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Research Article

# Development of Olive Harvesting Machine by Shaking

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## ABSTRACT

Olive harvesting machine by shaking was developed and fabricated using local materials with required specifications. The developed elements were frame and hitch, gear assembly, input and transmission shafts, vibrating unit, connecting rod, limb clamp, and transmission system. This research work aimed to evaluate the developed olive harvester capable to perform harvesting operation in the proper time using the tractor as the available economic source of power. Measurements covered the properties of olive fruit, stem, and limb for five olive varieties: Agizi, Manzanillo, Picholine, Kalamata and Arbiquen. The developed harvester was tested at three levels of frequency; 3.3, 6.7, and 10 Hz, four levels of stroke; 40, 80, 120, and 160 mm, and three levels of shaking time 60, 120 and 180 s. Results indicated that the effective range to attach the clamp on the olive limb were 30 to 40% of limb length. The average value of the maximum bending stress affecting the limb and limb deflection were 16.5 MPa and 196.6 mm respectively. In addition, results have provided the suitability of the developed shaker to harvest olive fruit. The suitability of the developed machine was judged through the fruit removal percentage. The values of performance parameters of olive harvester were 10 Hz optimum shaking frequency, 120 mm of stroke, and 120 s of shaking time.

**RESEARCH ARTICLE**

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## INTRODUCTION

Olive crops are considered one of the main crops all over the world. Olive cultivation increased considerably during the last two decades due to the great efforts paid for expanding olive cultivated areas with new cultivars in reclaimed areas (FAOSTAT, 2018). Olive harvesting is the most important operation among all production operation, and the manual harvesting is the traditional method in some countries. The cost of manual harvesting ranged from 30 to 60% of the total production costs and about 30% from the total price of crop production (Cicek, 2011). Mechanical harvesting of olives is a very important aspect in olive growing both to reduce the costs of production and to assure oil quality (Testa *et al.*, 2014). The mechanical harvesting of olives is performed either by shaking or combing the tree (Nasini and Proietti, 2014). Almeidaa *et al.* (2015) listed several factors that affect the mechanical harvesting of olive trees such as, tree shape, pruning methods, canopy density, orchard management, fruit removal force, fruit weight and the ratio between fruit removal force and fruit weight. Ferguson *et al.* (2010) stated that the factors affecting the mechanical harvesting of tree fruits by shaking are frequency, eccentricity, direction of shaking, fruit size, shaking time and detachment force to fruit weight ratio. Fruit detachment force (FDF) and fruit fresh weight were used to predict harvesting efficiency, although during harvesting process, fruit is subjected to bending and twisting movement besides pulling forces simulated by FDF measurements (Ruiz *et al.*, 2018). Babanatsas *et al.* (2019) derived a mathematical relationship to predict the power required for vibration. The derived equation correlates the modulus of elasticity at olive tree, rupture module on the olive tree, trunk diameter and length, correction module and shaking amplitude. Ghonimy (2006) derived a mathematical relationship to predict the suitable-shaking amplitude of limb tree shaker. The derived equation correlates the pulling force to fruit mass ratio, stem length, shaking frequency and damping ratio with the shaking amplitude. Bernardi *et al.* (2018) found that the work capacities varied between 5 tons of harvested olives per day when employing mechanical harvest aids and 18 tons per day when employing trunk shakers. Guirado *et al.* (2016) developed and tested a continuous lateral canopy shaker harvester on large olive trees in order to analyze the operating harvester parameters and tree properties to improve mutual adaptation. They found that the 77.3% of removal efficiency was achieved during 28 s shaking duration, 0.17 m amplitude vibration and 12 rod drum. This result was obtained reporting 0.26 s of accumulative shaking time over 200 m $s^{-2}$ resultant acceleration. Morad and El-Termezy (2020) evaluate the performance of manufactured olive harvester and they found that the harvester productivity, 26.7 tree/h, harvesting losses, 1.8%, specific energy, 0.674 kWh/tree, and operational cost, 3.152 L.E./tree were achieved at 300 rpm PTO speed, 15 cm vibration amplitude, and 1.0 m vertical height clamp position on the tree. Zipori, *et al.* (2014) compared between the final product quality and harvesting efficiency of the manual picking and trunk shaking mechanical harvesting for four different cultivars of green table olive. They found that elimination of rod beating significantly reduced harvesting efficiency, they also reported that the final product quality of the mechanically harvested olives of cv. Manzanilla was inferior to those picked manually. Alzoheiry *et al.* (2020) estimated the natural frequency (FN) of olive fruit stem system using one and two degrees of freedom models. Their result indicated that the FN value of full mature stage was 33.9 Hz, half-ripe olive was

31.9 Hz, and 28.0 Hz for full-ripe olive. They found that the maximum fruit removal percentage value, 90.6%, could be achieved at a frequency of 35 Hz and amplitude of 25 mm. A handheld olive harvester for small farms was developed and evaluated by Ghonimy et al. (2020). They found that a 1600 rpm of head rotating speed gave the optimal machine productivity, and fruit removal percentage. Thus, the aim of this study is to evaluate the developed olive harvester capable to perform harvesting operation in the proper time using the tractor as the available economic source of power.

## MATERIALS and METHODS

The plan of realizing the objective of this research was based upon designed the functional parts of the limb tree shaker, assembling of these functional parts in a compacted machine, and testing the developed machine in the field under normal operating conditions.

