Asian Journal of Plant Sciences

ISSN 1682-3974

Asian Journal of Plant Sciences 6 (3): 528-532, 2007
ISSN 1682-3974

Mechanical Harvesting of Almond with an Inertia Type Limb Shaker

[1]Refik Polat, [2]Metin Güner, [2]Ergin Dursun, [2]Dogan Erdogan, [3]İbrahim Gezer and [4]H.I. Cem Bilim
[1]Department of Agricultural Machinery, Faculty of Agriculture,
University of Harran, 63040, Sanliurfa, Turkey
[2]Department of Agricultural Machinery, Faculty of Agriculture,
University of Ankara, 06110, Ankara, Turkey
[3]Program of Agricultural Machinery, Malatya Technician Training Center,
University of Inonu, 44080, Malatya, Turkey
[4]Pistachio Research Institute, 27060 Gaziantep, Turkey

Abstract: An inertia type limb shaker were developed to mechanically harvest of tree fruits. The shaker, hydraulically powered and driven by the tractor power take off, was used for mechanical harvesting of almond. The study included optimum frequency and amplitude to obtain maximum fruit removal percentage, harvesting rate of the shaker. Harvesting rate was calculated by weighing both the harvested and unharvested almonds. In the tests the limbs of trees were shaken at 40 and 50 mm amplitude of the connecting rod attached to the crankshaft and 10, 15, 20 Hz frequencies. The results were analysed according to the maximum fruit removal percentage. Shaking time was 10 s for all of the frequency and amplitude tests. Maximum fruit removal (97 and 100%) was achieved by operating the shaker at amplitude of 50 mm and a frequency of 15 and 20 Hz. Therefore it can be suggested an amplitude of 50 mm and a frequency of 20 Hz for mechanical harvesting of almond. Moreover, the appropriate harvesting time for nonpearl variety of almond was found the second week of August. Because, the ratio of Fruit Detachament Force (FDF) to Weight (W) at different maturity times was found 1.8 N/g at the second week of August.

Key words: Almond, mechanical harvest

INTRODUCTION

Almond (*Amygdalus communis* L.) is perennial plant growing in inner Anatolia, the Mediterranean and the Marmara regions of Turkey. The kernel nut forms an important source of protein in human nutrition. Turkey is a producer country with an annual production of about 37.000 t and its yield ranges between 1789.5 and 2000 kg ha^{-1} (SSI, 2001). At present, the crop is usually planted as main crop in Turkey. Harvesting and handling of the crop are carried out manually. The threshing is usually carried out on a hard floor with a homemade threshing machine. For optimum threshing performance, processes of pneumatic conveying, storing and other processes of almond nut, its physical properties must be known. Almond is an edible, nutlike seed of fruit of a tree, *Prunus amygdalus*, of the rose family, the sweet variety of which is widely used in desserts, candy and cooking (Aydin, 2003). Turkey is one of the main almonds producing country in the world. Almond is grown in all over Turkey. The harvesting of almond has not been mechanised until recently in Turkey and there has been a very short period of maturity stage available for harvesting. Mechanical harvesting of almond as other tree fruits is necessary and important for Turkey.

Tree shakers are widely used to harvest different kinds of tree fruits. Limb shakers are especially popular and have the advantage of speed, particularly in orchards having many primary limbs. Limb shakers usually achieve a somewhat better removal of fruit on pliant trees (Horvath and Sıtkei, 2001). About tree shakers, structure of both trunk and main roots and the ratio of fruit detechament force have been studied since 1960s (Adrian and Fridley, 1965; Fridley *et al.*, 1964; Keçecioglu, 1975; Sansavini *et al.*, 1982; Affeldt *et al.*, 1989; Donald *et al.*, 1989; Parameswarakumar and Gupta, 1991; Sarig, 1993; Gezer, 1997; Polat, 1999; Erdogan *et al.*, 2003; Sessiz and Özcan, 2005; Lang, 2006).

There are two broad approaches to the mechanical harvesting considerations; one is the mass harvesting method, harvesting indiscriminately from the whole tree or a portion, without direct concern for individual fruits. The other is individual fruit harvesting, harvesting each fruit as distinct and separate from adjacent fruits. In individual

Corresponding Author: Refik Polat, Department of Agricultural Machinery, Faculty of Agriculture, University of Harran, 63040, Sanliurfa, Turkey

fruit harvesting, several fruits could be harvested at the same time by separators (Schertz and Brown, 1968). Examples of detaching device being considered for the mass harvesting of fruit include limb shakers and trunk shakers. The basic principle of limb shaking is based on the transmission of vibratory forces to the limb. Horvath and Sitkei (2001) proposed a new tree model which analyses three different kinds of trunk motion. Based on acceleration measurements in the soil body, a new mass component was included, in addition to the common mass components. The analysis of dynamics and power requirement of the system has shown that the elastic deformation of the trunk will continuously be higher as attachment height increases, resulting in a significant decrease in the net power requirement.

