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Design, construction and evaluation of a portable limb shaker for almond tree

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Abstract

The cost of picking fruit is probably the major factor in determining whether or not there will be an economically successful season for most farmers. Manual harvesting of fruit accounts for 30 to 60% of the total production costs. The aim of the present study was to design, construct and evaluate a portable limb shaker for almond tree. The shaker was powered by a 2-stroke (spark ignition) engine. A centrifugal clutch along with a gearbox was used in conjunction with a slider-crank mechanism to transmit power to a limb through a boom and C- shaped clamp. To evaluate the machine performance, a factorial experiment with complete randomized design in three replications was conducted, the factors being shaking frequency (10, 13 and 15 Hz), shaking duration (5 and 10 s) and almond cultivars (Azar, Harir and a kind of local almond). To calculate the ratio of fruit detachment force (F) to its weight (W), appropriate measurements were made. Also, the geometric mean diameter of the fruits was determined at different stages of maturity. Analysis of variance and comparison of means by Duncan's multiple range test showed that the effects of shaking frequency and shaking time on fruit detachment were significant, while the effect of almond cultivars and their interactions were not significant ($p<0.01$). The number of fruits detached increased by increasing the shaking frequency. Maximum number of fruits detachment (97.99%) was obtained by applying 15 Hz shaking frequency. Also the number of fruits detached increased by increasing the shaking duration. F/W ratio decreased with maturity, while the geometric mean diameter increased with maturity.

Keywords: almond, mechanical harvest, limb shaker, fruit harvester
Abbreviations: C_ almond cultivars; f _ shaking frequency; F_ fruit detachment force; F/W_ Ratio of fruit detachment force to its weight; gmd_ geometric mean diameter of fruit; M_ maturity stages; T_ shaking duration; W_ weight of fruit; R^2_ determining coefficient

Inroduction

For most farmers the cost of harvesting operation is probably considered as a major factor in determining whether or not there will be an economically successful season. According to statistics, manual harvesting of fruit accounts for 30 to 60% of the total production costs (Altisent and Canavate, 1999a). For cost reduction a mechanical harvesting can be a reasonable solution. Almond is a major crop in the eastern Azerbaijan province in Iran. At the present time, almond as many other fruits is still picked entirely by hand that is time consuming, costly and requires tremendous number of labors. The most popular methods in the world for fruit harvesting are: (a) contact removal, or (b) mass removal. Mass removal can be accomplished by limb shaking and foliage shaking or a combination of both using air blast (Parameswarakumar and Gupta 1991). In mass fruit harvesting method, whole tree or portion of it is stripped off the fruits. In contact harvesting, several fruits could be harvested simultaneously if separators are used (Schertz and Brown, 1968). Examples of detachment device being considered for the mass harvesting of fruits include limb shakers and trunk shakers (Coppock, 1974; Hedden et al, 1984; Whitney, 1999; Brown, 2002). The governing principle in this method is accelerating each fruit until the inertial force developed exceeds its bonding force to a tree (Kepner et al, 1987). Adrian and Fridley (1965) presented fundamental vibration theory and design criteria for inertia type tree shakers. They stated that harvesting by shaking the limbs and trunks was the most promising. Hoag et al (1971) determined internal damping with the logarithmic decrement method for specimens of almond branch. Trunk shakers are faster and easier to operate than limb shaker, but they are not well suited to trees larger than 50 cm in diameter or for trees with hanging branches, which lead to low fruit detachment, in these cases limb shakers are preferred (Altisent and Canavate, 1999b). Along with development of tree shaking equipment, engineering research was undertaken to determine empirical relation among amplitude, frequency and fruit removal. Experience with many tree fruits has indicated that high frequencies (25-40 Hz) and short amplitude (20-25mm) are generally most effective when tree structure and fruit attachment are relatively rigid. Long amplitudes (100-120 mm) and low frequencies (1.5-6 Hz) have been found superior for willowy tree with long branches that hang down under the mass of the fruits (Logavi and Mohseni, 2005). The aim of the present study was to design, construct and evaluate a limb shaker for detachment of nuts in particular. The features considered during design were:

i. suitability for small orchards,
ii. portability
iii. to be operable by one man
iv. low initial and operating cost, and
v. high maneuverability

Materials and methods

Design and construction stage

An inertia type portable limb shaker was designed based on the procedure outlined by Adrian and Fridley (1965) and

