XVII^th World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

THE EFFECTS OF SHAKING FREQUENCY AND AMPLITUDE ON DETACHMENT OF ESTAHBAN DRIED FIG (FICUS CARICA CV. SABZ)

M. LOGHAVI[1], F. KHORSANDI[2], S. KAMGAR[3], S. SOURI[2]

[1] M. LOGHAVI, Professor, Agricultural Engineering Dept., Shiraz University, Shiraz, Iran, loghavi@shirazu.ac.ir .
[1] F. KHORSANDI, Graduate Student.
[1] S. KAMGAR, Assistant Professor.
[1] S. SOURI, Graduate Student.

CSBE100348 – Presented at Section III: Equipment Engineering for Plant Production Conference

ABSTRACT The aim of this study was to determine the most suitable shaking frequency and amplitude for shake harvesting of Estahban edible fig (Ficus carica cv. Sabz). A hand held limb shaker with adjustable shaking frequency and amplitude and powered with a single cylinder gasoline engine was used for this study. A 3×3 factorial experiment with a completely randomized design with three replications was conducted to investigate the effects of shaking frequency and amplitude on fruit detachment. Three levels of oscillating frequency (10, 12 and 14 Hz) and three levels of shaking amplitude (20, 32.5 and 45 mm) were investigated. Analysis of variance and mean comparison showed that the effect of shaking amplitude and shaking frequency on fruit detachment was significant. The percent of unripe fruit detachment was significantly increased at higher levels of shaking amplitude and frequency. Complete ripe fruit detachment (100%) and relatively high unripe fruit detachment (16.92%) was obtained at shaking amplitude of 45 mm and frequency of 14 Hz, but shaking amplitude of 45 mm and shaking frequency of 10 Hz with high ripe fruit detachment (93.33%) and acceptable unripe fruit detachment (9.44%) is recommended. Harvesting rate during 5s of shaking was measured and showed that optimum time needed to harvest a limb is only 4s. The fruit detachment force (FDF) per fruit weight (FDF/W ratio) varied from 119 to 25 N/N when moisture content varied from 75.979 to 23.57 during fig ripening and drying process. This suggests the feasibility of utilizing limb shaker as a practical approach for selective harvesting of ripe fruits.

Keywords: Limb shaker, Figs, Fruit harvesting, Vibratory harvesting.

INTRODUCTION

Iran is one of the largest fig producers in the world. It is estimated by FAO that in 2008, fig trees were cultivated on an area of about 462800 hectares across the world. In Iran, fig trees constitute 52000 hectares of the land which produce 88000 ton of fig. Iran is the third largest fig producer after Egypt (304000 tones) and turkey (205000 tones) (FAO 2008).

This study was conducted in Estahban, which is the main rain fed fig producing region in Fars province of Iran with acreage of more than 20,000 ha propagated by stock. There are more than 2 million home bred trees of fig in 22000 hectares of plain and mountains of the region that produce about 22000 ton of dried figs. This distinguishes Estahban as the largest producer of dried figs in Iran and the world (Anonymous 2009). Dried figs are the fruit of the tree ″Ficus *Carica*.L cv. Sabz ″from which the greater portion of moisture has been removed. Figs are dried quite naturally through exposure to the sun. Dried figs are processed to bring their moisture content to 14 - 20% to as high as 30%. Most of the fruit is dried before marketing.

From the last days of July figs start to ripen. Harvesting season starts from the first days of August and continues to the middle of October. The amount of fruit yield depends on various factors such as; age of the tree, tree spacing, orchard management, weather conditions, the amount of, precipitation type of soil and existence or non existence of blights and diseases. The trees usually begin to fructify at age of 4 to 5 years, but in the water independent condition fig trees bear significantly economic yield when they are 10 to 15 years old. In Estahban, each tree yields almost 10 to 15 kg of dried figs (Khonbani 2009).