The objective of this study is to investigate the mechanical harvesting of almond.

MATERIALS AND METHODS

The experiments were conducted on almond (*Amygdalus communis* L.) of the Gulcan 101-9 variety (Fig. 1) at Gaziantep provinces in the south east of Turkey. The experiments were held in the second week of August 2005. Some orchard, tree and fruit properties are given in Table 1.

Determination of the parameter of fruit detachment force/fruit weight: The ratio of fruit detachment force to fruit weight (FDF/W) is used for comparing the suitability of almond. The fruit detachment force was measured by the help of hand dynamometer with 10 N capacity and 0.1 N divisions. The fruit weight was determined with an electronic scale 2.0 kg capacity and 0.01 g divisions.

Determination of branch spring rigidity: In order to determine the branch spring rigidity of almond trees, a dynamometer (model: viro-meter LTC 119-01) and a portable amplifier were used. One end of the dynamometer was attached to the branch of the tree via connecting rod; and the other end was attached to the drawbar of the tractor. The connection point at the branch was chosen to be as the same of that of the shaker. And the tractor was moved until the branch displaces somewhat. The displacement value of the branch and the dynamometer's value were recorded. The spring coefficient was calculated by putting these values in the following equations.

$$C = F/x \text{ (N/mm)}$$

Where; C is the spring rigidity of the tree; F is the pulling force, x is the displacement quantity of the branch.

Fig. 1: Almond orchard

Table 1: Some orchard, tree and fruit properties

Orchard (da)	10
Training system	Freely pruned
Distance between rows (m)	8
Tree spacing in the row (m)	8
100 dry fruit mass (g)	320
100 dry kernel (g)	102
Total tree height (m)	3.85
Crown width (m)	3.30

Inertia type limb shaker: An inertia type limb shaker designed by Erdogan *et al*. (2003) was used for mechanical harvesting of almond. Figure 2 shows the designed shaker. The shaker was completely hydraulically powered and driven by the power take-off. The main frame is mounted on the three-point linkage of the tractor. The equipment comprises a hydraulic pump, a hydraulic motor, a tank, a flow control valve, a hydraulic cylinder, a direction control valve and a vertical steel tubular frame to support the shaker, pendulum and other auxiliary components. The hydraulic pump is driven through a gearbox with an ouput speed of three times the standard power take-off speed of 540 min^{-1}. Firstly, the oil is pumped to the cylinder, one end of which is attached to the rod and the other end to the clamp. Each limb is clamped firmly and then the oil is pumped to the hydraulic motor to shake the limbs. A reciprocating motion is provided to the shaker arm by the hydraulic motor. Frequency can be easily adjusted in the range of 10-20 Hz by controlling the speed of the motor with a flow control valve. Amplitude can be changed between 20 to 60 mm. The shaker is capable of harvesting limbs up to 180 mm thick (Fig. 3). The total shaker mass with an empty tank is 246 kg. The shaker arm between the shaking mechanism and the clamp end is a tube, 3.34 m long, 85 mm diameter and 5 mm wall thickness. The masses of the housing with the driving motor and the shaker arm between the pendulum and clamp end are 70 and 56 kg, respectively. The complete shaker is balanced and pendulously hung

Fig. 2: The limb shaker used for almond harvesting

Fig. 3: The clamp of sahker

from a positioning mechanism by a swinging link attached to the vertical steel tubular frame. The design permits 360° rotation of the shaker about its longitudinal axis for aligning the clamp with the limbs. This design permits the frame to absorb some of the reactive force of the shaker without causing excessive vibration of the frame when the shaker is operating under long amplitude conditions. The limb clamp is an important component of the shaker and has been given special design consideration to eliminate possible damage to the tree bark. The clamp consists of a frame with two rubber pads, one stationary and the other attached to the rod end of a hydraulic cylinder. Total clamping area for each of the two plates is 0.014 m^2 and the type of padding is soft rubber 20 mm thick. The clamp action is controlled by a valve and its pressure on the limb is controlled by an adjustable relief valve.

Determination of the effects of shaking frequency and amplitude on fruit removal percentage: The trees with mature almond were identified and three to five limbs with appropriate properties and sizes on each tree in different directions were selected for shaking. The remainder fruits of the tree were picked manually by workers using traditional harvesting methods. Afterwards, the remaining limbs with fruits were attached to the shaker individually and harvested by applying different amplitude and frequency combinations. Almonds removed from each limb were collected, filled into boxes and then weighed. In the tests, the limbs were shaken at 40 and 50 mm amplitude and 10, 15 and 20 Hz frequencies. The results of three replicates were analysed to determine the effects of frequencies and amplitude on the fruit removal percentage. The shaker was attached to the limbs at a distance of 0.5-0.7 m from the trunk of the tree. Four persons including the tractor operator were employed in the tests. The fruit removal percentage was determined by

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

where: P_r is the fruit removal percentage; m_r is the mass of fruit removal in g; and m_u is the mass of fruit unremoval in g.