Fig 1. Limb shaker in operation

Table 1. Analysis of variance of data on almond removal (%) at different levels of shaking frequency, shaking duration and cultivars

source	*df*	*Mean squares*	*F Value*
Cultivars, C	2	7.870	$2.0773^{n.s.}$
Frequency, f	2	307.123	81.0649^{**}
C×f	4	0.630	$0.1662^{n.s.}$
Duration, T	1	63.159	16.6706^{**}
C×T	2	0.368	$0.0971^{n.s.}$
f×T	2	1.204	$0.3177^{n.s.}$
C×f×T	4	3.423	$0.9035^{n.s.}$
Error	36	3.789	
total	53		

n.s. Non significant ** Significant at p<0.01

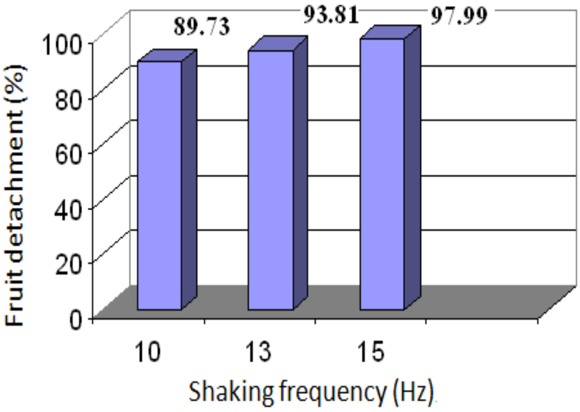

Fig 2. Comparison of mean values of fruit detachment (%) at different levels of shaking frequencies

Formulas employed by them were used to calculate design force, power and maximum torque required to vibrate the limb with certain amplitude and frequency; although these formulas were based on much higher shaking frequencies. The shaker was powered by a 1.7 hp, 2-stroke and spark ignition engine. The rotational speed of the engine could vary continuously between 1200 and 7000 rpm. A centrifugal clutch was used to transmit power from the engine to a gearbox. A pair of spiral bevel gears in the gear box was used for rotational speed reduction as well as changing the direction of rotation. A slider- crank mechanism which has widespread use in limb shakers was employed to generate reciprocating motion. Constant amplitude of 50 mm was achieved by connecting the shaking boom to an eccentric pin located at 25 mm off the crank's center of rotation. One end of the slider was connected to the pin while the other end to a link made of two 1m long, 0.016 m diameter rod. The linearly vibrating boom was supported within a hollow boom guide. A Teflon bushing was provided inside the boom guide to reduce friction. A C- Clamp connected the boom to a tree limb. To avoid bruising of limb's skin the inner surface of the C- Clamp was covered by rubber padding.

Determination of the effects of shaking frequencies and shaking durations on percentage of fruit removal

Orchard experiments were conducted in Shabestar, one of the major almond growing regions at eastern Azerbaijan province in Iran (Fig 1). In order to evaluate machine performance, a 3×3×2 factorial experiment with complete randomized design in three replications was conducted, the factors being shaking frequency(10, 13 and 15 Hz), shaking duration (5 and 10 s) and almond cultivars (Azar, Harir and a kind of local almond). Increasing shaking frequencies above 15 Hz caused excessive injuries to the limb. Therefore the lower frequencies were used. The experiments were carried out during late August 2009 when 95 to 100% of almonds' green hulls were pelt off. By employing a revolution counter (Auto craft AC-706), shaking frequencies were monitored constantly. The shaker attached to the limbs at a distance of 0.5 – 1 m from the trunk of the tree. After shaking, the number of detached fruits as well as the number of fruits remained on the limb were counted. The percentage of fruits detached during each test was calculated using the following formula (Erdogan et al, 2003; Sessiz and Ozcan, 2005; Polat, 2007):

$$P_r = \frac{m_r}{m_r + m_u} \times 100$$

Where:
P_r = percentage of fruits detached
M_r = number of harvested fruits by shaking
M_u = number of fruits remained on a limb after shaking.