There are two traditional methods for fruit harvesting; waiting for figs to be sun-dried on the trees and fall down spontaneously on to the ground or catching surfaces. Orchard men gather them once a week. Another method is hand shaking the fruit bearing limbs with a pole. In each method figs fall down on the ground or are caught on a catching surface. Then the collected fruits are spread on a concrete surface, exposed to straight sun light for further drying. In the first method, the produce is exposed to rain fall, bacteria and mould spores and pests. The second method is labour intensive and causes tree damages. In order to eliminate these difficulties and disadvantages, mechanical harvesting of fig is necessary and inevitable in the future.

Vibratory Harvesting Adrian & Fridley (1965) stated that harvesting by shaking the limbs and trunks is the most promising. The basic principle is to accelerate each fruit so that the inertia force developed will be greater than the bonding force between the fruit and the tree (Kepner *et al*., 1987). The excitation force is typically derived from cyclic oscillation of either a slider-crank mechanism or two opposite rotating eccentric masses connected to the tree to be harvested (Thomson, 1988). It was observed that the most important disadvantage of harvesting by mechanical shakers is the damage imparted to fruit (Domingan *et al.*, 1988). The catching units used in shake harvesting are collecting surfaces that extend under the tree, covering the drop area of the detached fruits (Cargill, 1999). Mechanical shakers are large scale harvesting equipment with potential applications in wide range of fruits, berries and nuts. In general, harvesting equipment based on principles of a mechanical shaker consist of a shaker, collecting frame (catching units) and conveying devices, usually mounted on a self-propelled carrier, usually a tractor (Mbuge and Langat, 2008). Three catching systems were designed, constructed and tested to pick the peaches detached from the trees by shaking with hand-held shaker. Fruit detachment percentage with the hand-held shaker ranged between 83% and 95%. Less than 2.4% of the fruits were severely injured (Torregrosa *et al.*, 2008).

Amplitude and Frequency An inertia type shaker for olive harvest was developed and it was suggested that for optimum fruit removal, the olive tree should be shaken in the range of 20-28 Hz frequency and 20-30 mm amplitude for 10s (Kececioglu, 1975). Parameswarakumar and Gupta (1991) developed an inertia type slider limb crank shaker used for harvesting mango fruits. Their studies showed that to obtain maximum fruit removal with minimum tree damage, the shaker should be operated in the range of 76–102 mm amplitude and frequencies of 11–13 Hz for 4 s.

One of the major problems in date harvesting is variable maturity. It was shown that the most effective detachment of ripe fruit with minimum unripe fruit detachment occurred at 5 Hz. frequency and 60 mm amplitude. It was stated that vertical shaking mode is more successful in detaching ripe fruits than hanging mode (Loghavi & Abounajmi, 2001).

An inertia type limb shaker, hydraulically powered and driven by the tractor power take-off was tested for apricot harvesting. The limbs were shaken at 20, 30, 40, 50 and 60mm amplitudes and 10, 15 and 20Hz frequencies. The optimum shaking time, frequency and amplitude for maximum fruit removal, were found as 5 s, 15 Hz, and 40 mm, respectively (Erdogan *et al.*, 2003). Three levels of oscillating frequency (5, 7.5 and 10 Hz) and three levels of shaking amplitude (40, 80 and 20 mm) were investigated by means of a tractor mounted limb shaker for shake harvesting of lime tree. The 80 mm amplitude and 10 Hz frequency were reported as the best combination with about 95% fruit detachment and negligible leaf shattering (Loghavi & Mohseni, 2005). Sessiz and Ozcan (2006) carried out harvesting of olive by pneumatic branch shaker and abscission chemical. The maximum harvesting efficiency (96%) was achieved at 24 Hz and 6.25 mL/L of abscission chemical concentration.

An inertia type limb shaker, hydraulically powered and driven by the tractor power take-off was tested for pistachio nuts harvesting. In the tests the limbs of trees were shaken at 40, 50, 60 mm amplitude and 10, 15, 20 Hz frequencies. The machine was able to remove 100 % of pistachio nuts at 60 mm amplitude and 20 Hz frequency but 50mm amplitude and 20 Hz frequency, that have 95% fruit removal, are suggested because the shaker caused excessive vibration of the frame when it was operated at great amplitudes (Polat *et al.*, 2007).