### Design considerations of the olive harvesting machine

1. It should be simple and should be constructed by locally available materials.
2. It should be small and realize reasonable capacity.
3. It should use standard components to save time and money.
4. It should be to minimize the mechanical damage of olives tree and fruits.

### The components of the developed olive harvester

The developed olive harvester consists of seven functional subsystems, frame and hitch, gear assembly, input and transmission shafts, vibrating unit, connecting rod, limb clamp, and transmission system.

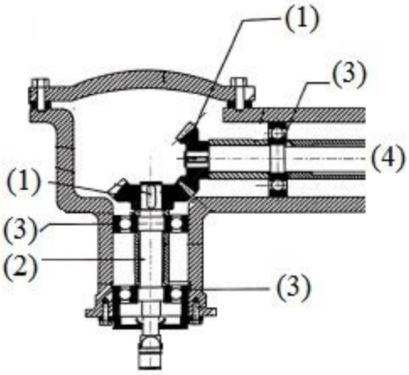
### Frame and hitch

The frame and three-point hitch of the developed harvester were manufactured of steel pipe having 2.0 inch (5.08 cm) outside diameter. The frame, Figure 1, has two parts; the first part manufactured of steel pipe 5.08 cm diameter and 3 mm thickness, and includes the three-point hitch. The second part of the frame was manufactured of steel plate to fix the shaker by six screw bolts in the shaker base. Rubber pads were imbedded under the shaker base to reduce the vibrations resulted from the tractor.

**Figure 1.** The frame and hitch points of olive harvester.

### Gear assembly

The gear assembly, Figure 2, of the olive harvester consisted of two bevel gears, two ball bearings, and input shaft. According to the design calculations, the kinematics of gears were 15 teeth, 5 mm module, 75 mm diameter, 20° pressure angle, and 41.42° pitch angle. In addition, the forces (tangential, axial, and radial forces) and bending stress applied on gear tooth were 832.24 N, 227.15 N, 200.40 N, and 54.39 MPa respectively. The gears material is made of steel 50. The endurance limit (Se) of gear material is 235.5 MPa, and the total resulted factor of safety (Fs total) is 1.73 > 1.




(1) Bevel gears (2) Input shaft (3) Ball bearing (4) Transmission shaft

**Figure 2.** The gear assembly of olive harvester.

The second part of gear assembly was input shaft. Input shaft receives the motion from the hydraulic motor and transmits it to gear assembly. According to the design calculations, the dimensions of input shaft are 274 mm length and 30 mm diameter. The input shaft material is steel 50. The mechanical properties of steel 50 included tensile strength, yield strength, elastic modulus, and poisson's ratio were 450 MPa, 345 MPa, 190-210 GPa and 0.27-0.30 respectively. Ball bearings (SKF) are usually used with some combination of radial and thrust (axial) load. The bearing 6006 satisfies safety.

The motion transmits from gear assembly to vibrating unit using transmission shaft, Figure 2. The length of transmission shaft is 840 mm. The transmission shaft material is steel 50. According to the design calculations, the minimum shaft diameter is 30 mm. Using transmission shaft of diameter equal to 40 mm satisfies safety.

**Vibrating unit**

Vibrating unit convert the rotating speed of the transmission shaft to a reciprocating movement (shaking stroke) to the connecting rod.

Vibrating unit, Figure 3, was designed from a circular disk ended with eccentric pin. The ball bearings are connected with a pin, which is fastened on the vibrating unit. The rotating disk of the shaker had four holes that were used to adjust the tested strokes.

To determine the suitable shaking stroke, five limbs for each olive variety were selected and balance hanged at the point, which represents 40% of the limb length, as recommended by Erdoğan *et al.* (2003). A test was run to measure the maximum limb deflection with load, Figure 4. A tree trunk was held vertically by a support the initial position of the limb attachment location where the load was applied was marked by using a pin on the leveling staff. Loads were added gradually at a rate of 5 kg and the limb deflection was measured. The loading was continued until the limb breaking occurred.

(1) Vibrating unit.
(2) Pin.
(3) Ball bearing.

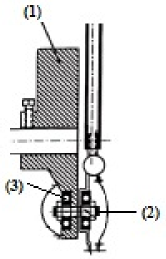



**Figure 3.** Vibrating unit.

**Connecting rod**

The dimensions of the connecting rod, Figure 5, are two meter long and 19 mm diameter.

**Limb clamp**

The limb clamp, Figure 5, consists of two parts of wood. The dimensions of the limb clamp were 200 mm length, 120 mm width and 70 mm depth. The inside phase of the clamp is covered with a layer of sponge which is covered with a layer of leather. The two inside parts of the clamp are called pad. The function of the pad system is to transmit shaking force from the shaker to the limb, and to distribute the shaking and clamping force over a layer area to minimize stresses in the contact area.

