot{z}$) was calculated for each vibration frequency (ω). The analysis of the vibrations was performed using the resultant acceleration value, that is, the vector sum of the three measurement axes on each accelerometer (Eq. 1).

$$\text{Resultant acceleration} = A(\omega) = \sqrt{\ddot{x}^2(\omega)+\ddot{y}^2(\omega)+\ddot{z}^2(\omega)} \qquad \text{Eq. 1}$$

The acceleration transmissibility (Ewins, 2000) is a frequency dependent function and describes the effective acceleration of the mature fruit or immature fruitlet response ($A(\omega)_{fruit}$) with the effective input acceleration of the electromagnetic shaker applied to the branch base ($A(\omega)_{branch}$) according to Eq. 2. For this ratio, values greater than one indicate vibration amplifications and values less than one indicate vibration reductions for each frequency studied.

$$\text{Acceleration transmissibility } (\omega) = \frac{A(\omega)_{fruit}}{A(\omega)_{branch}} \qquad \text{Eq. 2}$$

3. Results

The 14 branches tested bore a total of 76 mature fruits and 151 immature fruitlets. However, one immature fruitlet and three mature fruits were discarded from the study for previously damaged peduncles. The characteristics of the mature fruit and immature fruitlets are shown in Table 1. At the test moment, the mature fruits showed 18 times heavier and larger than immature the fruitlets, while the average fruit stem diameter was only 1.4 times larger for mature fruits versus fruitlets.

Table 1. Properties of mature fruit and immature fruitlets on vibration test branches (n=14).

	Mature fruit (n=76)	Immature fruitlets (n=151)
Distance between vibration and measurement (cm)	90.3 ± 21.0 [a]	89.7 ± 24.7 [a]
Stem diameter (mm)	3.9 ± 0.7 [b]	2.8 ± 0.4 [a]
Fruit weight (g)	253.7 ± 49.1 [b]	14.1 ± 3.8 [a]
Fruit diameter (cm)	8.2 ± 0.6 [b]	3.1 ± 0.3 [a]

Values showed are mean ± standard deviation.
Same superscript letter in the same row are not significantly different (T student, independent sample, $p < 0.05$)

Figure 1 shows the mean values of acceleration transmissibility from the base of the branch to mature fruits or immature fruits relative to vibration frequency. The frequency response of an individual fruit was dependent on the stage of maturity. For fruits of both maturities acceleration transmissibility reached values higher than one (vibration amplification) for vibration frequency values lower than 10 Hz. Mature fruits had the two maximum values for acceleration transmissibility with 2.7 and 1.9 times at frequencies of 2 and 4.5 Hz, respectively. A minimum acceleration transmissibility (vibration reduction) at 6.4 Hz was identified. For higher frequencies, an increase of acceleration transmissibility was observed with a maximum (1.8) at a vibration frequency of 8 Hz. For frequencies higher than 10.5 Hz, acceleration transmissibility produced a vibration reduction from the branch to the mature fruit. At frequencies of 2 and 8 Hz immature fruitlets demonstrated maximum values of acceleration transmissibility with a vibration amplification factors of 13.1 and 2.8, respectively. Immature fruitlets had limited acceleration transmissibility values for vibration frequencies above 18.5 Hz.