No attempt has been reported to investigate the possibility of vibratory harvesting of fig trees. So, the objectives of the present research were: (a) To investigate the effects of shaking frequency and amplitude on fig fruit detachment, (b) To determinate the optimum shaking frequency and amplitude for effective fruit detachment and (c) To determinate fruit detachment force/weight ratio (FDF/W).

MATERIALS AND METHODS

Shaking tests The field experiments were conducted during harvesting season of 2009 in Estahban Fig Research Station, located in Estahban valley in 777kM south east of Tehran in Fars province , 54 02'30" E 29 07'45" N , +1760m high. The trees (*Ficus Carica.* cv. Sabz) that were selected for shake harvesting tests had the same age and were in similar growing conditions. The experimental design was a 3×3 factorial experiment with a completely randomized design in three replications. The effect of three levels of shaking frequency (10, 12 and 14 Hz) and three levels of shaking amplitude 20, 32.5 and 54 mm) on fruit detachment was investigated.

Trees of fig in Estahban valley are mostly located in hillside, therefore tractor-mounted or self-propelled shakers cannot be used for fruit harvesting. A hand-held shaker (SCUOTIMAS, Italy), powered by a 2.1 kW gasoline engine was used for shake harvesting trials (figure 1). The shaker total mass including a 1.8 m boom and 40mm wide hook was 14 kg. The shaking amplitude was fixed at 32.5mm and the maximum shaking frequency at full engine throttle was 22.5 Hz. During the shaking tests, the predetermined shaking frequencies were selected by proper throttle setting of the shaker engine. For selecting the desired shaking amplitudes, a novel amplitude changing mechanism as presented in the following section, was designed, fabricated and mounted on the shaker.

Figure 1. The hand-held shaker and the the amplitude changing mechanism used for shake harvesting tials. (shaker boom and hook not shown).

Amplitude changer mechanism A novel mechanism as shown in figure 2 was designed, fabricated and mounted on the shaker. The original amplitude of the shaker was 32.5 mm. By changing the position of the fixed pivot point of the new mechanism, the other two desirable amplitudes (20 and 45 mm) were also selectable.

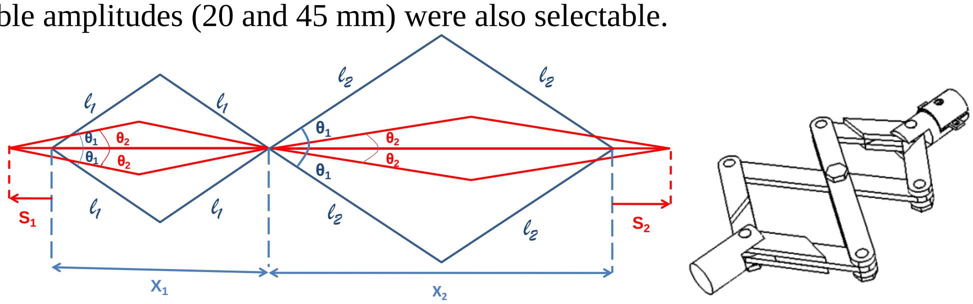

Figure 2. Schematic diagram of the amplitude changer mechanism.

The governing equations relating the output amplitude (S_2) to the input amplitude (S_1) is shown as following:

$$s_1 = 2l_1 \cos\theta_2 - 2l_1 \cos\theta_1 = 2l_1(\cos\theta_2 - \cos\theta_1)$$

$$s_2 = 2l_2 \cos\theta_2 - 2l_2 \cos\theta_1 = 2l_2(\cos\theta_2 - \cos\theta_1)$$

$$\cos\theta_1 = \frac{x_1}{2l_1} \qquad \cos\theta_2 = \frac{x_1 + s_1}{2l_1} \qquad S_2 = 2l_2\left(\frac{x_1 + s_1}{2l_1} - \frac{x_1}{2l_1}\right) = \frac{l_2}{l_1}(s_1)$$

Fruit catching frame One of the most important disadvantages of mechanical harvesting is fruit damage. In order to resolve this problem most common approach has been to remove the fruit by shaking the trees and collect them on a catching surface placed beneath the tree (Fridley et al 1964). For this purpose, a circular catching surface as show in figure 3 was designed and fabricated. Preliminary experiments showed that a 2 m diameter circular frame is suitable for collecting at least 95% of the detached fruits resulting from shaking of each individual limb. The circular frame was made of stainless spring wire with four short legs to hold it off the ground as shown in figure 3. The catching surface was made of a light weight washable canvas fabric. The total weight of the catching frame was about 250 g and it was easily foldable to a 70 cm circle.

