Title
Simultaneous Trunk and Canopy Shaking Improves Table Olive Harvester Efficiency versus Trunk Shaking Alone

Journal
Horticulturae, 9(6)

ISSN
2311-7524

Authors
Homayouni, Taymaz
Maharlooei, Mohammadmehdi
Toudeshki, Arash
et al.

Publication Date
2023-06-01

DOI
10.3390/horticulturae9060640

Peer reviewed

horticulturae

Article

Simultaneous Trunk and Canopy Shaking Improves Table Olive Harvester Efficiency versus Trunk Shaking Alone

Taymaz Homayouni [1,†], Mohammadmehdi Maharlooei [1,2,†], Arash Toudeshki [1], Louise Ferguson [3] and Reza Ehsani [1,*]

[1] Mechanical Engineering Department, University of California Merced, Merced, CA 95343, USA; mmaharlooei@ucmerced.edu (M.M.); amohammaditoudeshk@ucmerced.edu (A.T.)
[2] Biosystems Engineering Department, Shahid Bahonar University of Kerman, Kerman 76169-14111, Iran
[3] Department of Plant Sciences, University of California Davis, Davis, CA 95616, USA; lferguson@ucdavis.edu
* Correspondence: rehsani@ucmerced.edu
† These authors contributed equally to this work.

Abstract: Production of California table olives has declined significantly in recent years due to hand harvesting costs, often over 60% of gross return. Mechanical harvesting could sharply decrease harvest costs, increasing economic viability. Mechanical harvester efficiency is a combination of the percentage of the total fruit on a tree removed by a harvester, and the time required to do so. A comparison between an experimental canopy contact shaker and a commercial trunk shaker demonstrated low harvest efficiencies and no significant differences in harvester efficiency between the two, averaging no more than 8%. However, simultaneously combining both shaking methods increased fruit removal to an economically feasible 75% and produced better fruit quality. Combining both shaking methods increased the price per ton by 63% versus trunk shaking and 35% versus canopy shaking. These results suggest a mechanical olive harvester that simultaneously combines trunk and canopy shaking is more efficient than either shaking method alone, and, has potential for economically feasible mechanical table olive harvesting.

Keywords: amplitude; frequency; fruit removal; sensor; table olive

Citation: Homayouni, T.; Maharlooei, M.; Toudeshki, A.; Ferguson, L.; Ehsani, R. Simultaneous Trunk and Canopy Shaking Improves Table Olive Harvester Efficiency versus Trunk Shaking Alone. *Horticulturae* **2023**, *9*, 640. https://doi.org/10.3390/horticulturae9060640

Academic Editor: Riccardo Lo Bianco

Received: 6 April 2023
Revised: 23 May 2023
Accepted: 24 May 2023
Published: 30 May 2023

1. Introduction

Production of California's major table olive, Olea europaea cv. 'Manzanillo' has decreased by 60% in the last three decades due to the lack and high cost of hand labor [1–3]. Hand harvesting can account for up to 80% of the table olive labor input and 60% of the production costs [4]. Traditional hand harvesting is neither economically nor logistically feasible for the California table olive industry; mechanical harvesting is the only solution [5]. The mechanical harvesting options include robotic harvesting and mass harvesters such as canopy and trunk shakers. Robotic harvesting has been developed for multiple vegetables and fruit trees [6,7]. However, robotically harvesting an olive tree with its dense willowy canopy with multiple small fruits is significantly more challenging in terms of fruit detection and efficient fruit removal.

Trunk shakers are being increasingly used for table olive harvesting [8,9]. Trunk shaking harvesters require between 0.6 and 1 m of straight trunk beneath the canopy. Traditional table olive orchards generally have short, irregular trunks with branching below one meter—see Figure 1.

Horvath and Sitkei [10] described a fruit tree as a vibrating system composed of multiple vibrating components; branches, limbs, trunk, and root-soil mass. Maximum fruit removal with a shaker is achieved when the shaking frequencies approach the tree's natural frequency. However, the proper shaking frequency varies for each individual tree, as the tree's natural frequency is a function of its size, age, morphology, wood properties, moisture content, and leaf density [11,12]. The tree's natural frequency can even shift during the harvest season due to mass changes during harvesting [13].

Figure 1. Short (**left**) and irregularly shaped (**right**) trunks that prevent a trunk shaker from attaching.

Multiple table olive harvesting methods have been developed as prototypes, but few are commercially available. Trunk and canopy shakers are the most popular mechanical harvesters; the duration, amplitude, and frequency of shaking parameters differ between them. However, for both the amplitude is greatest near the shaking point and decreases with distance and angle [13].

Trunk shakers were introduced in the early 1960s [14]. The shaker vibration transfers through the trunk to the branches, causing fruit detachment. Olive trees significantly damp trunk vibrational energy due to their wood properties and branch orientation (Figure 2).

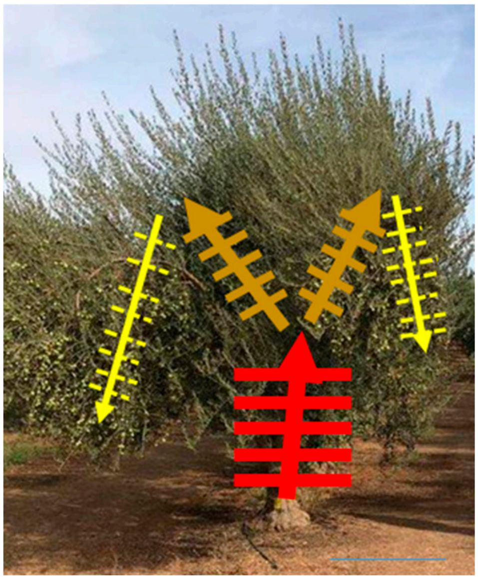

Figure 2. The vibration dampens as it transfers from the trunk to the main branches and secondary branches.