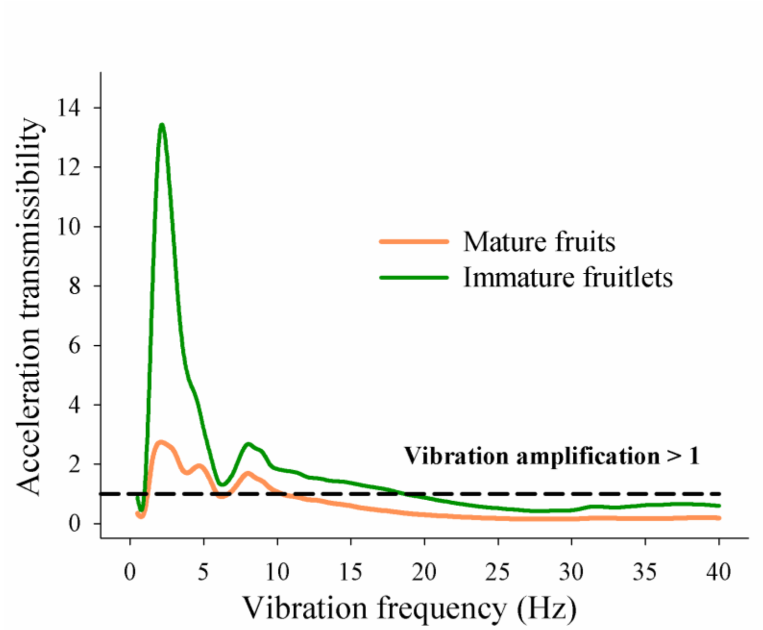

Figure 1. Mean values of acceleration transmissibility from branch base to mature fruit (n=74) and immature fruitlets (n=147) relative to vibration frequencies.

Mature fruit and immature fruitlets had characteristic and proportional frequency responses as can be seen by mean value of acceleration transmissibility shown in Figure 1. However, the individual response of each fruit varied from the mean value of the maturity set. Figure 2 provides a histogram of percentage by number of fruit that contributed with a maximum value of acceleration transmissibility relative to vibration frequency. Until five maximum values of acceleration transmissibility were identified in each fruit to make the histogram. The vibration frequency range was limited from 0.5 to 20 Hz, with 0.5 Hz resolution, as the current mechanical harvesting methods operate in this range.

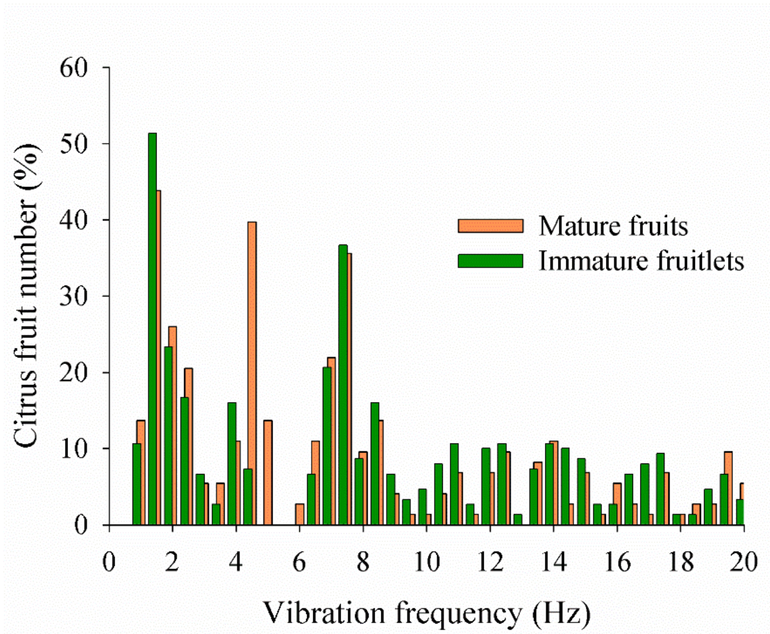

Figure 2. Histogram showing the percentage by number of mature fruit and immature fruitlets contributing with a maximum acceleration transmissibility value as a function of vibration frequency.