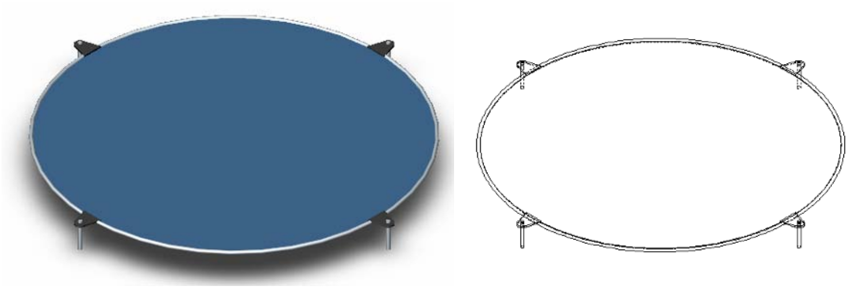

Figure 3. Light weight catching frame for collection of detached figs during shake harvesting trials.

Before conducting any limb shaking test, total length and limb diameter at the point of shaker boom attachment (1/3 of the limb length from the base) were measured with a graduated tape and a calliper, respectively. Diameter of the chosen branches was 30-40 mm on the shaker attachment point. The number of ripe and unripe figs on the selected limb and other neighbouring branches were counted because it was possible that fruits of other branches fall on the catching surface during the shaking test. After completion of any shaking test which lasted for only 5 seconds according to the corresponding shaking amplitude and frequency combination, detached ripe and unripe fruits on the catching frame and those remained on the shaken branches were removed and then separately counted and weighted. The fruit removal percentage was determined by following Equations:

$$P_r = 100\frac{M_{rr}}{M_{rr} + M_{ur}} \quad \text{and} \quad P_u = 100\frac{M_{uu}}{M_{ru} + M_{uu}}$$

Where Pr is the ripe fruit removal percentage, M_{rr} is the mass of ripe fruits removed in g, and M_{ur} is the mass of unremoved ripe fruits in g. P_u is the unripe fruit removal percentage, M_{uu} is the mass of unremoved unripe fruits in g and M_{ru} is the mass of removed unripe fruits in g.

The limb shaking frequency was measured by a Vibration meter Model TV300 made by Time Group Company in China.

Fruit removal rate In order to determine the rate of fruit detachment along the shaking duration, a digital Sony camera model DSC-H10, that was able to take consecutive pictures every 0.5 second was used. This camera, fixed on a tripod was aimed at the fruit catching frame such that the picture of the whole catching surface be grabbed in consecutive shots. The camera was triggered to take pictures at the same moment that the shaker was started to shake a branch. Therefore, for every shake harvesting test that lasted for 5s, ten consecutive pictures of detached fruits were available for determination of fruit removal rate.

The fruit detachment force to weight ratio, (FDF)/ (W) The ratio of fruit detachment force to fruit weight (FDF/W) is used for comparing the suitability of figs for mechanical harvesting. The fruit detachment force was measured with a force gauge Model FG- 5100 made by Lutron with 981 N capacity and 0.1 N divisions. The fruit weight was determined with an electronic scale with 1 kg capacity and 0.1 g divisions.

RESULTS AND DISCUSSION

The effects of shaking frequency and amplitude on fruit removal The results of analysis of variance as shown in table 1 indicate highly significant effect ($p<0.01$) of shaking frequency, shaking amplitude and interactive effect of frequency and amplitude on ripe fruit removal.

Comparison of mean values of the total detached ripe fruits at frequency-amplitude combinations are shown in figure 4. At the lowest frequency level (10Hz), significantly higher ($p<0.05$) fruit detachment has occurred at higher shaking amplitudes, while at the other two frequency levels, the increase in fruit detachment at higher amplitudes has not been so prominent.

Table 1. Analysis of variance of data on ripe fruit removal (%) at different levels of shaking frequency and amplitude.