The specific detachment force (force per fruit weight) for table olives is significantly higher than for other fruits harvested by trunk shaking. For oil varieties, this ratio can reach 200–400; for table olive varieties, it can be 100–200 [15]. Due to the olive canopy's damping action, trunk shaking must be at a higher intensity and a longer duration than for nut trees to achieve an acceptable fruit removal rate [16]. This damages the trunk bark and loosens the root system, though the latter had not been observed to cause problems.

O'Brien and Fridley [17,18] determined the maximum allowable stresses that did not damage the trunk or limbs of fruit and olive trees. They reported a maximum radial stress of 3.5 to 6.9 MPa and maximum longitudinal and tangential stresses of roughly 25% and

33% of the radial stress, respectively. The main problem with trunk shakers is the shaking intensity and duration required to achieve acceptable fruit removal rates bruises the fruit and damages the trunk bark [19,20].

A canopy shaker, or canopy contact shaker, is an alternative to a trunk shaker [21,22]. The machine shakes the tree canopy with an array of rods attached to an eccentric wheel. These rods may also contact the tree branches, impacting and shaking the entire tree canopy periodically, resulting in fruit removal [23]. Sessiz and Özcan [24] created a pneumatic branch shaker that attained 50% efficiency without the use of abscission chemicals. Shaking frequency and amplitude, like previous approaches, were found to be the most critical parameters affecting canopy shaker efficiency. Shaking frequency and amplitude were the most critical parameters affecting canopy shaker efficiency. High amplitudes injure branches, low amplitudes may be insufficient to remove fruits [25]. For optimal fruit removal rates, it is essential that the shaker and the tree canopy have continuous contact [23].

It is critical to choose an appropriate harvesting strategy and apply the necessary force at the proper region to ensure an effective harvest without fruit or tree damage. These elements differ based on the type, size, and morphology of the tree [9]. Other parameters including the fruit's weight, shape, size, and maturity level also need to be taken into account when choosing the harvesting technique [26].

UC Davis researchers built a canopy shaker prototype that produced economically feasible harvest efficiency in properly prepared olive canopies, demonstrating that canopy-contacting harvesting has potential [22]. Similar canopy shakers have been used for citrus harvesting [27,28]. However, when used on olive trees, the harvester was bulky and could not easily adapt to the olive trees' shapes.

The objectives of this study were to develop an affordable mechanical harvester for California's table olive industry and to compare its shaking characteristics to those of the commercially available trunk shakers. The quantity and quality of the harvested olives were also evaluated.

2. Materials and Methods

2.1. Design Procedures

A canopy shaker was designed specifically for the 'Manzanillo' table olive. The mechanism had three improvements compared to existing shakers:

1. It could compress the tree canopy.
2. It could adjust to tree size and height.
3. It could harvest fruit within the tree row.

Vibration efficiency is improved by canopy compression while shaking; this decreases the duration and intensity required and increases harvester efficiency.

Figure 3 depicts the shaker design. The shaker consists of two wings and two vibrating wheels with rods. Two wings, each with one linear hydraulic cylinder, were utilized in this design to squeeze the canopy and to enhance the vibration efficiency by retracting and releasing each wing. These wings allow the shaker to follow the canopy's form dynamically and freely. A shaking pattern was produced using an off-center mechanism. The off-centered shaft on each wing was driven indirectly by the hydraulic motor through a chain and sprocket reducer system. The vibration frequency and amplitude can be adjusted by altering the rotary speed of the hydraulic motor and the eccentricity of the shaking wheel, respectively. As can be seen in Figure 3, an adjustable counterweight attachment was also added to the off-centered shaft; this additional part dampens the undesirable vibration transmitted back toward the harvester shaker.

This new canopy shaker mechanism was attached through a retractable boom to a Bobcat 337. Using this configuration, the harvester head could climb to 4.5 m and harvest up to a 6.0 m-tall tree (Figure 4).

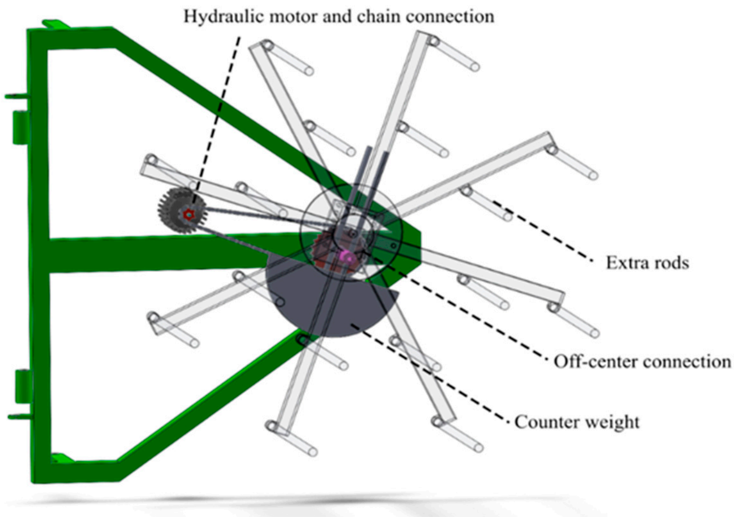

Figure 3. Connecting the rods' wheel to the off-center balanced hub to create a circular shaking pattern.

