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Evaluation of different mechanical harvesting systems of table olive (*Olea europaea* cv. Gemlik)

Sofralık zeytinde farklı mekanik hasat sistemlerinin değerlendirilmesi (Olea europaea cv. Gemlik)

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ABSTRACT

The experiments were conducted in Gemlik olive variety (Olea europaea cv. Gemlik)'s orchard to determinate the harvesting performance of different harvesting methods namely hand, branch shaker and trunk shaker at different frequencies and compare the harvesting methods. Trunk shaker with eight different frequencies were operated. In the first and second year of the experiments at the optimum harvest time, fruit volume, fruit detachment force, fruit weight, the ratio of fruit detachment force to fruit weight were found to be 3.9-4.0 cm^3, 3.27-3.99 N, 4.23-4.28 g, 0.77-0.94 N g^{-1} respectively. Best results were obtained by using the trunk shaker with low frequencies as trunk shaker machine (TSM) 22 Hz. Fruit damage, tree damage levels, harvesting efficiency, duration of operation per tree and work productivity of trunk shaker with 22 Hz were found as less than 1.5%, 2.86%-7.24%, 93.93%-92.92%, 2.51-2.81 min $tree^{-1}$ and 286.22-355.72 kg $worker^{-1}$ h^{-1} respectively in two-years (2012 and 2013) trials.

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ÖZ

Denemeler, Gemlik çeşidi zeytin bahçelerinde farklı zeytin hasat yöntemleri; elle toplama dal sarsıcı ve gövde sarsıcının farklı frekanslarındaki hasat performanslarının belirlenmesi amacı ile yürütülmüştür. Gövde sarsıcı sekiz farklı frekansta çalıştırılmıştır. Denemelerin birinci ve ikinci yılında optimum hasat zamanında, meyve hacmi, meyve kopma kuvveti, meyve ağırlığı, meyve kopma kuvvetinin meyve ağırlığına oranı sırasıyla 3.9-4.0 cm^3, 3.27-3.99 N, 4.23-4.28 g, 0.77-0.94 N g^{-1} olarak bulunmuştur. Genel performans kriterleri incelendiğinde, en olumlu sonuçlar gövde sarsıcının 22 Hz. Frekans değerinde alınmıştır. İki yıllık çalışmalar sonucunda, meyve hasarı, ağaç hasar seviyeleri, hasat etkinliği, ağaç başına hasat süresi iş başarısı 2012 ve 2013 yılları için sırasıyla, %1.5'den az, %2.86-%7.24, %93.93-%92.92, 2.51-2.81 min $ağaç^{-1}$ ve 286.22-355.72 kg $işçi^{-1}$ $saat^{-1}$ olarak bulunmuştur.

1. Introduction

Providing more than 95% of global olive production, the Mediterranean basin countries include Spain, Italy, Greece, Portugal, France, Turkey, Tunisia, Syria and Morocco (FAO 2016). Turkey has been one of the major producers of olives among Mediterranean countries and ranks the fourth among olive producer countries.

Harvesting is one of the most important operations in olive growing. High quality olives need careful supervision of the operators in each step of the production and processing. Spain and Italy are the main olive producers and have developed new technologies in harvesting.

The most common harvest method for table olive is hand picking that is traditional method. In this method, work productivity is low and harvesting cost is high. If the product quality is protected properly, and suitable techniques are implemented at each step of production and processing, the costs of production and environmental degradation will reduce. Beside these the long harvest poles are widely used in traditional olive harvesting method and causing major problems. This method damages both fruit and the yearly shoots carrying buds that provide the following year's product. This situation lowers the quality of the fruit and increases of periodicity much more. Also, both the difficulty of finding laborers and the high prices make mechanical harvesting unavoidable (Saraçoğlu 2008). Çiçek et al. (2010) expressed that time and management size are two most important factors in olive harvesting and machinery harvesting methods over traditional methods should be preferred.

The total labor time for harvest of fruit is 40-80% of total production time, forming 30-60% of total production costs (Saraçoğlu 2006). Saraçoğlu and Özarslan (2003) reported that harvesting with mechanical limb shakers provided least harvest damage and highest productivity. Jiménez-Jiménez et al (2013) expressed that the olives harvested with trunk shakers and dropped to the ground had 12 times higher than handpicked fruits. Gezer and Güner (2000) determined that apricot fruit weight, strength of fruit hold to branch, bending force of stalk, stalk length, amplitude, frequency, location of bracket and link points, spring rigidity of branches and so on are factors affecting the detachment of fruit from the branch. Tombesi et al. (2017) determined that sucker such as vegetative, unproductive shoots borne on the main branches, removal prior to mechanical harvesting increases trunk and branch acceleration especially at low frequencies. Hoshyarmanesh et al. (2017) expressed that best harvesting efficiency was obtained when the trunk shaker mounted on 1.1 m above the ground at 20 Hz in warm condition for 10 s. Testing of new methods and machines that will be an alternative to traditional harvesting methods and determination of the best working conditions is of great importance for increasing productivity and quality in olive production.