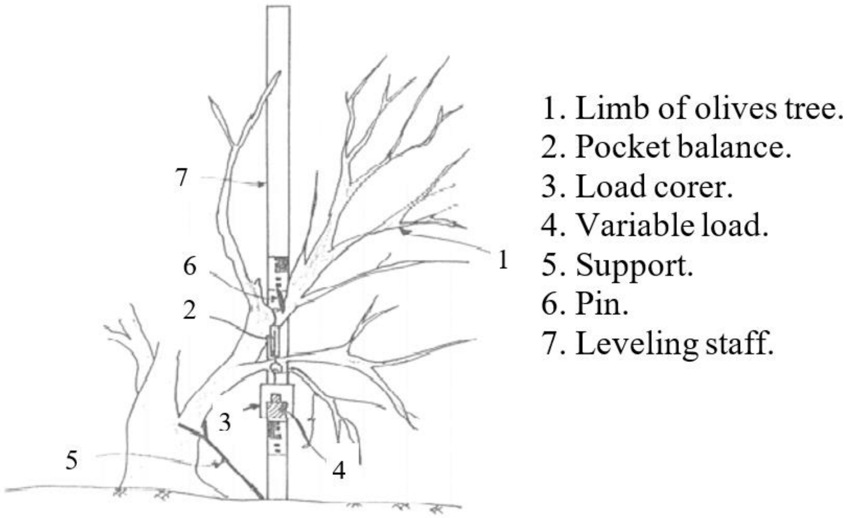
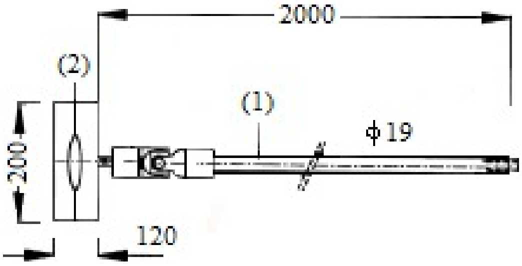



**Figure 4.** Schematic diagram of loading procedures.




(1) Connecting rod (2) Limb clamp Dimensions in mm

**Figure 5.** Connecting rod and limb clamp.

**Transmission system**

To transmit the motion from the tractor to olive harvester, hydraulic transmission system was used. The transmission system of the olive harvester consists of three main elements.

**a) Hydraulic hose**

The function of the hydraulic hose is to convey hydraulic fluid to hydraulic components, valves, actuators, and tools. SAE 100R1 hydraulic hose were used to convey the hydraulic oil from the tractor to flow control valve, oil hydraulic motor and returns to the tractor. This hose is a high-pressure hose is used with petroleum or water-based fluids designed to power general industrial applications. The hose is single steel, wire-braided tubing that will operate in temperatures ranging from -40°C to 100°C.

**b) Flow control valve**

The VRFB 90-series flow control valve is used to adjust the speed of an actuator in both directions, which enable controlling on the rotating speed of the Input shaft and bevel gears. The specifications of the used control valve were 35 l min$^{-1}$ maximum flow rate, 350 bar maximum pressure, and 0.4 kg weight.

**c) Hydraulic motor**

The oil hydraulic motor MP 40 is used. The specifications of the used hydraulic motor are shown in Table 1.

**Table 1.** The specifications of the hydraulic motor.

| Type | MP 40 | | |
|---|---|---|---|
| | Continous | Intermittierend | Peak |
| Max. Speed, rpm | 1500 | 1750 | -- |
| Max. Torque, daNm | 6.2 | 8.2 | 10.7 |
| Max. Output, kW | 8.4 | 11.6 | -- |
| Max. Oil Flow, l min$^{-1}$ | 60 | 70 | -- |
| Max. Pressure Drop, kPa | 12000 | 15500 | 22500 |
| Max. Inlet Pressure, kPa | 17500 | 20000 | 22500 |
| Max. Return Pressure, kPa | 17500 | 20000 | 22500 |
| Weight, kg | | 5.7 | |

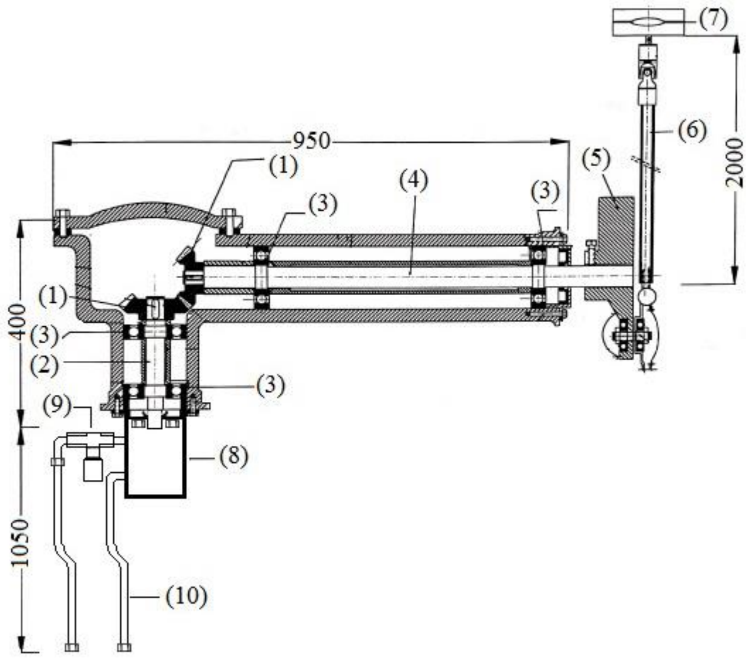
These subsystems were assembled in the compacted machine, Figures 6 and 7.

**Olive varieties**

The tested five olive varieties were Agizi, Manzanillo, Picholine, Kalamata and Arbiquen.

**Treatments**

The olive harvester was tested at three low tested values of frequencies were 3.3, 6.7 and 10 Hz (Leone *et al.*, 2015), four tested values of stroke 40, 80, 120, and 160 mm. While the period to shake any limb were 60, 120 and 180 s (O'brien *et al.*, 1983).