Figure 4. The shaker header is attached to the retractable boom of a Bobcat 337.

2.2. Acceleration Sensor and Wireless Data Logging

The vibration produced by the canopy shaker head was transmitted through the tree canopy to the branches, fruits, leaves, and trunk.

The generated acceleration was gauged by accelerometer sensors in real time [29]. Commercially available accelerometers were not sufficiently durable. Connecting sensors through wires is impractical for delivering the data and electric power from the power source to the accelerometer, due to the damage caused during shaking [5]. We developed an accelerometer equipped with a micro-SD and wireless data logger (Figure 5). A 9-volt battery and independent storage was incorporated into each sensor. All the sensors were wirelessly connected to the wireless router. The wireless router used for this experiment was a 300 Mbps wireless N router (TL-WR841N; version: 14.6; TP-Link; Vientnam). For quick access to each sensor during the field experiment, a unique static IP address was assigned to each sensor. To remotely control the sensors, a Raspberry Pi 3 A+ single-board computer was utilized along with a 5 V battery pack. The controller unit could select which sensors to activate or deactivate remotely, or begin recording data simultaneously. Each record had a predetermined shaking duration.

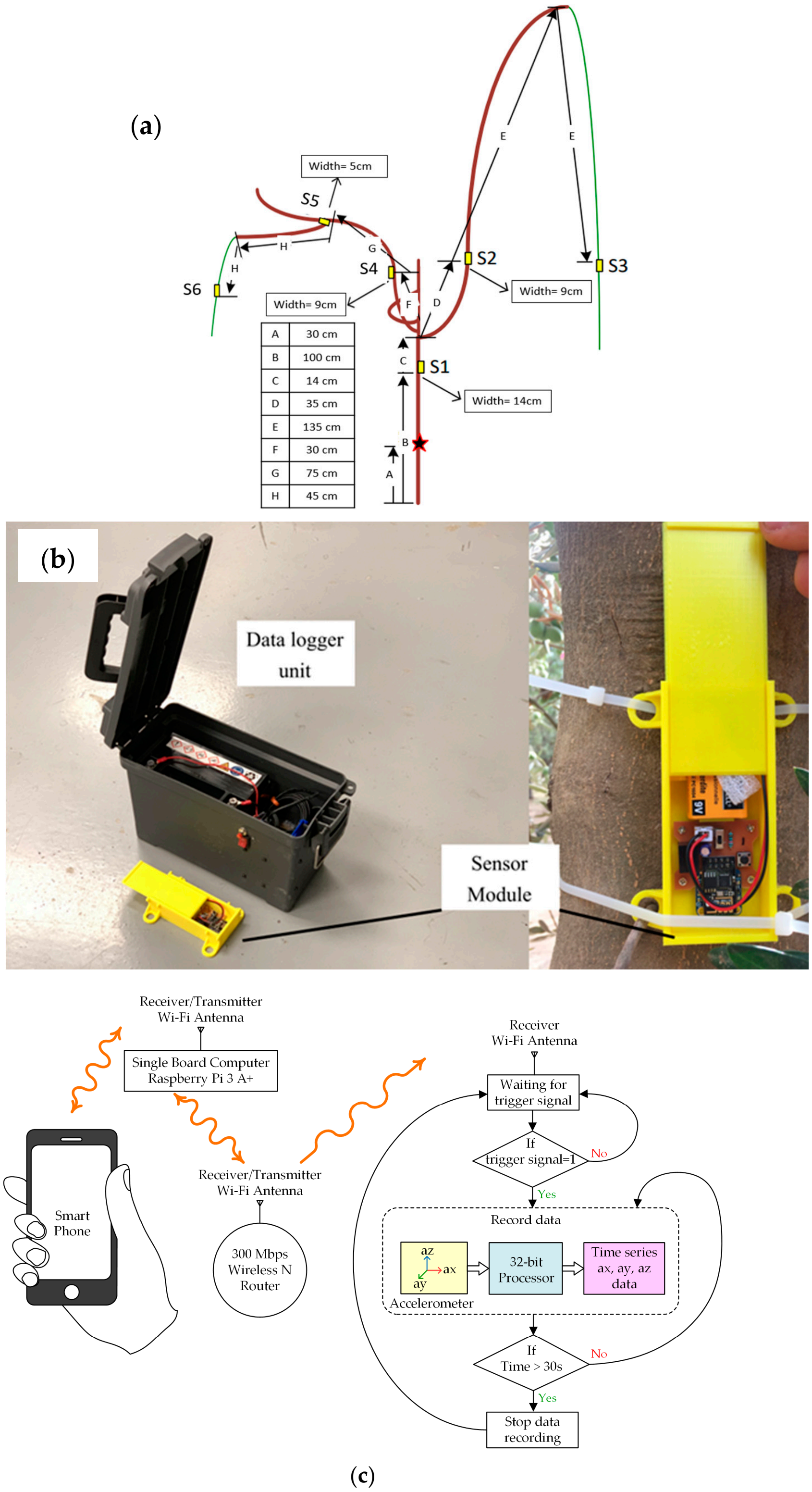

Figure 5. (**a**) Orientation of sensors (S1–S6) installed on a typical olive tree. (**b**) Wireless accelerometer and data logging system. (**c**) Diagram and flowchart of accelerometer data acquisition system.