The aim of this study is to determine the harvest performance of hand picking, limb shaker machine (LSM) and TSM with different frequencies which include shock frequencies for Gemlik olive variety.

2. Materials and Methods

The research was conducted at the trial area of Atatürk Horticultural Central Research Institute in the south of the Marmara region of Turkey. Characteristics of orchard and olive trees are given in Table 1.

Table 1. Characteristics of orchard and trees.

Orchard Tree Characteristics	Gemlik (black, table)
Planting interval (m)	7 x 7
Planting density (tree ha^{-1})	204
Slope	0%
Year planted	1989
Pruning style	Free
Mean tree crown height (m)	4.05±0.38
Mean crown diameter (m)	4.21±0.10
Mean trunk height (m)	0.88±0.35
Mean trunk diameter (m)	0.19±0.04
Mean productivity (kg tree^{-1})	16.0±4.50

Trials were conducted for two years except for the preliminary trials. In the second year, the method given high performance in the first year trials was repeated.

Studies related to olive fruit before harvest was carried out in orchard and laboratory. In order to identify color differences of fruits; L, C*, h° coordinates were determined by using Minolta CR 300 Chroma Meter at harvest time.

To determine fruit maturity index (I_z) (Table 2), 100 olives were cut and color intensity was evaluated (Boskou 1996, Saraçoğlu 2008). The maturity index was calculated by the equation below;

$$I_z = \frac{[(n_0.0)+(n_1.1)+(n_2.2)+\cdots+(n_n.n)]}{100} \quad (1)$$

In the formula above;
I_z: Olive maturity index (0...7),
n_n: Sample number in the characteristic group.

When maturity index (I_z)≅ 5-6 the decision to harvest is made (Qabatty 2010). For fruit oil measurement, Soxhlet extractor was used (Cemeroğlu 2013). Fruit volume was determined by the water displacement method and Kavalier

Table 2. Maturity index (Saraçoğlu and Ulusoy 2008).

Group number	Skin color	Fruit flesh	Fruit's Outside appearances	Fruit's Inside appearances
0	Deep green	Hard		-
1	Yellow green	Starting to soften		
2	<Half the fruit surface turning red, purple or black			
3	>Half the fruit surface turning red, purple or black			
4	All purple or black	All white or green flesh		
5	All purple or black	< Half the flesh turning purple		
6	All purple or black	> Half the flesh turning purple		
7	All purple or all black	All flesh purple to the pith		

Stabil brand Simax glass measuring cylinder was used. All of these analyses were carried out to determine the level of fruit maturity.

In order to determine the optimum harvest time, fruit detachment force (N) was measured by using a push-pull Chatillon brand analog force gauge within 0.1 N accuracy, with 3 repetitions using 10 fruits from the four different sides of the tree. The ratio of fruit detachment force to fruit weight (FDF/FW) was determined.

Table olive varieties can be damaged easily. For that reason, table olive is harvested by hand. Hand harvest method consists of hand picking of fruit, putting to baskets, using ladder to reach high branch of tree (Figure 1c). Consequently it takes more time than other harvesting methods and hand or traditional harvesting is not satisfactory in terms of time and cost. Accordingly, it is inevitable that the machines will be used for harvesting. In this study three different harvesting methods such as, trunk shaker at different frequencies (Figure 1a), limb shaker (Figure 1b) and harvesting by hand (Figure 1c) were tested and compared. The technical characteristics of limb shaker and mobile trunk shaker used in this study are given in Table 3.