Source	df	Mean square	F
Amplitude	2	760.81	47.16**
Frequency	2	608.14	37.70**
Amplitude * Frequency	4	79.94	4.96**
Error	18	16.13259	
Total	26		

** Significant at p<0.01

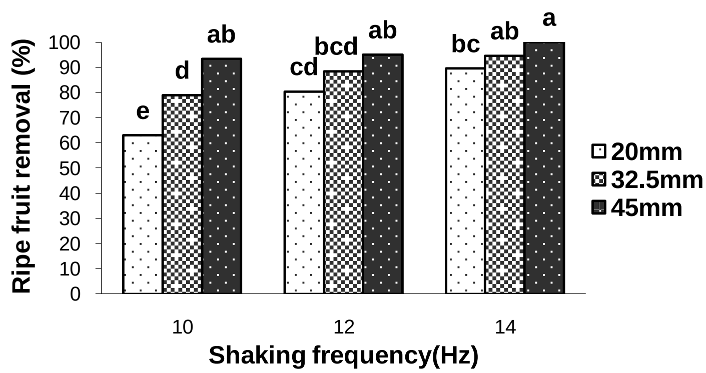

Figure 4.The effects of shaking frequency and amplitude on ripe fruit detachment, similar letters indicate no significant difference at p= 0.05.

The linear relationships correlating ripe fruit removal percentage (P_r) with shaking frequency (F) and shaking amplitude (A) are presented in tables 2 and 3, respectively. High R^2 values indicate the goodness of fit of linear regression lines.

Table 2. The linear relationship between ripe fruit removal percentage and shaking frequency.

Regression equation	Amplitude(mm)	R^2
P_r =1.667 F+ 76.1	45	0.923
P_r = 3.9 F+ 40.56	32.5	0.984
P_r = 6.625 F- 1.863	20	0.968

Table 3. The linear relationship between ripe fruit removal percentage and shaking amplitude.

Regression equation	Frequency(Hz)	R^2
P_r = 5.25A + 84.2	14	0.999
P_r= 7.295A + 73.38	12	0.996
P_r= 11.03A + 50.06	10	0.917

Results of analysis of variance for the effects of different levels of shaking frequency and amplitude on unripe fruit removal as shown in table 4 indicates highly significant differences ($p<0.01$) among different levels of shaking frequency, but the effect of amplitude and interactive effect of frequency and amplitude are not significant. The reason could be attributed to the fact that the dynamic force imparted to the fruit-stem or stem-branch junction by the forced vibration is proportional to the second power of frequency, while it is only a linear function of amplitude.

Table 4. Analysis of variance of data on unripe fruit removal (%) at different levels of shaking frequency and amplitude.

Source	df	Mean square	F
Amplitude	2	12.83	1.141^{ns}
Frequency	2	137.47	12.226^{**}
Amplitude * Frequency	4	15.56	1.384^{ns}
Error	18	11.24	
Total	26		

** Significant at $p<0.01$

Comparison of mean values of the total detached unripe fruits at frequency-amplitude combinations are shown in figure 5. It seems reasonable to assume that shake harvesting fig fruits at any shaking frequency × amplitude combination resulting more than 90 percent ripe fruit removal and less than 10 percent unripe fruit removal is justifiable. Therefore, by comparing figures 4 and 5 we conclude that the only shaking frequency x amplitude combination meeting this criterion is 10Hz x 45mm treatment with 93.3% ripe fruit and 9.4% unripe fruit removal.

The effects of shaking time on fruit removal The representative patterns of instantaneous and cumulative fruit removal rates are shown in figures 6 and 7, respectively.