To measure the impact of each machine's operation on the tree and harvesting efficiency, we utilized LIS3DH accelerometers to gauge the resulting vibration. We analyzed the data collected from each sensor to evaluate how each shaker affected the harvest. The data from each sensor was recorded in a labeled *.CSV file on a MicroSD (16 GB) inserted into the memory socket (model: Adafruit MicroSD card breakout board+) of each wireless sensor system. More technical details for this wireless sensor network were discussed by [5].

The intensity of vibrations can be quantified as acceleration. Unlike earlier studies, in this trial, both the acceleration peak and root mean square (*RMS*) were used to express the vibration in terms of acceleration. To determine these metrics, first, the acceleration resultant (a_r) was calculated using the acceleration components in the x, y, and z directions by Equation (1) [30]; after that, the acceleration peak and *RMS* were obtained using Equations (2) and (3)—where n in Equation (3) was the number of acceleration resultant samples during the experimental trials.

$$|a_r| = \sqrt{a_x^2 + a_y^2 + a_z^2} \tag{1}$$

$$\text{peak} = (|\text{a}_r|) \tag{2}$$

$$RMS = \sqrt{\left(\frac{1}{n}\right)\sum_{i=1}^{n}(a_{r_i})^2} \tag{3}$$

2.3. Experimental Tests

This experiment was conducted at Leslie J. Nickel's Trust in Arbuckle California, USA (38°58′01″ N, 122°04′36″ W) in an *Olea europaea* cv. Manzanillo orchard planted in 2001 with N–S rows at 3.7 m in-row and 5.5 m between rows: 486 trees per hectare. The trees were topped at 3.7 m, and every other row middle was double side hedged 0.9 m from the trunk, annually. The experimental trials were designed to study the vibration properties of the newly developed canopy shaker and to compare them with a commercial trunk shaker made by the Orchard Machinery Corporation (OMC). Four accelerometers were attached to different parts of each tree: one to the tree trunk, one to the main branch, and two other sensors to the secondary branches on both sides of the canopy, to measure the propagation of vibrations through the tree in each trial.

Three distinct shaking frequencies were chosen for each shaker machine (trunk and canopy shaker). Eleven trials were completed: nine different combinations of shaking frequencies using both shakers simultaneously (Figure 6), one trial using only the trunk shaker, and one trial using only the canopy shaker (Table 1). Each trial was repeated three times (a total of 33 trees). The canopy shaker was tuned to a five cm off-center distance, generating a ten cm displacement. The rotary speed of the hydraulic motor was adjusted to 100, 150, and 200 rpm for each experiment. The shaking intensity of the commercial trunk shaker was adjusted by the machine interface to three preset shaking modes (low, medium, and high). The shake period was 15 s.

Figure 6. Trunk shaker and canopy shaker, shaking an olive tree simultaneously.

Table 1. Experiment design for selecting the optimum combined shaking frequency. Each treatment was replicated three times.

Canopy Shaker (rpm)	Trunk Shaker Intensity		
	Low	**Medium**	**High**
100	Trial-1	Trial-2	Trial-3
150	Trial-4	Trial-5	Trial-6
200	Trial-7	Trial-8	Trial-9
Canopy shaker	Trial-10		
Trunk shaker	Trial-11		

Four to six tarps were spread on the ground before each shaking to catch the detached olives. Following the shaking, the mechanically detached olives were weighed, and a sample submitted to the Musco Company commercial receiving station for quality grading and value per ton [31]. A hand gleaning team harvested the olives remaining on the tree. The hand-harvested olives were also weighed. The harvest efficiency was calculated using Equation (4) [32]:

$$Efficiency(\%) = \left(\frac{Mechanically\ harvested\ (\text{kg})}{Manually\ harvested\ (\text{kg})\ +\ Mechanically\ arvested\ (\text{kg})}\right)100 \quad (4)$$

The data was analyzed using a one-way ANOVA in a completely randomized design with eleven treatments (Table 1) of 3 replications each and $\alpha = 0.05$. The multi-range Duncan post-hoc test was used to compare the means of the treatments.

3. Results and Discussion

Figure 7 illustrates the maximum acceleration of the two harvesting machines. The data demonstrates that the canopy shaker vibration amplitude was higher in thin branches than in the trunk or larger branches; this is directly due to their relative sizes. The result was less energy being transmitted to the tree trunk and root system, and therefore less potential damage to the tree compared to the trunk shaker. The opposite trend was observed for the trunk shaker, with the vibration amplitude in the trunk higher than in the small branches due to their proximity to the point of the applied vibration. This suggests that the canopy shaker applies most energy to the fruit-bearing zone and is therefore more energy efficient. An examination of the maximum amplitude of both shakers shows that the canopy shaker increased the peak acceleration by 76.5% in small branches and decreased it by 70% in the trunk. A previous study on mechanical harvesting for citrus also reported the ability of larger peaks to successfully detach fruits with fewer cycles [33].

