



## DETERMINATION OF OPTIMUM SHAKING FREQUENCY AND AMPLITUDE OF PROTOTYPE BODY SHAKER USED FOR MECHANICAL HARVESTING OF PISTACHIO

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### SUMMARY

Important problems have been seen during harvesting of different fruit trees in Turkey. The highest cost in fruit growing constitutes harvesting process as 43.99% of total cost. In this research, a body shaker which was mounted to tractor three-point linkage system and driven by power take off system was designed and manufactured to decrease the cost of harvesting of tree fruits. A tractor with 70 BG power is enough to transport and operate this body shaker. This prototype was functioned with a system including a hydraulic pump taking movement from power take-off and hydraulic motor. Body shaker could be controlled by only one person. Harvesting tests using different frequencies and amplitudes were carried out with body shaker. Two pistachio tree cultivars namely Siirt and Kirmizi were used during the harvesting tests. Pistachio fruits which remained on the branch and leaved from branch were weighed separately to determine of harvesting efficiency. For this aim, performance of body shaker was determined. As a result, the best performance result was determined using 40 Hz frequency and 20 mm amplitude. The

harvesting efficiency values in harvesting tests carried out using 40 Hz frequency and 20 mm were calculated 93.27% for pistachio cultivar of Siirt and 87.06% for pistachio cultivar of Kirmizi.

**Key words:** body shaker, fruit harvesting, pistachio nut

## INTRODUCTION

Pistachio nut (*Pistachio Vera* L.) is a perennial plant growing in inner South Eastern Anatolia regions of Turkey. Turkey is one of the most important pistachio producer countries, with 128.000 tones annual pistachio production, and Turkey comes after Iran (446.647 tonnes) and the United States of America (213.000 tonnes) (FAO, 2011). The most popular pistachio cultivars in Turkey are Kirmizi, Siirt and Uzun.

Tree shakers are widely used to harvesting of 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 plant trees (Horvath and Sitkei, 2001). About tree shakers, structure of both trunk and main roots and the ratio of fruit detachment force have been studied since 1960's (Adrian & Fridley, 1965; Fridley 1983; Keçecioglu, 1975; Sansavini & Costa 1986; Parameswarakumar & Gupta, 1991; Polat et. al. 2011, Gezer et. al, 1998, Sessiz & Özcan 2005, Lang 2006).

There are two broad approaches for the mechanical harvesting considerations. One of these approaches is the mass harvesting method, namely harvesting indiscriminately from the whole tree or a portion, without direct concern for individual fruits. The other is individual fruit harvesting, namely harvesting each fruit as distinct and separate from adjacent fruits. In individual fruit harvesting, several fruits could be harvested at the same time by separators (Schertz & 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 & 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 analyses of dynamics and power requirement of the system have 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 research is to investigate the mechanical harvesting of pistachio nut cultivars in Turkey. Designing, manufacturing and testing of a prototype body shaker for determining optimum operation conditions namely shaking frequency and amplitude values were also aimed.

## MATERIAL AND METHODS

### Design and Manufacturing of Body Shaker and Seizure Platform

After computer aided designing of body shaker, manufacturing of prototype system was carried out in workshop of Harran University Machine Factory in Sanliurfa City of Turkey. Main parts of body shaker are roof, oil tank, oil-cooling system, boom, hydraulic pump, hydraulic motor, oil transmitting pipes, vibrator heads, boots and control panel (Fig. 1).



**Fig. 1. Manufacturing process of body shaker**



**Fig. 2. Orchard tests with body shaker**

Performance tests were carried out in pistachio orchards as seen in Fig. 2.

Body shaker was driven with power take-off and tractor electric system. The movement taken from power take-off stimulated by hydraulic pump. Hydraulic pump transmitted the oil to the hydraulic motors on vibrator system.

### **Pistachio orchards used for harvesting tests**

Harvesting tests with the body shaker for Siirt and Kirmizi pistachio cultivars were conducted in orchards that are belong to Pistachio Research Institute during harvesting season (September and October). Trees in the orchards are 35 years old and were planted with intervals of 8x8 mm.

## Determination of harvesting efficiency and work success

Orchard trials with body shaker were carried out in Tagem-Pistachio Research Institute in Turkey. Vibrating process with body shaker was conducted during the harvesting of pistachio fruits by applying different amplitude and frequency values. 3 different amplitude values were applied as 10,15 and 20 mm. Values of frequency were selected as 20, 30, and 40 Hz. After each amplitude and frequency applications, the fruits dropped from the tree were collected by a catching mechanism. Fruit bulks that were dropped from the tree and staying on the tree were weighted separately. Harvest efficiency was calculated using these weighted fruit amounts by the equation as given below (Polat et al. 2007):

$$\text{Harvesting efficiency (\%)} = \frac{K_1}{K_1 + K_2} \times 100$$

In this equation;

$K_1$  is the mass of product (kg/tree) collected from branch as mechanical (harvested);

$K_2$  is the mass of product (kg/tree) which could not be dropped (staying on the branch).

As a result of these trials with body shaker, optimum shaking amplitude and frequency providing the most appropriate harvest efficiency were determined.

## RESULTS AND DISCUSSION

### Results of harvesting efficiency values

Harvesting trials were carried out during in September and October months as three replications for each frequency and amplitude values. Average values of results of three-years obtained for Kirmizi cultivar were given in Table 1.