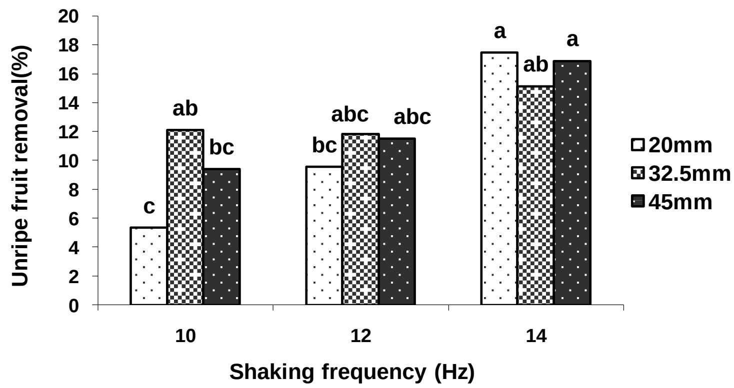

Figure 5.The effects of shaking frequency and amplitude on unripe fruit detachment, similar letters indicate no significant difference at p= 0.05.

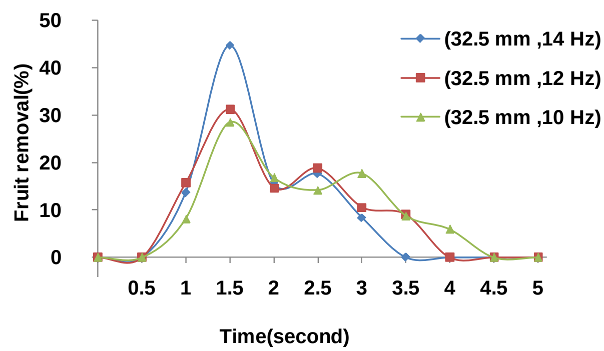

Figure 6. Representative instantaneous fruit removal rate curves during a 5 second shaking test.

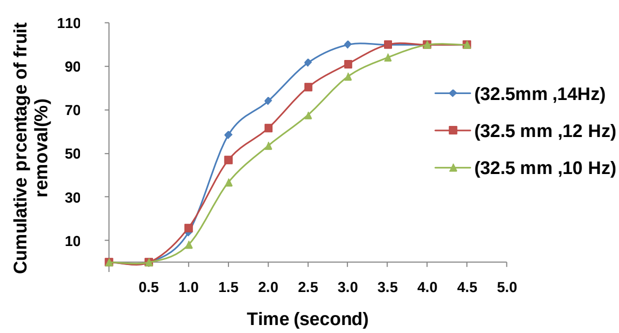

Figure 7. Representative cumulative fruit removal rate curves during a 5 second shaking test.

The results show that at all frequency levels the highest rate of fruit detachment occurs about 1.5 seconds after starting the shaker with the highest rate (47%) pertaining to the highest frequency (14Hz). This could be mainly attributed to the combined effects of maximum number of shaking cycles and maximum inertial force imparted to the fruits at this frequency. The cumulative fruit removal cures show that almost 100% of fruits are removed during the first four seconds of shaking. This suggests that for avoiding the destructive effects of shake harvesting such as excessive unripe fruit removal and tree damage, the shaking duration be limited to five seconds.

Variation of fruit detachment force to weight ratio (FDF)/W) Table 5 lists the mean values of fig fruit moisture content, geometric mean diameter, mass and static detachment force at different stages of maturity and natural drying on the tree branches. The results show that fruits are growing in size up to the second stage and then start to shrink gradually as natural drying proceeds. At the same time, fruit mass increases up to the fourth stage due to building up of more sugar content and then reduces sharply with loosing water content. Sharp reduction of detachment force (and consequently, F/W ratio) is attributed to the weakening of the stem-calyx junction, as the natural abscission layer develops under normal ripening process. F/W ratio is a good indicator of ease of fruit detachment and its sharp reduction during the ripening and drying process, suggests the feasibility of selective harvesting of ripped and semi-dried fruits by limb shaking to avoid fruit contaminations resulting from natural detachment and falling on the ground due to natural over-ripping and drying.

Table 5. Mean values of some physical and mechanical properties of fig fruits classified in five maturity (moisture content) groups.

Group No.	Moisture content (wet basis)	Geometric mean diameter (mm)	Mass (g)	Weight (N)	Detachment force F (N)	F/W ratio
1	76	25.06	9.85	0.0966	11.3	119.12
2	70	27.2	13.41	0.1315	8.30	62.98
3	62	26.35	13.93	0.1366	6.40	46.163
4	47	25.93	14.24	0.1397	3.43	25.04
5	24	25.6	10.68	0.1047	2.71	27.26

CONCLUSION

The results of this study revealed that:

1. Fig ripe fruit detachment is significantly affected by shaking frequency and amplitude, while unripe detachment is only affected by shaking frequency.