(1) Bevel gears (2) Input shaft (3) Ball bearing
(4) Transmission shaft (5) Vibrating unit (6) Connecting rod
(7) Limb clamp (8) Hydraulic motor (9) Flow control valve
(10) Hydraulic hose
Dimensions in mm

**Figure 6.** Sectional plan of the developed olive harvester.

**Figure 7.** Olive-harvester during operation.

## Laboratory and experimental measurements

### Laboratory measurements

The laboratory measurements included some properties of fruit, stem and limb. The properties of fruits were mass, volume, length, maximum diameter, density, moisture content, oil content, flesh thickness of and detachment force. The properties of stem were stem length, diameter and the moisture content.

### Bending stress ($\sigma b$) of limb tree

The applied stress ($\sigma_b$) on the limb was calculated from equation (1) (Shigley and Mitchell, 1983),

$$\sigma_b = \frac{10^{-6} \times F \times L \times d/2}{\frac{\pi}{64} d^4} \quad (1)$$

Where:
$\sigma_b$ = Bending stress, MPa,
$F$ = Applied load, N,
$L$ = Distance between load location and the base of limb, m,
$d$ = Limb diameter, m.

**Determine the point to attach the machine clamp on the limb length**

Five limbs for each olive's variety were selected and shacked under constant frequency 6.7 Hz, 40 mm stroke, 60 s shaking time and different attachment locations (10, 20, 30, 40, and 50% of limb length).

**Experimental tests**

The olive limbs were vibrated using the developed harvester. These limbs were chosen in a critical stage of maturity (contains full-ripe, half-ripe and full mature stage). Nylon nets were fixed on a stand to collect the removed fruits. The fruit removal percentage (*FR*P) was calculated from equation (2) according to Polat *et al.* (2007).

$$FRP = \frac{N_1}{N_2} \times 100 \quad (2)$$

Where:
$FRP$ = Fruit removal percentage, %
$N_1$ = Number of harvested olive fruits from one limb
$N_2$ = The total number of olive fruits from one limb

Also, the effect of mechanical harvesting on the trees were determined. The status of mechanically harvested trees was monitored through two seasons. These observations included leaf status (yellowing or falling leaves), main and subsidiary branches (fractures in the main or subsidiary branches of the tree), tree productivity, and bruises to the spines at the contact point of the vibrator clutch with the limb.

**Statistical analysis**

The measured data for all variables were statistically analyzed by microcomputer program (CoStat ver. 6.400, 2008) via analysis of variance using randomized complete block design, three factors model. The means of treatments were obtained, and differences were assessed with Student-Newman-Keuls at 5% level of probability.

## RESULTS AND DISCUSSION

**The properties of olive fruit, stem, and limb**

The mean values of some physical and mechanical properties of fruits for five full-ripe olive verities are shown in Table 2.

**Table 2.** Mean values of some properties of olive fruits for five varieties.

| Characteristics | Olive varieties | | | | |
|---|---|---|---|---|---|
| | Agizi | Manzanillo | Picholine | Kalamata | Arbiquen |
| **Length, mm** | 26.5 | 20.3 | 22.5 | 23.3 | 13.6 |
| **Diameter, mm** | 18.4 | 16.2 | 14.4 | 11.8 | 11.2 |
| **Volume, cm$^3$** | 4.95 | 3.06 | 2.11 | 1.96 | 0.97 |
| **Density, g cm$^{-3}$** | 1.02 | 1.00 | 1.20 | 1.04 | 1.04 |
| **Moisture content, %** | 69.97 | 66.78 | 66.47 | 67.16 | 63.18 |
| **Oil content, %** | 4.72 | 20.29 | 15.30 | 15.10 | 15.55 |
| **Flesh thickness, mm** | 5.62 | 3.84 | 3.51 | 3.33 | 1.87 |
| **Detachment force ($F$), N** | 6.65 | 5.81 | 5.36 | 4.36 | 2.40 |
| **Mass ($m$), g** | 5.04 | 3.05 | 2.53 | 2.03 | 1.01 |
| ***F/m*, N g$^{-1}$** | 1.32 | 1.90 | 2.12 | 2.15 | 2.38 |

It is clear that a noticeable difference in the characteristics among the tested varieties existed. Detachment force of fruit was thoroughly examined as it plays an important role in the performance of shaking machine. The detachment force of great number olive limbs of the five different varieties of olives was determined. The frequency distribution of these measurements shown in Figure 8.

Analysis of these data proves that there is a direct relationship between the value of the detachment force of olive fruit and it's mass. As the mass of olive fruit decreases the required detachment force decreases.

The stem and the limb of the olives tree for the five tested varieties occupied a significant interest as they are the affected parts of the tree and they determine the limits of the shaking action. The results of the physical properties of stem for different varieties were measured and are given in Table 3. Also, Table 3 shows the results of the physical properties of stem such as stem length, diameter and moisture content of different varieties. The minimum stem length is 24.7 mm for Arbiquen variety, and the maximum stem diameter is 43.5 mm for Agizi variety.