Ratio of fruit detachment force (F) to its weight (W)

The harvesting of almond at the proper stage of maturity affects the rate of harvesting. Therefore, before each test, fruit size, mass, detachment force, which can be used as the criteria for deciding when to begin harvesting were measured (Erdogan et al, 2003). Detachment force of each fruit was measured by a 50 N capacity hand held dynamometer (FG - 5000 A) with an accuracy of 0.01 N. The fruit weight was determined with 2.0 kg capacity electronic scale with an accuracy of 0.01 g. Fruit diameter was measured by a digital caliper with 0.001 mm division. Measurements were made in order to determine the ratio of fruit detachment force (F) to its weight (W) as well as the geometric mean diameter at different maturity stages (May, June, July and August) of three almond cultivars. The free end of the hand dynamometer was attached to the selected fruit by a light – weight gripping device and a pulling force was gradually increased until the fruit was detached. The maximum force developed was read and recorded as the static detachment force. Each fruit was weighted and its dimensions along the three principle axes were measured and recorded. The geometric mean diameter (gmd) of the fruits was calculated by following formula

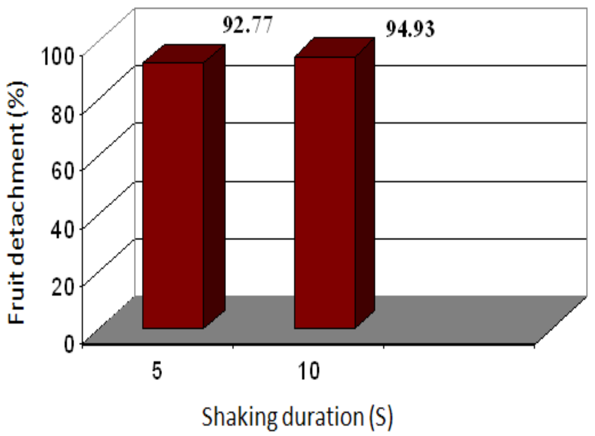

Fig 3. Comparison of mean values of fruit detachment (%) at different levels of shaking duration.

Table 2. Analysis of variance of data collected on fruit detachment force (N) to its weight (g) ratio at different levels of maturity stages and cultivars

source	*df*	*Mean squares*	*F Value*
Maturity stages, M	3	13.707	274.7949**
Error	27	0.050	
Cultivars, C	2	0.804	14.9807**
M×C	6	1.400	26.0916**
Error	72	0.54	
total	119		

n.s. Non significant, ** Significant at p<0.01

(mohsenin, 1970; Aydin, 2003):

$$gmd = (LWT)^{1/3}$$

Where:
gmd= geometric mean diameter (mm)
L= length (mm)
W= width (mm)
T= thickness (mm)

Results and discussion

The effects of shaking frequency and shaking duration on fruit removal percentage

Analysis of variance for the effects of different levels of shaking frequency, shaking duration and cultivars on fruit detachment is shown in Table 1. The results indicated that the effects of shaking frequency and shaking duration on fruit detachment were highly significant (P<0.01), while the effect of almond cultivars and interactive effects of them were not significant.

Means comparisons by Duncan's multiple range test showed that the percentage of detached fruits was increased by increasing the shaking frequency. Maximum fruit detachment (97.99%) was obtained by applying the shaking frequency of 15 Hz (fig 2).

Previous work also confirmed this optimal combination of frequency and amplitude values for almond fruit removal. O'Brien et al (1983) stated that optimum shaking frequency and amplitude of almond limbs were 15-20 and 25-40 mm respectively. Polat (2007) reported that the optimum shaking frequency and amplitude of almond limbs were 15 or 20 Hz and 50 mm, respectively. Erdogan *et al.* (2003) stated that the optimum shaking frequency and amplitude of apricot limbs were 15 Hz and 40 mm respectively. Polat *et al.* (2007) suggested amplitude of 50 mm and a frequency of 20 Hz for mechanical harvesting of pistachio nut tree.Also the percentage of detached fruits was increased by increasing the shaking duration (fig 3). Polat (2007) found that 10s is sufficient for almond harvesting by limb shaker. Detachment force and geometric mean diameter.Analysis of variance for the effects of different levels of maturity stages and cultivars on (F/W) is shown in table 2. The results indicated that the effects of maturity stages and cultivars on (F/W) were highly significant (P<0.01), also interactive effects of them were significant. Mean comparisons by Duncan's multiple range test showed that the (F/W) ratio decreases at higher maturity stages and its value was least in latest week of August in three almond cultivars (table 3). It was reported that the holding force to pedicle decreased as the fruit matured. This is due to the cork that is formed in the stem holding place. Moreover, the F value decreases as the fruit mass increases (Erdogan et al, 2003; Sessiz and Ozcan, 2005; Polat, 2007). According to O' Brien et al. (1983), the ratio of detachment force to weight should be higher than 1 for mechanical harvesting. By using data from fig 4, Equation (1) was obtained (R^2= 0.6792).