2. The optimum shaking frequency and amplitude for fig harvesting resulting over 90% ripe fruit and less than 10% unripe fruit removal is 10Hz and 45mm, respectively.

3. By selecting the proper shaking frequency and amplitude, almost 100% of fruits are removed during the first four seconds of shaking.

4. F/W ratio is a good indicator of ease of fruit detachment and its sharp reduction during the ripening and drying process, suggests the feasibility of selective harvesting of ripped and semi-dried figs by limb shaking.

REFERENCES

Adrian, P. A. and R. B. Fridley. 1965. Dynamics and design criteria of inertia type tree shakers. Trans. of the ASAE, 8(1), 12–14.

Anonymous. 2009. Estahban is the source of world fig for a long period. Gardener, July No. 31, 18-19.

Cargill, B. F. 1999. Fruit and Vegetable Harvest Mechanization – Technological Implications, Rural Manpower Center, Michigan State University, Michigan.

Domingan, I. R., R. G. Diener, K. C. Elliot, S. H. Blizzard, P. E. Nesseelroad, S. Singa and M. Ingle. 1988. A fresh fruit harvester for apples trained on horizontal trellises, Journal of Agricultural Engineering Research, 41(4): 239-249.

Erdogan, D., M. Gu¨ner, E. Dursun and I. Gezer. 2003. Mechanical harvesting of apricots. Biosystems Engineering, 85(1), 19–28.

FAO. 2008. Available from http://faostat.fao.org/faostat/collections?subset=agriculture.

Fridley R. B., H. Goehlich, L. L. Claypool and P. A. Adrian. 1964. Factors affecting impact injury to mechanically harvested fruit. Trans. of the ASAE, 7(4), 409–411

Kececioglu, G. 1975. Atalet kuvvet tipli sarsıcı ile zeytin hasadı imkanları uzerine bir arastırma [Research on olive harvesting possibilities with an inertia type shaker]. Department of Agricultural Machinery, Agricultural Faculty, Ege University. Izmir, Turkey.

Kepner, R. A., R. Bainer and E.L. Barger, 1987. Farm Machinery, CBS Publishers and Distributors, Daya Basti, Delhi.

Khonbani , J. 2009. Culturing, preservation, harvesting. Gardener July no. 31, 8-11.

Loghavi, M. and M. Abounajmi. 2001. Effects of shaking mode, frequency and amplitude on “Shahani” date fruit detachment ,II: field experiment. Iran Agricultural Research 21:1-14

Loghavi, M. and Sh. Mohseni**.** 2006. The Effects of shaking frequency and amplitude on detachment of lime fruit. Iran Agricultural Research, Vol. 24, No. 2 and Vol. 25, No. 1:27-38

Mbuge, D. O. and P. K. Langat. 2008. Principles of a mechanical shaker for coffee harvesting. CIGR Ejournal. Manuscript PM 07016, Vol. X.

Parameswarakumar, M. and C. P. Gupta. 1991. Design parameters for vibratory mango harvesting system. Transactions of the ASAE, 34(1):14–20.

Polat, R., I. Gezer, M. Guner, E. Dursun, D. Erdogan and H.C. Bilim**.** 2007. Mechanical harvesting of pistachio nuts. Journal of Food Engineering, 79:1131–1135.

Sessiz, A., and M. T. Ozcan. 2006. Olive removal with pneumatic branch shaker and abscission chemical. Journal of Food Engineering, 76,148–153.

Sirvastava, A. K., G. E. Georing, and R. P. Rohrbach. 1993. Engineering Principle of Agricultural Machines. ASAE, textbook No.6, ASAE. 601p.

Thomson, W.T., 1988. Theory of Vibration with Applications, 3rd Ed, New Jersey: Prentice Hall.

Torregrosa, A., B. Martín, J. García Brunton and J. J. Bernad. 2008. Mechanical Harvesting of Processed Peaches. Applied Engineering in Agriculture, Vol. 24(6): 723-729.