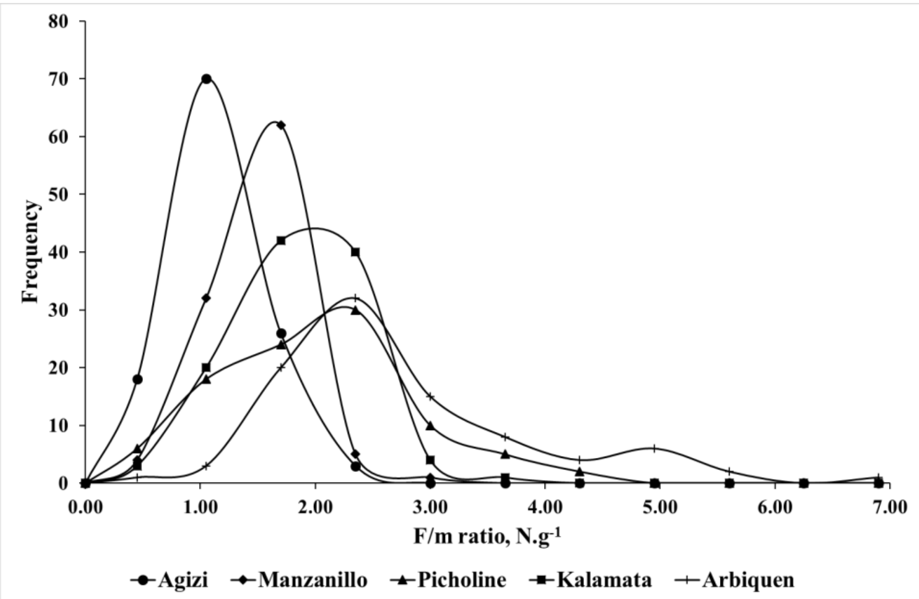



**Figure 8.** The frequency distribution of the F/W ratio.

**Table 3**. Mean values of some physical properties of stem and limb of five olive varieties.

| Characteristics | Olive varieties | | | | |
|---|---|---|---|---|---|
| | Agizi | Manzanillo | Picholine | Kalamata | Arbiquen |
| Stem length, mm | 43.5±2.13[a] | 37.7±0.85 | 33.5±1.44 | 30.4±2.16 | 24.7±1.75 |
| Stem diameter, mm | 1.3±0.93 | 1.4±0.47 | 1.3±0.23 | 1.1±0.32 | 1.2±0.85 |
| Stem MC, % | 48.57±4.54 | 50.84±3.19 | 63.40±2.18 | 59.30±2.16 | 79.22±3.20 |
| Limb length, m | 2.71±0.80 | 2.27±0.23 | 2.34±0.14 | 2.43±0.15 | 2.17±0.41 |
| Limb MC, % | 12.50±1.85 | 13.00±2.05 | 12.00±1.85 | 16.50±3.15 | 19.00±2.65 |

[a] Standard deviation (SD); difference between two means ≥SD indicates significant difference.

The results of the limb diameter of five olive varieties are given in Table 4. In this experiment, five limbs were chosen for each of the tested varieties, and the limb diameter was estimated at five locations on the limb; 10, 20, 30, 40, and 50% of the limb length from its base. The results in table 4 show that the limb diameter increased by decreasing the location at the limb. The minimum value of limb diameter was 25.2 mm for Picholine variety at 50% of limb length while the maximum value of limb diameter was 50.3 mm for Arbiquen variety at 10% of limb length. In addition, the mean value of limb diameter is 35.7 mm. The results in Table 4 affect the dimensions of the padding area of the developed limb clamp of the harvester.

**Table 4.** Mean values of limb diameter of five olive varieties.

| Characteristics | Limb diameter, mm | | | | | |
|---|---|---|---|---|---|---|
| | Agizi | Manzanillo | Picholine | Kalamata | Arbiquen | Average |
| 10% Limb length | 37.6± 0.58* | 34.5± 0.93 | 37.5± 0.75 | 41.4± 0.68 | 50.3± 0.93 | **40.3**± 5.48 |
| 20% Limb length | 36.0± 0.40 | 32.1± 0.37 | 34.3± 0.93 | 39.9± 0.58 | 47.6± 1.03 | **38.0**± 5.45 |
| 30% Limb length | 34.3± 0.51 | 29.7± 0.55 | 31.5± 1.02 | 37.8± 0.75 | 44.4± 0.86 | **35.5**± 5.21 |
| 40% Limb length | 32.1± 1.12 | 28.1± 1.05 | 28.5± 0.51 | 36.0± 0.58 | 43.1± 0.40 | **33.6**± 5.56 |
| 50% Limb length | 29.9± 0.40 | 26.6± 0.66 | 25.2± 0.81 | 33.0± 0.97 | 41.1± 1.51 | **31.2**± 5.66 |
| **Average** | | | | | | **35.7** |

* STDEV standard deviation based on the entire population

## Performance Parameters and Preliminary Experiments Analysis

### a) Effect of load on the limb deflection

Figure 9 shows the relation between the load in kg and the limb deflection in mm for each olive's variety. The maximum limb deflection causing a limb breaking was 235 mm for Picholine variety at 70 kg load. While the minimum limb deflection causing a limb breaking was 160 mm for Arbequien variety at 60 kg load. Thus, it can be considered that the deflection of the limb at which a breaking occurs is 160 mm. If a safety factor of 50% is used, then the maximum deflection of the limb was 80 mm, thus the maximum stroke was 160 mm. Thus, the tested values of stroke were 40, 80, 120 and 160 mm.