RESULTS AND DISCUSSION

Variation of the fruit detechament force (FDF)/ weight (FW) at different maturity times: Fruit maturity has an important effect on the force required for removal on mechanical properties and on relative susceptibility of the fruit to mechanical damage (Kader, 1983, 1991). According to O'brien *et al.* (1983), the ratio of fruit detechment force in N to the weight in N should be higher than 1 for mechanical harvesting. The changes in FDF/W ratio as a function of maturity times are shown in Fig. 4. FDF/W ratio decreased when as maturity time increased. The FDF/W ratio for almond varied from 20.6 N/g to 1.8 N/g within one month of tests. Keçecioglu (1975) reported that the holding force to pedicle decreased as the fruit matured. This is due to cork that is formed in the stem holding place. Moser (1984) said that mass and rupture force were important for mechanical harvesting and gave the fruit detachment force as 1-5 N at maturity stage for stone fruits. Sessiz and Özcan (2005) reported that FDF/W ratio for olives decreased from 49.72 N/g to 10.02 N/g within 100 days of tests.

Branch spring rigidity of almond: Branch spring rigidity of almond fruits according to the different branch diameters are given in Table 2. Branch spring rigidity increased with increasing branch diameter. This result was supported for different fruit branches by Kececioglu (1975), O'Brien *et al.* (1983), Gezer (1997) and Cetinkaya (1989).

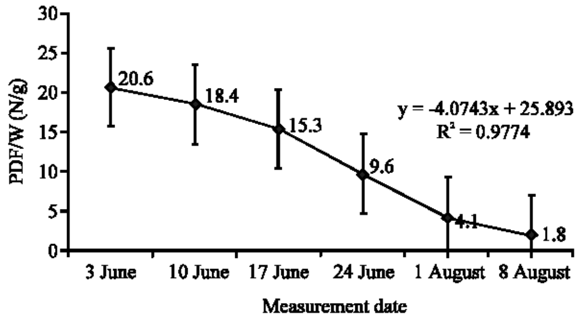

Fig. 4: The variation of the fruit detachment force/weight (FDF/W) at different maturity times

Table 2: Coefficient of spring rigidity of almond trees

Limb diameter (mm)	Force (N)	Changes of limb position (mm)	Coefficient of spring rigidity
30-35	87	100	0,87
35-40	143	100	1,43
40-45	186	100	1,86
50-55	249	100	2,49
55-60	285	100	2,85

Table 3: The fruit removal results in relation to the effects of shaking frequency and amplitude

Amplitude (mm)	Frequency (Hz)	Fruit removal (%)*
40	10	72.6a
	15	85.5b
	20	93.8c
50	10	86.2a
	15	97.7b
	20	100.0b

*Values in the same column followed by the same letter(s) are not significantly different (probability $p<0.01$)

The effects of shaking frequency and amplitude on fruit removal percentage: The fruit removal depending primarily on shaking frequency and amplitude are shown in Table 3. Mechanical harvested fruit is defined as pre-harvest fruit drop plus fruit removal by a shaker from a tree. The harvesting was carried out in the second week of August. The shaker amplitude and frequency are important variables for fruit removal percentage, but the fruit removal is also dependent on the limb amplitude.

Fruit removal percentage of almond increased with increasing frequency and amplitude. Orchard tests showed that maximum fruit removal (100%) was achieved at an amplitude of 50 mm and a frequency of 20 Hz. Fruit removal for the amplitude of 50 mm and frequency of 15 Hz was 97.7%. Statistical analysis has shown that shaking amplitude and frequency affected the romowal fruit percentage of almond at 0.01% significance level (probability $p = 0.01$). In these tests, to determine the effects of shaking frequency and amplitude on fruit removal percentage, shaking time was taken 10 sec. Sessiz and Özcan (2005) investigated the effect of vibration on mechanical olive harvesting and found that no more than 66.24% of fruit was removed. Erdogan *et al.* (2003) stated that the optimum shaking frequency and amplitude of apricot limbs were 15 Hz and 40 mm, respectively.

CONCLUSIONS

The results of almond fruit (Gulcan 101-9) harvesting with an inertia type limb shaker can be summarised as follows.