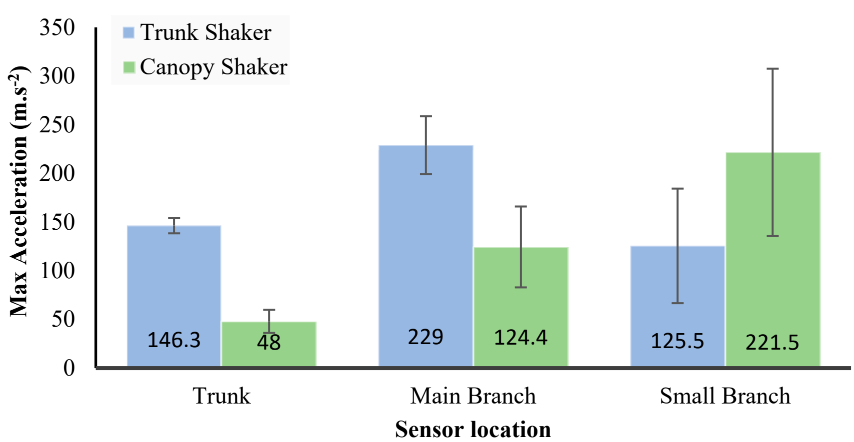

Figure 7. Maximum peak acceleration created by the two tested harvesters.

Comparing the vibration frequency of both harvesters demonstrates the canopy shaker produced a lower vibrating frequency (3.5 Hz) than the trunk shaker (15.5 Hz) in small limbs and higher amplitudes, producing less damage to the fruits. Similar results have been reported for cherry and other olive mechanical harvesting trials; higher frequencies cause more fruit damage [26,34].

As Figure 8 shows, the harvest efficiency was not significantly different among the eleven field trials (p value = 0.054). However, using both shakers simultaneously—except for Trial 8—produced better harvester efficiency than either shaker alone. The average harvest efficiency of all three shaking methods demonstrated that the combined shaker method improved harvester efficiency by 41% and 19% compared to the canopy shaker and trunk shaker, respectively.

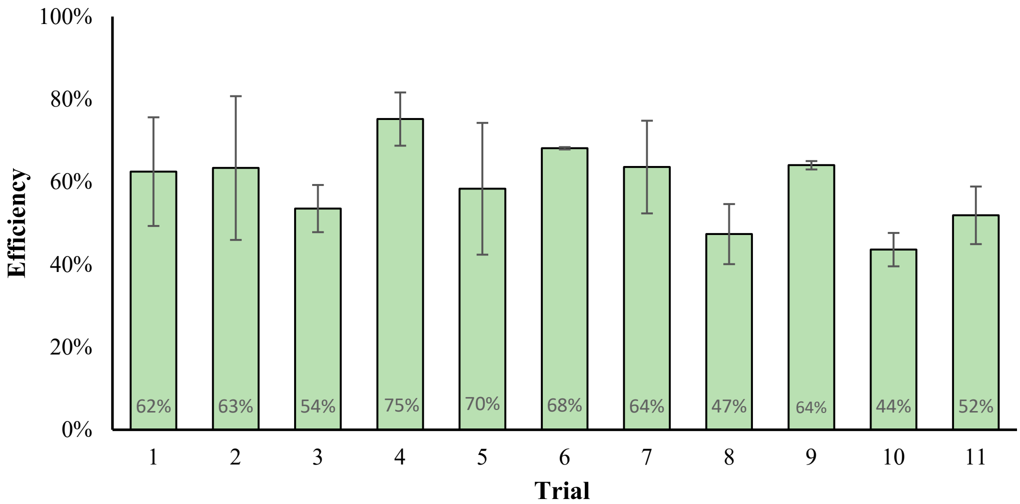

Figure 8. Harvest efficiency of all 11 trials. In Trials 1 to 9, both shakers were used simultaneously, and in Trials 10 and 11 the canopy and trunk shaker, respectively, were used alone.

The results of the combined shaking trials versus the solo shaking trials (Trials 10 and 11) demonstrated that shaking olive trees simultaneously with both canopy and trunk shakers resulted in higher harvest efficiencies by 22% and 10%, on average, respectively. Among the nine trials in which both shakers were employed, Trials 4 and 6 showed the best harvest efficiencies of 75% and 68%, respectively.

Combined shaking methods previously reported in the literature also showed promising results compared to solo shaking methods. Zipori et al. [35] reported that using a trunk shaker while three to four workers simultaneously beat the tree with fiberglass rods improved harvester efficiency to above the 80% economic threshold. Without the four-man beating crew, the harvester efficiency dropped to 40–58%. Similar results were reported using hand-held pneumatic combs, mechanical beaters, and trunk shakers for large 60 to 100-year-old olive trees. Harvesting with a hand-held comb and mechanical beater removed 87.2–89.9% of the olives versus a solo trunk shaker removing 40–72.5% [36]. These high harvesting efficiencies used two to four workers per tree and were 60 s long; a potential reason for the high efficiencies reported. Their reported efficiencies for mechanical operation without the simultaneous beating teams reported values consistent with the results reported here. Table 2 compares our results with those of earlier studies.

Figure 9 shows the root mean square (RMS) of vibrations measured by the accelerometer sensors installed in the olive tree canopies; it reveals that the vibrations were more uniform when the two shakers were operated simultaneously versus using the shakers individually. These results are consistent with the higher harvest efficiency observed when using the combined method.

Table 2. Comparison of fruit removal and shaking period in different studies on mechanical harvesting.