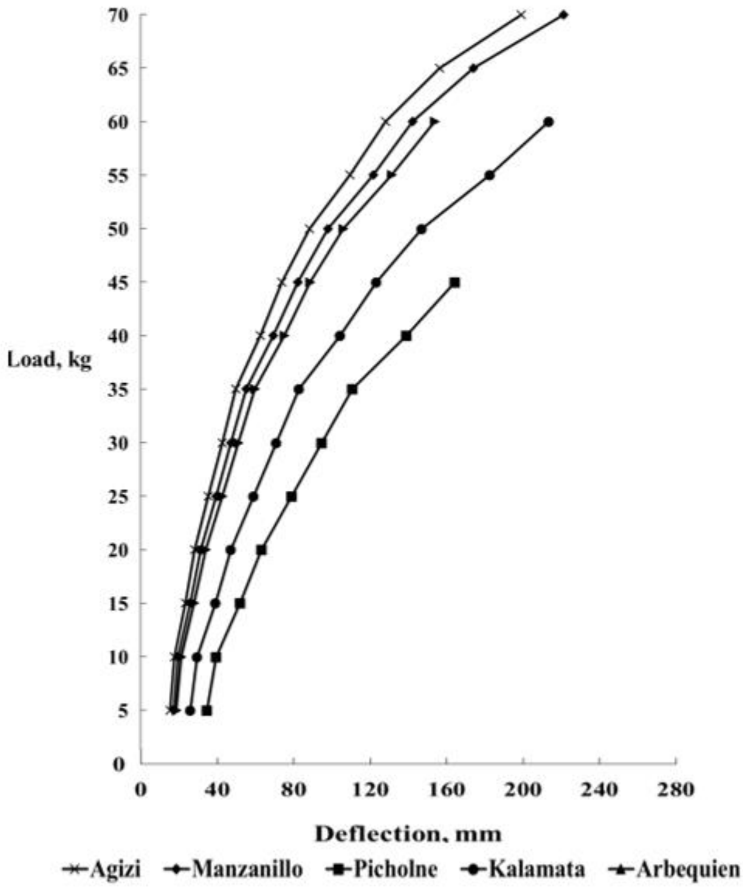



**Figure 9.** The effect of load on the olive limb deflection.

**b) Effect of the point to attach the machine clamp with the limb on the fruit removal**

The results of this experiment are tabulated in Table 5. The results show that increasing the attachment locations from 10% to 40% tends to increase the removal percentage by 8%, but the increase of attachment location from 40 to 50%, decreased the removal percentage by 4%. Thus, the optimum point to attach the clamp of the machine ranged from 30 to 40% of the limb length. These results are close to the results found by Erdoğan *et al.* (2003).

**Table 5.** The removal percentage under different location of olives varieties.

| Location | Olive varieties | | | | | Average |
|---|---|---|---|---|---|---|
| | Agizi | Manzanillo | Picholine | Kalamata | Arbiquen | |
| 10 % L | 26.70±1.21[a] | 23.72±0.66 | 24.85±0.61 | 23.03±0.95 | 20.04±1.76 | 23.67 |
| 20 % L | 29.25±1.05 | 26.26±1.21 | 25.91±1.01 | 26.38±1.00 | 22.64±0.63 | 26.09 |
| 30 % L | 32.07±0.92 | 30.22±1.00 | 27.48±1.82 | 28.83±1.01 | 24.14±1.07 | 28.55 |
| 40 % L | 34.98±1.16 | 33.29±1.66 | 32.01±1.16 | 31.87±1.44 | 26.76±1.54 | 31.78 |
| 50 % L | 31.82±0.82 | 29.89±1.01 | 25.89±0.46 | 26.36±1.18 | 24.44±0.90 | 27.68 |

[a] Standard deviation (SD); difference between two means ≥SD indicates significant difference.

**c) Relationship between shaking stroke and bending stress (σb) affecting the olive limb**

The results of bending stress (σb) are presented in Table 6 and Figure 10. Table 6 shows the maximum stress on the limb causing breaking and the maximum deflection. The average value of maximum bending stress on the limb is 16.5 MPa with SD ± 3.626 MPa. The average value of maximum limb deflections for all varieties is 196.6 mm with SD ± 0.964 mm, this value were between (-) 36.6 mm and (+) 38.4 mm around the average. Figure 10 shows the bending stress on the limb at four chosen strokes. It is clear that the affected stress at the different strokes ranged between 20.85% and 75.03% of the maximum stress causing breaking of the limb.

**Table 6.** The maximum bending stress ($\sigma_b$) affecting the limb and maximum deflection

| Varieties | Maximum ($\sigma_b$), MPa | Maximum deflection, mm |
|---|---|---|
| Agizi | 17.8 | 200 |
| Manzanillo | 17.7 | 164 |
| Picholine | 20.8 | 235 |
| Kalamata | 14.8 | 224 |
| Arbiquen | 11.2 | 160 |
| Average | 16.5 | 196.6 |
| S.D. | 3.626 | 0.694 |