- The fruit detachament force/weight ((FDF/ W) ratio of almond fruit decreased with increasing maturity time. Consequently, the most appropriate time for harvesting of almond is the second or third week of August
- Shaking time was 10 sec for all of the frequency and amplitude tests. It was found out that this time is enough for the average time needed to harvest a tree limb.
- To obtain maximum fruit removal with minimum vibration and reactive force, the inertia type limb shaker should be operated in the range of 50 mm amplitude and 15 or 20 Hz frequency. Fruit removal percentage increased with an increase in shaking frequency and amplitude.
- The shaker and clamp did not cause any bark damage.
- Tree structure is the most significant factor influencing the success with mechanical harvesting of fruits. Shaking of the limbs in the centre of the trees was difficult because of the pruning method for almonds.
- As a result, this study showed that mechanical harvesting of almonds by an inertia type limb shaker is feasible.

REFERENCES

Adrian, P.A. and R.B. Fridley, 1965. Dynamics and design criteria of inertia type tree shakers. Trans. ASAE, 8: 12-14.

Affeldt, H.A. Jr., G.K. Brown and J.B. Gerrish, 1989. A new shaker for fruit and nut trees. J. Agric. Eng. Res., 44: 53-66.

Aydin, C., 2003. Physical properties of almond nut and kernel. J. Food Eng., 60: 315-320.

Cetinkaya, S., 1989. Vişne hasadında mekanizasyon olanakları üzerine bir araştırma. [A research on the mechanical harvesting of sour cherry.] Ph.D Thesis, Graduate School of Natural and Applied Sciences, Ankara University, Ankara, Turkey.

Donald, L., D.L. Peterson and Stephen S. Miller, 1989. Advances in mechanical harvesting of fresh market quality apples. J. Agric. Eng., 42: 43-50.

Erdoğan, D., M. Güner, E. Dursun and I. Gezer, 2003. Mechanical harvesting of apricots. Biosys. Eng., 85: 19-28.

Fridley, R.B., H. Goehlich, L.L. Claypool and P.A. Adrian, 1964. Factorsaf fecting impact injury to mechanically harvested fruit. Trans. ASAE, 7: 409-411.

Gezer, I., 1997. Malatya yöresinde kayısı hasadında mekanizasyon imkanlarının araştırılması. [A research on the mechanical harvesting of apricots in Malatya region.] Ph.D Thesis, Graduate School of Natural Applied Sciences, Selçuk University, Konya, Turkey.

Horvath, E. and G. Sıtkei, 2001. Energy consumption of selected tree shakers under different operational conditions. J. Agric. Eng. Res., 80: 191-199.

Kader, A., 1983. Influence of harvesting methods on quality of deciduous free fruits. Proceedings of the Symposium on the Influence of Mechanical Harvesting on the Quality of Horticultural Crops, Virginia, USA. Hortscience, 18: 409-411.

Kader, A., 1991. Maturation, harvesting and nut quality of pistachio. University of California, Davis, CA 95616-8683.

Kececioglu, G., 1975. Atalet kuvvet tipli sarsıcı ile zeytin hasadı imkanları üzerine bir araştırma. [Research on olive harvesting possibilities with an inertia type shaker.] Ph.D Thesis, Ege University, Izmir, Turkey.

Lang, Z., 2006. Dynamic modelling structure of a fruit tree for inertial shaker system design. Biosyst. Eng., 93: 35-44.

Moser, E., 1984. Verfahrenstechnik Intensivkulturen. [Management of Intensive Agricultural Crops.]. Verlag Paul Parey, Hamburg.

O'Brien, M., B.F. Cargil and R.B. Fridley, 1983. Harvesting and Handling Fruits and Nuts. Avi. Publishing Comp. Inc., Westport, CT, USA

Parameswarakumar, M. and C.P. Gupta, 1991. Design parameters for vibratory mango harvesting system. Trans. ASAE, 34: 14-20.

Polat, R., 1999. Antepfıstğının Mekanik Hasat Olanakları ve Mekanizasyona Yönelik Özelliklerinin Belirlenmesi Üzerine Bir Araştırma. Ph.D Thesis. Trakya University, Tekirdag, Turkey.

Sansavini, S., G. Costa, M. Grandi and U. Lunatı, 1982. Performance and suitability for mechanical harvesting of processing apricots: A comparison of six cultivars two training systems and prune interstock. Symposium on Apricot Culture and Decline, Bucarest, Romania, 16-21 July, pp: 364-374.

Sarig, Y., 1993. Robotics of fruit harvesting: A state of the art review. J. Agric. Eng. Res., 54: 265-280.

Schertz, C.E. and G.K. Brown, 1968. Basic considerations in mechanising citrus harvest. Trans. ASAE, 11: 343-346.

Sessiz, A. and M.T. Özcan, 2005. Olive removal with pneumatic branch shaker and abscission chemical. J. Food Eng. (In Press).

SSI, 2001, Agricultural statistics, Ankara, Turkey.