Crop	Fruit Removal Efficiency	Shaking Period	Description	Ref.
Olive	50%	—	No obsession chemical	[24]
Citrus	69.1%	—	—	[16]
Olive	>80%	30–60 s	Trunk shaker + 3 to 4 beating crews	[35]
Olive	40–60%	30–60 s	Trunk shaker + 3 to 4 beating crew	[35]
Olive	87.2–89.9%	60 S	Trunk shaker + Mechanical comb +2 Beating crews	[36]
Olive	40–72%	60 S	Trunk shaker	[36]
Olive	54–75% 52% 44%	15 S	Trunk Shaker + Canopy shaker Trunk Shaker Canopy shaker	This study

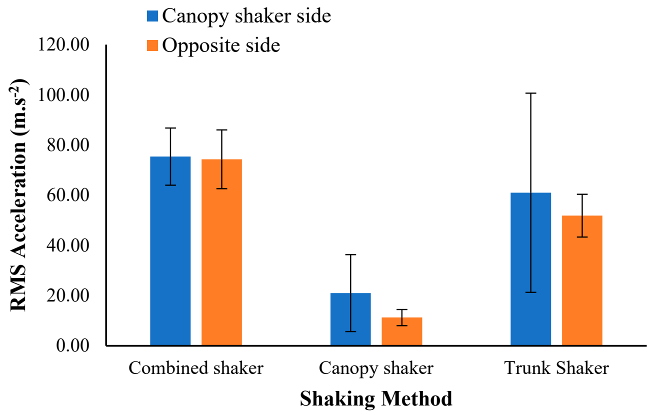

Figure 9. RMS of acceleration in olive tree canopies in different experimental trials.

Fruit size and damage were measured at a commercial grading station to produce a price per ton. The results of the ANOVA test for the Price Per ton index were significantly different (p value = 0.035). Mean comparisons using the multi-range Duncan test are presented in Figure 10. Trials 5 and 6 received the highest values among all the trials and were also distinguishably different.

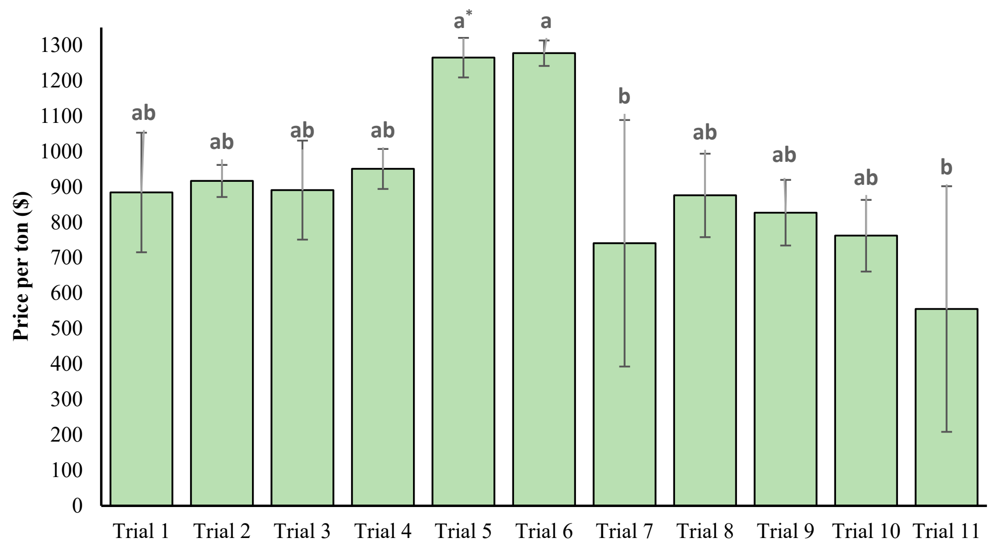

Figure 10. Price per ton for each trial. * Means with different letters are significantly different at a 5% confidence level.

By comparing the mean price per ton of the three shaking methods, it was confirmed that using both shakers simultaneously could increase this index by 63% and 37% compared to a trunk shaker and canopy shaker, respectively. These results again prove the higher performance of combined shaking compared to using a canopy or trunk shaker individually.

Figure 11 shows the fruit size distribution by percent among the individual and combined shaking methods. The uniformity of spread in the vibrations inside the tree canopy in the combined shaking method detached significantly more extra-large, large, and medium size olives compared to the other two solo harvest methods.

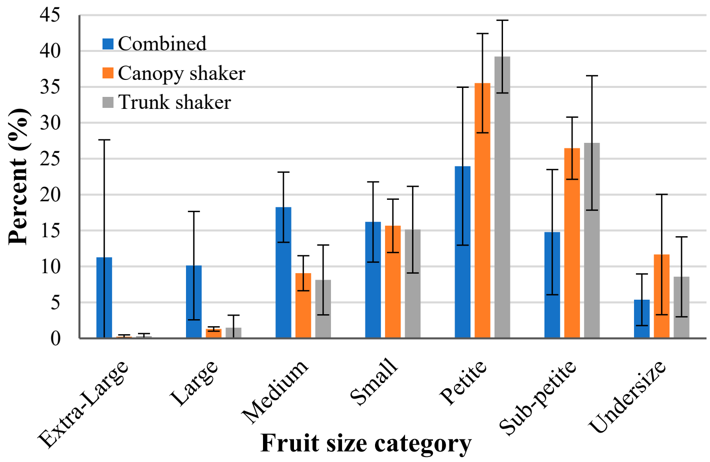

Figure 11. Harvested fruit size using combined, canopy, and trunk shakers.

Since harvested fruits with extra-large, large size, and medium size affect the final quality evaluation metrics more than the other size categories, the combined percentages of harvested fruits in these categories were statistically analyzed. The results of the ANOVA test for these size categories were highly significant (p value = 0.0004). Comparing the means also revealed that Trials 5 and 6 harvested significantly more fruit in these size categories versus those trials with 89% and 79% of total harvested fruits, respectively.