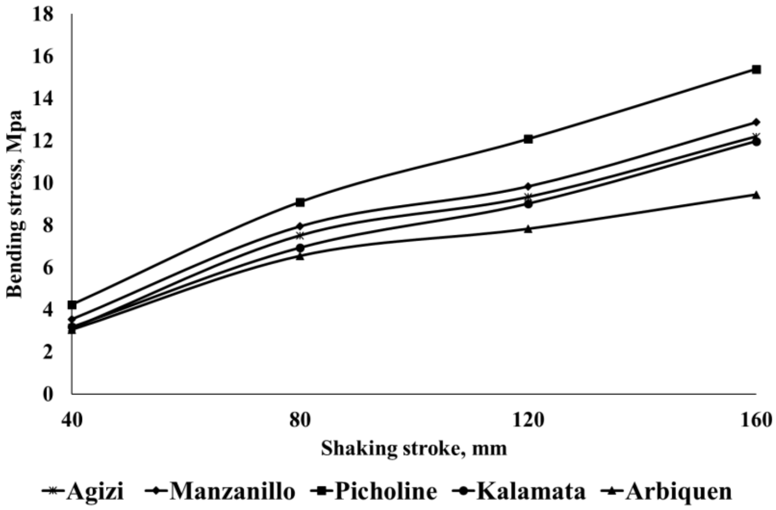



**Figure 10.** Relation between shaking stroke and bending stress affecting the olive limb.

## Fruit removal percentage (*FRP*)

The average values of fruit removal percentage *(FRP)* for five olive varieties are shown in Figure 11. It is clear that the *FRP* increased by increasing applied frequency, shaking stroke and shaking time.

### a) Effect of applied frequency on the fruit removal percentage

For Agizi variety at 40 mm stroke and 60 s shaking time, the *FRP* increased by 7.3 and 19.39% when the frequency increased from 3.3 Hz to 6.7 and 10 Hz respectively. Also, the *FRP* increased by 8% when the applied frequency increased from 6.7 Hz to 10 Hz. The same trend found at 80, 120 and 160 mm of shaking stroke. Thus, for Agizi variety, the increasing rate of *FRP* was 3% for each 1 Hz shaking frequency.

For Manzanillo variety at 40 mm stroke and 60 s shaking time, the *FRP* increased by 6.7 and 19.2% when the frequency increased from 3.3 Hz to 6.7 and 10 Hz respectively. Also, the *FRP* increased by 12.5% when the applied frequency increased from 6.7 Hz to 10 Hz. The same trend found at 80, 120 and 160 mm of shaking stroke.

For Picholine variety at 40 mm stroke and 60 s shaking time, the *FRP* increased by 7.95 and 22.39% when the frequency increased from 3.3 Hz to 6.7 and 10 Hz respectively. Also, the *FRP* increased by 14.44% when the applied frequency increased from 6.7 Hz to 10 Hz. The same trend found at 80, 120 and 160 mm of shaking stroke.

For Kalamata variety at 40 mm stroke and 60 s shaking time, the *FRP* increased by 4.96 and 13.91% when the frequency increased from 3.3 Hz to 6.7 and 10 Hz respectively. Also, the *FRP* increased by 8.95% when the applied frequency increased from 6.7 Hz to 10 Hz. The same trend found at 80, 120 and 160 mm of shaking stroke.

For Arbiquen variety at 40 mm stroke and 60 s shaking time, the *FRP* increased by 4.14 and 15.65% when the frequency increased from 3.3 Hz to 6.7 and 10 Hz respectively. Also, the *FRP* increased by 11.51% when the applied frequency increased from 6.7 Hz to 10 Hz. The same trend was found at 80, 120 and 160 mm of shaking stroke.

The detachment of the fruits can be attributed to the increase in the forces acting to detach the fruit as the frequency and the stroke increases the 10 Hz frequency with 160 mm stroke gave the highest fruit removal percentage for all olive varieties while, the 3.3 Hz frequency with 40 mm stroke was the smallest treatment for fruit removal percentage for olive varieties. These results are similar to those found by Sola-Guirado *et al.* (2019), who reported that the optimum frequency to operate the vibrator at 7.8 Hz. Ghonimy *et al.* (2021) found that the highest values of fruit removal, 81%, was performed at 27 Hz frequency and 60 mm or 70 mm stroke. Younis *et al.* (2017) found that the highest harvesting productivity was achieved at 1600 rpm and 3 min. Low damage percent were evaluated at 900 rpm and 3 min, machine achieved highest productivity and Low damage with Kornaki variety.

**b) Effect of shaking stroke on the fruit removal percentage**

For Agizi variety at 3.3 Hz frequency and 60 s shaking time, the *FRP* increased by 14.92, 37.88 and 48.58 % when the shaking stroke increased from 40 mm to 80, 120, and 160 mm respectively. The *FRP* increased by 14.92%, 22.96%, and 10.7% when shaking stroke increased (from 40 mm to 80 mm), (from 80 mm to 120 mm), and (from 120 mm to 160 mm) respectively. The same trend was found at 6.7 and 10 Hz of applied frequency. Thus, the rate of increase of the *FRP* was 0.4% for each 1 mm shaking stroke. The same trend was found for varieties Manzanillo, Picholine, Kalamata, and Arbiquen. It was noted that the use of 160 mm stroke caused some bruising to the tree limbs. Therefore, the suitable stroke is 120 mm.