**Table 1. Harvesting efficiency values determined after body shaker trials for Kirmizi pistachio cultivar**

Amplitude (mm)	Frequency (Hz)	Harvesting Efficiency (%)			
		1 <sup>st</sup> year	2 <sup>nd</sup> year	3 <sup>rd</sup> year	Average
10	20	22.21	25.1	22.76	23.36
	30	36.43	38.09	37.4	37.31
	40	53.83	52.1	57.89	54.61
15	20	35.22	34.49	36.71	35.47
	30	56.29	54.5	56.58	55.79
	40	63.25	66.21	66.69	65.38
20	20	67.42	65.37	69.95	67.58
	30	79.46	74.54	82.67	78.89
	40	87.66	83.42	90.11	87.06

As a result of harvesting tests, the lowest harvesting efficiency was obtained in body shaker with 10 mm amplitude and 20 Hz frequency values. On the other hand, the highest harvesting efficiency was obtained with body shaker with 20 mm vibrating amplitude and 40 Hz vibrating frequency. 87.06 % of the fruits on the tree was harvested during test conditions

of 20 mm amplitude and 40 Hz frequency when the highest harvesting efficiency was obtained. The reason of staying of pistachio nuts on the tree after mechanical harvesting was examined. It was found that the split resistance of pistachio fruits staying on the tree is somewhat high compared to pistachio fruits that could be dropped by mechanical shaking. The reason of this higher split resistance can be explained that fruits not dropped are still in ripening period or some part of the remaining fruits includes hollow fruits.

Three-years average values for harvesting efficiency results obtained for Siirt cultivar pistachio were given in Table 2.

**Table 2. Harvesting efficiency values determined after body shaker trials for Siirt pistachio cultivar**

Amplitude (mm)	Frequency (Hz)	Harvest Efficiency (%)			
		1.year	2.year	3.year	Average
10	20	27.62	25.98	27.66	27.09
	30	33.62	34.5	35.85	34.66
	40	48.69	48.13	46.96	47.93
15	20	40.03	35.72	37.72	37.83
	30	59.17	58.87	59.31	59.12
	40	65.9	69.23	72.04	69.06
20	20	73.21	72.84	78.25	74.77
	30	81.83	82.16	85.91	83.30
	40	92.48	92.8	94.53	93.27

In this research, the lowest harvesting efficiency value for Siirt cultivar pistachio for every three years determined after using of body shaker was determined as 27.09% in the conditions of 10 mm amplitude and 20Hz frequency. On the other hand, highest harvesting efficiency was calculated as 93.27% in the conditions of 20 mm amplitude and 40 Hz frequency.

The reason of pistachio nuts were not dropped was examined throughout the vibration tests using body shaker. Similar to trials results of Kirmizi cultivar pistachio, fruit splitting resistance of the pistachio nuts remained on the branch was determined somewhat high. In addition to this, pistachio nuts remaining on the branch consist of either immature or hollow fruits. Therefore, falling down of these immature or hollow fruits by means of vibration method is rather difficult. Therefore, in this research, ratio of fruits, (empty and full) remaining on the branch after mechanical harvesting were determined. Sola-Guirado et al. 2016 searched on vibration parameters assessment to develop a continuous lateral canopy shaker for mechanical harvesting of traditional olive trees. In this research they found that fruit detachment is influenced by the point of application of the vibration to the tree. For this reason in this research, pistachio fruit plucking resistance namely detachment force measurements were also performed. The results about these measurements were conducted for each pistachio cultivars separately after harvesting trials carried out using operation conditions of 20 mm amplitude and 40 Hz frequency in which the highest harvesting efficiency was obtained. Obtained results were given in Table 3.

**Table 3. The ratio of full and empty pistachio nuts remained on the branch after mechanical harvesting**

Cultivars	Ratio of full and empty pistachio nuts		Fruit Plucking Force (N)
	Full (%)	Empty (%)	
Siirt	43	57	315
Red	52	48	291

After mechanical harvesting of Siirt cultivar; only 43% ratio of remained fruits ratio on the branch (5.47% of all fruits on the tree) was determined as full fruits. For Kirmizi cultivar of pistachio fruits, full fruit ratio was determined as 52% (9.89% of all the fruits on the tree). Average values of fruit plucking force of the fruits remaining on the branch were measured as 315 N for Siirt cultivar and 291 N for Kirmizi cultivar. These results showed that it is very hard to fall down all pistachio fruits remained on the branch. Because using of higher frequency and amplitude values than optimum values can seriously harm the trees.

## CONCLUSIONS

According to results of this research, pistachio cultivation should be performed by taking into consideration mechanization since the beginning. It is somewhat too hard to conduct mechanization practices in pistachio nut gardens in which growing is not carried out in accordance with mechanization. These difficulties have been encountered in mechanical harvesting. Planting intervals, tree's corolla structure and disorder of body form shape have constituted a problem for mechanical harvesting. Particularly pruning procedure in pistachio nut must be carried out with a great attention if mechanical harvesting is also performed. Until the vibration reaches the end of the branch in vibrating mechanical harvest machines especially in branch shakers, it fades and turns into a whipping movement.

The highest harvesting efficiency was obtained in harvesting trials carried out with 20 mm amplitude and 40 Hz frequency using body shaker. Approximately 90% harvesting efficiency was obtained for both pistachio cultivars after harvesting process conducted with this frequency and amplitude values. It was seen that much higher efficiency values may be result of permanent damage in body form of the trees.

Fruit harvesting is generally performed by means of the hand throughout the world using manual labour due to the fact that it is still cheap and growers are worried about the detrimental effects of mechanical harvesting to the trees. Nonetheless, labour cost and difficulties in finding of labour have been increasing day recently. Thus, mechanical harvesting becomes unavoidable for growers of pistachio nuts and other fruits. In this research, a body shaker that can be connected to the tractor and removed any time and that have lower cost compared to self-propelled shakers was designed and tested for pistachio trees. Results showed that this system with optimum frequency and amplitude can be suggested to obtain high harvesting efficiency for pistachio harvesting safely.

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