4. Conclusions

This study evaluated a new canopy contact shaker prototype versus a commercial trunk shaker harvesting machine in a moderate-density hedgerow table olive orchard. Although the canopy shaker harvested fruits with higher quality, the harvest efficiency was unacceptable as the shaker could not properly access the space between the trees within the row.

Combining the canopy and trunk shaking methods improved the efficiency and quality of the harvested olives. A canopy shaker rotational speed of 150 rpm and a trunk shaker vibration intensity setting of medium and high, respectively, produced significantly higher harvest efficiency and better removal of larger fruit than either harvester individually. This suggests that incorporating both trunk and canopy shaking technologies into a single harvester would produce a more efficient harvester.

Compared to prior studies with fruit removal efficiencies above 80%, our final harvester efficiency was 5% lower at 75%. However, our trial had a significantly shorter shaking time of 15 s compared to the 30 to 60 s reported in the previous studies. Also, our method did not use manual labor; the earlier studies used 2 to 4 man beating crews per tree.

Author Contributions: Conceptualization, M.M. and R.E.; methodology, T.H., M.M., A.T. and R.E.; software, T.H., A.T. and M.M.; validation, L.F.; formal analysis, A.T. and L.F.; investigation, T.H., M.M., A.T., R.E. and L.F.; resources, L.F. and R.E.; data curation, T.H., A.T. and L.F.; writing—original draft preparation, T.H. and M.M.; writing—review and editing, M.M., A.T., R.E. and L.F.; visualization, T.H., M.M. and A.T.; supervision, R.E. and L.F.; project administration, R.E.; funding acquisition, R.E. and L.F.; All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the California Olive Committee, grant number A18-0057.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data Sharing is not applicable.

Acknowledgments: The authors are grateful to the California Olive Committee for partially funding this project.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. California Department of Food and Agriculture. California Agricultural Statistics Review. 2021. Available online: https://www.cdfa.ca.gov/Statistics/PDFs/2021_Ag_Stats_Review.pdf (accessed on 27 March 2023).
2. Macías-Macías, M.; Sánchez-Santamaria, H.; García Orellana, C.J.; González-Velasco, H.M.; Gallardo-Caballero, R.; García-Manso, A. Mask R-CNN for quality control of table olives. *Multimed. Tools Appl.* **2023**, *82*, 1–15. [CrossRef]
3. Emmanouilidou, M.G.; Koukourikou-Petridou, M.; Gerasopoulos, D.; Kyriacou, M.C. Evolution of physicochemical constitution and cultivar-differential maturity configuration in olive (*Olea europaea* L.) fruit. *Sci. Hortic.* **2020**, *272*, 109516. [CrossRef]
4. Cicek, G. Determination of harvesting costs and cost analysis for different olive harvesting methods. *J. Food Agric. Environ.* **2011**, *9*, 201–204.
5. Homayouni, T.; Gholami, A.; Toudeshki, A.; Afsah-Hejri, L.; Ehsani, R. Estimation of proper shaking parameters for pistachio trees based on their trunk size. *Biosyst. Eng.* **2022**, *216*, 121–131. [CrossRef]
6. Defterli, S.G.; Shi, Y.; Xu, Y.; Ehsani, R. Review of robotic technology for strawberry production. *Appl. Eng. Agric.* **2016**, *32*, 301–318.
7. Gholami, A.; Homayouni, T.; Ehsani, R.; Sun, J.-Q. Inverse Kinematic Control of a Delta Robot Using Neural Networks in Real-Time. *Robotics* **2021**, *10*, 115. [CrossRef]
8. Bayano-Tejero, S.; Martínez-Gila, D.; Blanco-Roldán, G.; Sola-Guirado, R.R. Cleaning system, batch sorting and traceability between field-industry in the mechanical harvesting of table olives. *Postharvest. Biol. Technol.* **2023**, *199*, 112278. [CrossRef]
9. Ursol, L.M.; Conchione, C.; Peroni, D.; Carretta, A.; Moret, S. A study on the impact of harvesting operations on the mineral oil contamination of olive oils. *Food Chem.* **2023**, *406*, 135032. [CrossRef]
10. Horvath, E.; Sitkei, G. Damping properties of plum trees shaken at their trunks. *Trans. ASAE* **2005**, *48*, 19–25. [CrossRef]
11. Ma, R.; Homayouni, T.; Toudeshki, A.; Ehsani, R.; Zhang, X. An Experimental Study and Mathematical Modeling of Vibration Transfer in Pistachio Trees Using an Inertia-Type Trunk Shaker and Field-Adapted Wireless Sensors. *Shock Vib.* **2022**, *2022*, 99666848. [CrossRef]
12. Sanchez-Cachinero, P.; Luque-Mohedano, R.; Sola-Guirado, R.R. Computational Model for the Dynamic Characterisation of a Trunk Shaker. *Agriculture* **2022**, *12*, 2158. [CrossRef]
13. Afsah-Hejri, L.; Homayouni, T.; Toudeshki, A.; Ehsani, R.; Ferguson, L.; Castro-García, S. Mechanical harvesting of selected temperate and tropical fruit and nut trees. *Hortic. Rev.* **2022**, *49*, 171–242.
14. Affeldt Jr, H.A.; Brown, G.K.; Gerrish, J.B. A new shaker for fruit and nut trees. *J. Agric. Eng. Res.* **1989**, *44*, 53–66. [CrossRef]
15. Ravetti, L.; Ravetti, L. *Guide to Efficient Olive Harvesting*; Rural Industries Research and Development Corporation: Kingston, Australia, 2008.
16. Castro-Garcia, S.; Castillo-Ruiz, F.J.; Jimenez-Jimenez, F.; Gil-Ribes, J.A.; Blanco-Roldan, G.L. Suitability of Spanish 'Manzanilla'table olive orchards for trunk shaker harvesting. *Biosyst. Eng.* **2015**, *129*, 388–395. [CrossRef]
17. O'Brien, M.; Fridley, R.B. Measurement of vibrations related to harvesting and handling of fruits and vegetables. *Trans. ASAE* **1970**, *13*, 870–873.
18. Fridley, R.B.; Claypool, L.L.; Mehlschau, J.J. A new approach to tree fruit collection. *Trans. ASAE* **1975**, *18*, 859–863. [CrossRef]
19. Liu, T.H.; Ehsani, R.; Toudeshki, A.; Abbas, M.; Zou, X.J. Shaking functionality evaluation of four different types of citrus canopy-shaker tines. *Appl. Eng. Agric.* **2018**, *34*, 809–817. [CrossRef]
20. Sarkar, P. Use of shaking mechanism and robotic arm in fruit harvesting: A comprehensive review. *J. Crop Weed* **2021**, *17*, 1–9. [CrossRef]
21. Sola-Guirado, R.R.; Ceular-Ortiz, D.; Gil-Ribes, J.A. Automated system for real-time tree canopy contact with canopy shakers. *Comput. Electron. Agric.* **2017**, *143*, 139–148. [CrossRef]
22. Ferguson, L.; Castro-García, S.; Burns, J.K.; Glozer, K. Mechanical harvesting of California table and oil olives. *Adv. Hortic. Sci.* **2010**, *24*, 53–63.
23. Pu, Y.; Toudeshki, A.; Ehsani, R.; Yang, F. Design and evaluation of a two-section canopy shaker with variable frequency for mechanical harvesting of citrus. *Int. J. Agric. Biol. Eng.* **2018**, *11*, 77–87. [CrossRef]
24. Sessiz, A.; Özcan, M. Olive removal with pneumatic branch shaker and abscission chemical. *J. Food Eng.* **2006**, *76*, 148–153. [CrossRef]