Three frequency ranges with a high percentage of fruit with maximum values of acceleration transmissibility were identified (Figure 2). These frequency ranges corresponded well with the maximum values of vibration transmission identified in Figure 1. The first frequency range corresponded with values from 1.5 to 2.5 Hz, and resulted in the most important response of the fruit, both in acceleration transmission magnitude and in the number of fruit affected. In this frequency range, 91% of immature fruitlets amplified the vibration an average of 16.2 times, while 90% of mature fruit amplified the vibration an average of 3.4 times. The most important difference in frequency response of fruit relative to maturity was in the frequency range from 4.5 to 5 Hz. At this range, 53.4% of mature fruit amplified the vibration by a factor of 2.2 while only 7.3% of immature fruitlets amplified the vibration 4.4 times. The third frequency range, 7 to 8 Hz affected a similar percentage of mature fruit and immature fruitlets, 67.1% and 66% respectively. This frequency range enhanced the acceleration transmission for mature fruit (1.9) and immature fruitlets (2.9). Higher frequency ranges had less effect relative to acceleration transmission and a lower percentage of fruit were affected. However, some machinery can operate at these frequencies. For example, frequencies from 11 to 14 Hz produced acceleration transmission values of 1.1 and 1.7 for mature fruit and immature fruitlets, respectively. This frequency range affected 43% of mature fruit and 53% of immature fruitlets.

4. Discussion

The results produced in this trial demonstrated that there was a different frequency response between mature fruit and immature fruitlets in a narrow frequency range (4.5-5 Hz). This differential response can possibly be used to develop a selective harvesting process of late-season oranges. However, there are at least two limiting factors.

First, for an economically feasible mechanical harvesting a high percentage of mature fruit (> 85%) must be harvested without greatly impacting the subsequent year's yield by removing the too many immature fruitlets. This suggest successful trunk shaking will require an effective abscission agent. Second, the vibration frequency should be produced at an amplitude that can produce sufficiently high acceleration without damaging the trees. The vibration applied to the trunk, branches or canopy will be the determining factor in harvester efficiency.

4.1. Fruit detachment with blast shakers

Both mature fruit and immature fruitlets had higher acceleration transmission in the 1.5-2.5 Hz frequency range. This response contributes to reach a high percentage values of fruit removal with mechanical harvesting methods which use a very low frequency values. Air blast shakers generate a force vibration with frequency values close to 1 Hz (Whitney, 1977) or 1.2 Hz (Sumner, Coppock, Churchill, & Hedden, 1979) and can achieve 90-95% percentage mature fruit removal. However, these machines also remove immature fruitlets resulting in a 16% yield reduction of following crop year (Whitney & Wheaton, 1987). The high frequency response of the fruit at 2 Hz would correspond to the evolutionary response of tree to wind loads (Niklas & Speck, 2001) for a natural detachment of fruit. Wind loads are periodic and produce a complex movement of tree (James, 2003) that could contribute to the detachment process by natural causes (Sumner & Coppock, 1982). It appears that air blast shakers have little commercial potential as they require the use of abscission agent and have high power requirements, close to 242 kW (Whitney, 1975).

4.2. Fruit detachment with canopy shakers

The frequency range from 2.5 to 8 Hz involve interesting responses of fruit, both in acceleration transmission magnitude and in the discrimination among the mature fruit stages. Both trunk or canopy tree contact technologies can harvest the 4.5-5 Hz frequency range.