Table 3. Variations of the ratio fruit detachment force (N) to its weight (g) at different maturity stages

Almond cultivars	(F/W) maturity stages			
	may	June	July	August
Azar	1.97	1.825	2.064	0.414
Harir	2.293	1.826	1.396	0.942
Local almond	2.289	2.648	1.58	0.706

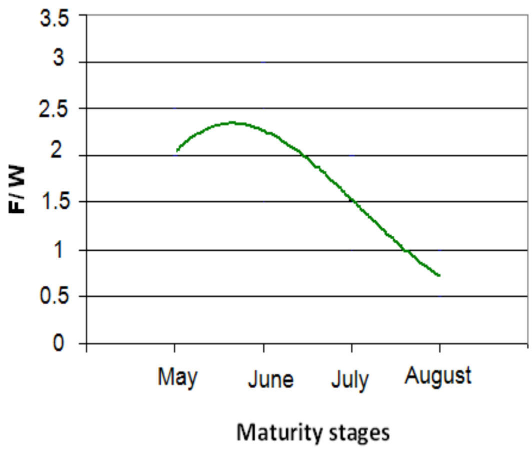

Fig 4. Relation between (F/W) ratio and different maturity stages

$$Y = 0.1443x^3 - 1.3411x^2 + 3.2368x \quad (1)$$

Where:

Y= ratio fruit detachment force to its weight, (N/g)
x = maturity stages
Analysis of variance for the effects of different stages of maturity and cultivars on geometric mean diameter is shown in table 4. The result s indicated that the effects of maturity

Table 4. Analysis of variance of data collected on geometric mean diameters (mm) at different maturity stages and cultivars

source	*df*	*Mean squares*	*F Value*
Maturity stages, M	3	76.588	31.0067**
Error	27	2.470	
Cultivars, C	2	108.984	77.1490**
M×C	6	6.289	4.4519**
Error	72	1.413	
total	119	665.027	

n.s. Non significant ** Significant at p<0.01

Table 5. Variations of the geometric mean diameter (mm) at different stages of maturity and cultivars

Almond cultivars	Geometric mean diameter (mm)			
	maturity stages			
	may	June	July	August
Azar	25.39	29.65	29.71	30.5
Harir	26.27	28.74	28.73	29.522
Local almond	24.371	25.107	25.37	27.582

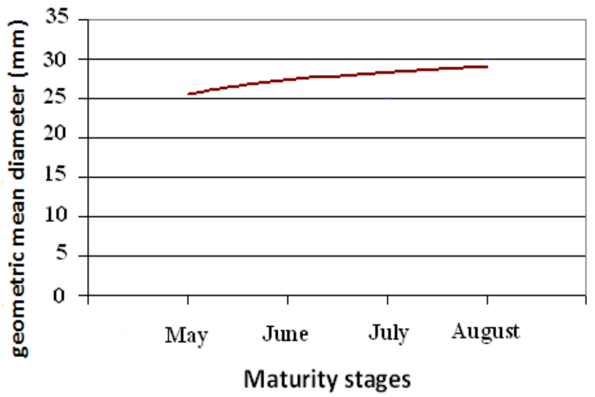

Fig 5. Relation between geometric mean diameter and different maturity stages

stages and cultivars as well as their interaction on geometric mean diameter were highly significant (P<0.01). Mean comparisons made by Duncan's multiple range tests showed that the geometric mean diameter increases at higher maturity stages (Table 5). Equations (2) was obtained using data from fig 5 (R^2= 0.3041).

$$Y = 2.5056 \; Ln\,(x) + 25.505 \qquad (2)$$

Where:

Y= geometric mean diameter, (mm)
x = maturity stages

Conclusion

The results of this study revealed that: Almond can be harvested by the portable limb shaker. Increasing shaking frequency causes higher number of fruits to be detached and maximum fruit removal with minimum vibration and force obtained at 15 Hz. At frequencies above 15 Hz, excessive injuries to a limb occurs. Increasing shaking duration causes higher number of fruits to be detached and an average duration needed is 10s. The (F/W) ratio decreases at higher maturity stages; an appropriate time for harvesting being the last week of August. The geometric mean diameter of three almond cultivars increased with increasing the maturity stages.

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