25. Zhang, X.; He, L.; Karkee, M.; Whiting, M.D.; Zhang, Q. Field evaluation of targeted shake-and-catch harvesting technologies for fresh market apple. *Trans. ASABE* **2020**, *63*, 1759–1771. [CrossRef]
26. Zhou, J.; He, L.; Karkee, M.; Zhang, Q. Analysis of shaking-induced cherry fruit motion and damage. *Biosyst. Eng.* **2016**, *144*, 105–114. [CrossRef]
27. Savary, S.K.J.U.; Ehsani, R.; Schueller, J.K.; Rajaraman, B.P. Simulation study of citrus tree canopy motion during harvesting using a canopy shaker. *Trans. ASABE* **2010**, *53*, 1373–1381. [CrossRef]
28. Castro-Garcia, S.; Aragon-Rodriguez, F.; Sola-Guirado, R.R.; Serrano, A.J.; Soria-Olivas, E.; Gil-Ribes, J.A. Vibration monitoring of the mechanical harvesting of citrus to improve fruit detachment efficiency. *Sensors* **2019**, *19*, 1760. [CrossRef]
29. Pu, Y.; Toudeshki, A.; Ehsani, R.; Yang, F.; Abdulridha, J. Selection and experimental evaluation of shaking rods of canopy shaker to reduce tree damage for citrus mechanical harvesting. *Int. J. Agric. Biol. Eng.* **2018**, *11*, 48–54. [CrossRef]
30. Liu, T.; Ehsani, R.; Toudeshki, A.; Zou, X.; Wang, H. Experimental Study of Vibrational Acceleration Spread and Comparison Using Three Citrus Canopy Shaker Shaking Tines. *Shock Vib.* **2017**, *2017*, 9827926. [CrossRef]
31. Burns, J.K.; Ferguson, L.; Glozer, K.; Krueger, W.H.; Rosecrance, R.C. Screening fruit loosening agents for black ripe processed table olives. *HortScience* **2008**, *43*, 1449–1453. [CrossRef]
32. Du, X.; Chen, K.; Ma, Z.; Wu, C.; Zhang, G. Design, construction, and evaluation of a three-dimensional vibratory harvester for tree fruit. *Appl. Eng. Agric.* **2020**, *36*, 221–231. [CrossRef]
33. Torregrosa, A.; Albert, F.; Aleixos, N.; Ortiz, C.; Blasco, J. Analysis of the detachment of citrus fruits by vibration using artificial vision. *Biosyst. Eng.* **2014**, *119*, 1–12. [CrossRef]
34. Castro-Garcia, S.; Rosa, U.A.; Gliever, C.J.; Smith, D.; Burns, J.K.; Krueger, W.H.; Ferguson, L.; Glozer, K. Video evaluation of table olive damage during harvest with a canopy shaker. *HortTechnology* **2009**, *19*, 260–266. [CrossRef]
35. Zipori, I.; Dag, A.; Tugendhaft, Y.; Birger, R. Mechanical harvesting of table olives: Harvest efficiency and fruit quality. *HortScience* **2014**, *49*, 55–58. [CrossRef]
36. Famiani, F.; Farinelli, D.; Rollo, S.; Camposeo, S.; Di Vaio, C.; Inglese, P. Evaluation of different mechanical fruit harvesting systems and oil quality in very large size olive trees. *Span. J. Agric. Res.* **2014**, *12*, 960–972. [CrossRef]