Canopy shakers operate in the frequency range from 2 to 6 Hz (Savary, Ehsani, Schueller, & Rajaraman, 2010). However, in this frequency range the strokes values, usually range between 100 and 300 mm (S. Castro-Garcia et al., 2009; Peterson, 1998). So, high acceleration values on the tree canopy would result, with instant values up to 500 ms^{-2} (Savary et al., 2010; Sola-Guirado et al., 2014). These vibration parameters have removed 90-95% of mature fruit without an abscission agent when an experienced operator is harvesting a continuous uniform tree canopies less than 5.5 m tall (F.M. Roka, Ehsani, Futch, & Hyman, 2014). However, vibration applied directly to the bearing branches with high stroke amplitudes can cause significant damage to the tree branches and stems (Spann & Danyluk, 2010). The ability of canopy shakers to get an achieve high fruit removal percentages is one reason of why these machines are being adapted other crops, particularly mechanically pruned table olives (Ferguson et al., 2009; Sola-Guirado et al., 2014). Canopy shaker trial with early and mid-season oranges have demonstrated that with the correct vibration parameters these machines harm neither the tree, nor the subsequent yields (F.M. Roka, House, et al., 2014). However, with late-season oranges canopy contact shakers have been reported to decrease yields, by as much as 18% (Whitney, 1975) to 40%(Whitney & Sumner, 1977); primarily through removing immature fruitlets. Therefore, for late-season varieties the current recommendation is to limit the use of these harvesters to before the immature fruitlets had major changes in growth (Coppock, 1972) to approximately six weeks after flowering and before they are 22 mm in diameter. More restrictive recommendations suggest no more than a 1inch diameter by early May (F.M. Roka, Ehsani, et al., 2014). Although canopy shakers can be operated in the frequency ranges in order to produce a fruit size discrimination (4.5-5 Hz), the vibration generated is highly energetic, resulting in high response to detachment of all fruit and even branches and stems. This suggests selective harvesting with canopy shaker technology would be difficult to achieve.

4.3. Fruit detachment with trunk shakers

There are extensive reports about citrus mechanical harvesting with trunk shakers in the literature. Supplementary material summarizes the major results of field tests without abscission agents. These multiple studies demonstrate that, although the vibration frequency is an important parameter, combination with a stroke value is essential for achieving high percentages of mature fruit removal. Initially, (Lenker & Hedden, 1968) established 3.3 to 5 Hz as the optimum frequency range for detaching mature 'Valencia' oranges. However, in this frequency range trunk shaker must have a high stroke value which with a heavy unbalanced mass to generate sufficient acceleration to detach the fruit. High stroke values are one of the major sources of machine damage to trees, particularly with inertial mass shakers (Abdel-Fattah, Shackel, & Slaughter, 2003; Affeldt Jr, Marshall, & Brown, 1988). The unidirectional vibration pattern for trunk shakers was developed to solve this problem. These did produce better results than the multi-directional shaker (S. L. Hedden, Whitney, & Churchill, 1984). The acceleration level issue has been addressed by increasing the vibration frequencies. This resulted in loss of the ability to selectively discriminate by size among the mature fruit. However, using an abscission agent to reduce the fruit acceleration level required to detach fruit (Whitney, Hartmond, Kender, Burns, & Salyani, 2000).(Whitney et al., 2000) determined that without an abscission agent the percentage of mature fruit removal with trunk shakers would be 10-15% higher for low frequency and high stroke values (6-10 Hz and 50 mm) than for high frequency and medium stroke values (15-18 Hz and 30 mm). The required acceleration level to detach fruit reported by (Torregrosa, Ortí, Martín, Gil, & Ortiz, 2009) when using an inertial trunk shaker with reduced unbalance and eccentricity mass suggested frequencies up to 9 Hz were. They also reported that vibration frequency values in the range of 15-20 Hz significantly defoliated the trees.

Previous field tests with trunk shakers in sweet oranges, without an abscission agent application (supplementary material), showed a relationship between vibration frequency and percentage of mature fruit removal (Figure 3). This relationship can be affected by differences in trunk diameter, tree size, fruit mass and maturity, machines configuration or the variability inherent in field replication (Moreno et al., 2015; Whitney, 2003). These earlier trials collectively demonstrate it is difficult to achieve more than 85% mature fruit removal with trunk shakers, and no abscission agent with vibration frequencies above 10 Hz. This observation has been verified by laboratory trials with mature fruit (Figure 1), measured acceleration transmission and amplification of frequency values less than 10 Hz.