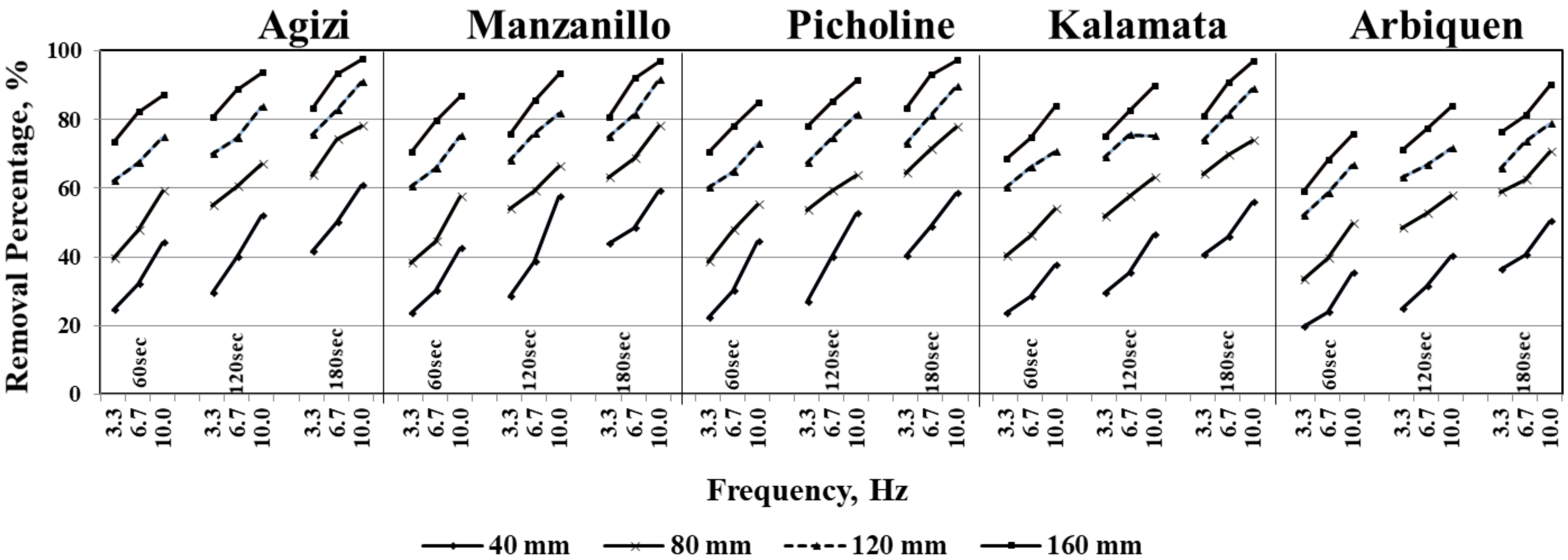



**Figure 11.** The effect of applied frequency, shaking stroke and shaking time on olive removal percentage for Agizi, Manzanillo, Picholine, Kalamata, and Arbiquen varieties.

**c) Effect of shaking time on the fruit removal percentage**

For Agizi variety at 3.3 Hz frequency and 40 mm shaking stroke, the *FRP* increased by 4.76 and 16.96% when the shaking time increased from 60 to 120, and 180 s respectively. Also, the *FRP* increased by 12.2 % when the shaking time increased from 120 s to 180 s. The same trend was found at 80, 120, and 160 mm shaking stroke. Thus, the rate of increase of the *FRP* was 0.14% for each one s shaking time. The same trend was found for the varieties Manzanillo, Picholine, Kalamata, and Arbiquen.

The results of the average values of *FRP* for all treatments indicated that the existence of sufficient variability among the five olive varieties under three frequencies; 3.3, 6.7, and 10.0 Hz and four strokes; 40, 80, 120, and 160 mm for fruit removal percentage, Figure 11. The 10 Hz frequency with 160 mm stroke gave the highest fruit removal percentage for all olive varieties while, the 3.3 Hz frequency with 40 mm stroke was the smallest treatment for fruit removal percentage for olive varieties. However, the Arbiquen olive variety gave the lower percent of fruit removal compared to the other olive verities.

**The status of mechanically harvested trees**

Harvested limbs were examined for signs of damage or breaking. Small bruising was found on the limbs when precisely examined. This bruising may increase the flowering and stimulate the floral buds. This may be because the bruising block the transportation of hormones other materials through the phloem and cause these materials to be diffused into the xylem and carried upward to the leafs, also the ethylene produced by bruising induces the flowering processes. An increase in flower initiation following possible phloem blockage due to vibrating action, is usually evident in the season following treatment (Gawankar *et al.*, 2019).

## CONCLUSION

The following conclusion can be made from the study:

**1.** At 30% to 40% of limb length were effective range to attach the clamp on the limb.

**2.** The minimum deflection which causes damage to the limb was 160 mm. The corresponding stroke was 320 mm. using safety factor 50%, the chosen range of stroke was 40, 80, 120 and 160 mm.

**3.** The fruit removal percentage *(FRP)* increased by increasing both stroke, shaking frequency and shaking time.

**4.** The increasing rate of *FRP* was about 3% for each 1 Hz shaking frequency for the range of applied frequency from 3.3 Hz to 10 Hz.

**5.** The *FRP* increased by 48.58% when the shaking stroke increased from 40 to 160 mm.

**6.** The *FRP* increased about 16.96% by increasing shaking time from 60 to 180 s.

Therefore, the olive harvesting machine can be fabricate using local materials with required specifications. The values of performance parameters of olive harvesting machine are 10 Hz shaking frequency, 120 mm of stroke, and 120 s of shaking time.

## DECLARATION OF COMPETING INTEREST

There is no conflict of interest between authors.

## CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

This work was carried out in collaboration among all authors. All authors contributed equally in various roles.

## ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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