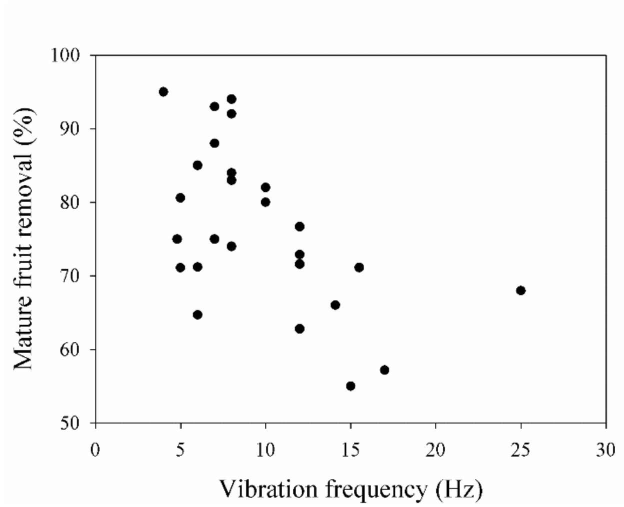

Figure 3. Percentage of mature citrus fruit removal by trunk shaker harvesters without previous abscission agent (data provided by references in supplementary material).

The reduction of fruit detachment force using an abscission agent facilitates the harvesting process by any method (Sumner et al., 1979) and therefore increases mechanical harvesting capacity (Burns et al., 2005). The average percentage of mature fruit removal is generally increased by 10-15% when the fruit detachment force of the orange is reduced by 50-80% (Whitney et al., 2000). Abscission agents increased mature fruit removal by trunk shakers from 74 to 91% (Scott L. Hedden, Churchill, & Whitney, 1988). The combination of an abscission agent and frequencies close to 8-10 Hz produced 90% to 95% mature sweet orange fruit removal (Burns et al., 2005; Whitney, 2003).

4.4. Fruit selectivity by vibration frequency

The frequency range between 4.5-5 Hz has been identified as the frequency which excites a moderate percentage of mature fruit (53.4%), while detaching a low percentage of immature fruitlets (7.3%), while maintaining an effective level acceleration transmission (2.2). However, this does not imply that this frequency range is more effective for mature fruit detachment but that this frequency range could be used for selective mechanized harvesting. (Burns et al., 2006) showed that trunk vibration at 4.8 Hz, without abscission agent, significantly removed less mature fruit than other treatments at 8 Hz. But, an abscission agent increased the percentage of mature fruit removal for both frequencies (89-97%). They reported that a 4 second vibration at 4.8 Hz removed significantly less immature fruitlets than a 2 or 4 second vibration at 8 Hz. The abscission agent did not affect the detachment of immature fruitlets with a trunk shaker. The differential response of mature fruits at this frequency appears to be the reason for this response.

5. Conclusion

The analyses of the frequency responses of the mature fruit and immature fruitlets has identified three frequency ranges below 10 Hz with potential for mechanical harvesting of late-season 'Valencia' oranges. The first frequency range (1.5-2.5 Hz) correlated best with the most efficient vibration transmission, involving more than 90% of fruit. The second frequency range (4.5-5 Hz) successfully discriminated between mature fruit and immature fruitlets. The third frequency range (7-8 Hz) had the lowest vibration transmission value of all three frequency rages but involving close to 67% of fruit. The frequency responses of mature citrus fruits, and their markedly higher fruit mass, were the significant factors in efficient selective mechanical harvesting.

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Supplementary material. Previous results of citrus mechanical harvesting with trunk shakers and without any previous abscission agent application.

Reference	Variety	Frequency (Hz)	Stroke (mm)	Vibration pattern/Unbalanced masses/Weigh	Eccentricicty (mm)	Vibration time (s)	FRF (N)	Mature fruit Removal %
J. D. Whitney & Wheaton, 1987	Valencia	n.a.	n.a.	Multidirectiona/Two/31 kg each	n.a.	3-7	n.a.	81
Hedden, Churchill, & Whitney, 1988	Valencia	6	25.6	Linear/One/60.4 kg	140	7	n.a.	64.7
Hedden et al., 1988	Valencia	5	29.3	Linear/One/90.9 kg	140	7	n.a.	80.6
Hedden et al., 1988	Valencia	11-13	25.6	Multidirectiona/Two/30.9 kg each	114	7	n.a.	72.9
Hedden et al., 1988	Valencia	11-13	28.9	Multidirectiona/Two/30.9 kg each	114	7	n.a.	76.7
Jodie D. Whitney, Churchill, Hedden, & Smerage, 1988	Valencia	6	n.a.	Linear/One/ 60.4 kg	140	7	n.a.	49.8
Jodie D. Whitney et al., 1988	Valencia	5	n.a.	Linear/One/90.9 kg	140	7	n.a.	71.1
Jodie D. Whitney et al., 1988	Valencia	11-13	n.a.	Multidirectiona/Two/30.9 kg each	114	7	n.a.	62.8
Jodie D. Whitney et al., 1988	Valencia	11-13	n.a.	Multidirectiona/Two/30.9 kg each	114	7	n.a.	71.6
J. D. Whitney, 1999	Valencia	8	50	Multidirectional/Two/125 kg	220	5-7	107	74
J. D. Whitney, 1999	Hamlin	8	50	Multidirectional/Two/125 kg	220	12-14	69	94
Koo, Salyani, & Whitney, 2000	Valencia	6	50	n.a.	n.a.	5	96.2-102.5	84.3-86.6
J. D. Whitney, Hartmond, Kender, Burns, & Salyani, 2000	Hamlin	15-18	30-35	Multidirectiona/Two/30.9 kg each	114	5	73	57.2
J. D. Whitney et al., 2000	Hamlin	6	50-80	Multidirectiona/Two/n.a.	n.a.	12-15	73	71.2
J. D. Whitney et al., 2000	Hamlin	10	50	Multidirectiona/Two/125 kg	220	5	61-85	79-80.7
J. D. Whitney et al., 2000	Valencia	8	80	Multidirectiona/Two/130 kg	220	5	99-101	79.7-85.6
J. D. Whitney et al., 2000	Hamlin	15-18	30-35	Multidirectional/Two/30.9 kg each	114	5	73	57.2
J. D. Whitney et al., 2000	Hamlin	6	50	Multidirectional/Two/30.9 kg each	114	12-15	73	71.2
J. D. Whitney et al., 2000	Hamlin	10	50	Multidirectional/Two/125 kg	220	5	61-85	81.5-83.9
J. D. Whitney et al., 2000	Valencia	8	80	Multidirectional/Two/130 kg	220	5	99-101	79.7-87.8
J. D. Whitney, BenSalem E, & Salyani, 2001	Hamlin	7	70	Multidirectiona/Two/205-250 kg	n.a.	5-10	61-94	84.9-93
J. D. Whitney et al., 2001	Hamlin	7	60-70	Linear/Two/ 205-250 kg	n.a.	5-10	61-94	92.1-94.9
Salyani, BenSalem, & Whitney, 2002	Valencia	7	60	Linear/Two/ 205 kg	n.a.	5 s	120 N	64-83
Li & Syvertsen, 2005	Hamlin	4	65	Linear/One/ 70.8 kg	n.a.	10-20	n.a.	>90
Burns, Roka, Li, Pozo, & Buker, 2006	Valencia	4.8-8	n.a.	Multidirectiona/Two/n.a.	n.a.	2-4	109.8	75-92
Torregrosa, Porras, & Martín, 2010	Lemon	14.4-22.6	n.a.	Orbital/One/n.a.	n.a.	n.a.	70	77
Torregrosa, Ortí, Martín, Gil, & Ortiz, 2009	Valencia	15-25	n.a.	Orbital/One/n.a.	130	3.8	49-62	55-68
Moreno, Torregrosa, Moltó, & Chueca, 2015	Navel Lane Late	14.1-15.5	15-35	Orbital/One/n.a.	n.a.	5	124-147	66.03-71.14

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