In preharvest trials, in order to determine the limit of tree by the usage of shakers, the spring rigidity of tree was measured. As previous studies used intervals from 5-15 s, duration of vibration for harvesting was chosen as 8 s (Güner and Gezer 2001; Saraçoğlu 2008; Keçecioğlu 1975; Hoshyarmanesh et al. 2017; Leone et al. 2015). Mayo (1994) determined that the effect of instant shock frequencies was to ease fruit fatigue and falls. Three different shock frequencies were determined as 18+22 Hz, 22+25 Hz, 22+28 Hz. Harvest studies were carried out with hand picking (three laborers) and LSM (one laborer/operator) and TSM (one laborer/operator) 18 Hz, 20 Hz, 22 Hz, 25 Hz, 28 Hz frequencies and 18+22 Hz, 22+25 Hz, 22+28 Hz frequency combinations) (one laborer/operator) with 8 s vibration duration within 5 repetitions. During the operation of shock frequencies; for example shock frequency such as 22+25 Hz was carried out uninterrupted and continually 4 s for 22 Hz and 4 s for 25 Hz in total 8 s. Trials were done on 5 trees

Figure 1. a; Harvest by trunk shaker, b; Harvest by limb shaker, c; Harvest by hand.

Table 3. Technical characteristics of mechanical limb shaker and trunk shaker.

Limb Shaker	**Numbers/Measures**
Weight (kg)	12
Maximum length (m)	6
Frequency (Hz)	20
Amplitude (mm)	6.2
Cylinder volume (cm³)	50
Fuel tank capacity (L)	1.5
Power (kW)	2.5
Mobile Trunk Shaker	
Movement	Hydrostatic, 360 degree, joystick and steering wheel
Fuel	Diesel
Motor Power	Motor: 99 kW (135 HP) diesel
Amplitude	20-60 mm (catalogue value)
Vibration frequency	20-58 Hz (catalogue value)
Boom (telescopic)	4.5 m
Rotational motion	360°
Controls (Joystick)	2
Arm length	2.8 m - 6 m
Measurements of shaking head	45-75-110 cm
Weight	5200 kg
Gripping tongs	0-80 cm opening, 30° with ability to grip sloped branches and trunk. Also head can be directed up and down and be raised and lowered.

on Gemlik table olive cultivar for each variable. TSM harvesting was completed by one laborer (operator) operates the trunk shaker. The following variables were investigated for all harvest methods in the trials;

- Work productivity kg worker^{-1} h^{-1}
- Harvest efficiency (%)
- Duration of operation per tree (min tree^{-1})
- Damage levels (%)

The variable of work productivity (kg worker^{-1} h^{-1}) were measured for LSM and TSM for each tree separately and work productivity value was calculated using the equation given below;

$$\text{Work Productivity } (kg\ worker^{-1} h^{-1}) = \frac{(\text{Amount of produce harvested}).60}{\text{Time spent on harvest } (min)} \quad (2)$$

During the harvesting by hand, duration of operation per tree (min tree^{-1}) was measured. The handling and idle time of them were excluded while the actual duration of operation per tree of the trunk shaker and limb shaker were determined. Duration of operation per tree for limb shaker and trunk shaker included approaching- grapping of trunk/limb–shaking of trunk for trunk shaker (8 s)/shaking of each limb of tree. Fruit remaining on the tree were also collected by hand.

$$HY = \left(\frac{K_1}{K_1 + K2}\right).100 \quad (3)$$

In the formula above;
HY: Harvest efficiency (%),
K_1: Amount of fruit harvested (kg tree^{-1}),
K_2: Amount of fruit remaining on the tree (kg tree^{-1}).

To obtaining variable of damage levels; The leaf+branch+shoots amount was determined as a percentage of the total material shed by the tree at the end of the harvest (Saraçoğlu and Ulusoy 2009);

$$Damage = \left[\frac{(Leaf + Branch + Shoots) kg\ tree{-1}}{((fruit + leaf + Branch + Shoots) kg\ tree{-1}}\right].100 \quad (4)$$

The detection of tree damage caused by trunk shaking and limb shaking; Visual inspection was carried out to identify the presence of any damage to tree trunk and branches due to mechanized harvesting. In first year experiments, fruit damage was determined by visual inspection.

The results of TSM, LSM and hand harvesting variables were statistically analyzed and compared. According to the first year results obtained from all methods, the best results were achieved by using of trunk shaker with 22 Hz frequency for Gemlik variety olive harvesting. In the second year, harvesting by trunk shaker with 22 Hz frequency was repeated in the same area. In the second year trials, once again harvest performance values such as harvest efficiency, work productivity, duration of operation per tree, and damage level for TSM 22 Hz were determined. The values of variables were analyzed using the MSTAT-C statistical program. The significance levels of variation values of the methods were investigated with variance analysis ($p<0.05$) and differences in means of factor levels were compared with the Duncan multiple range test. Obtained two years results were compared with each other.

3. Results and Discussion

At the harvest time, I_z, L, C*, h$^\circ$ were determined as 5.67, 60, 20, 50 respectively. Maturity index increased over time. In one and a half month duration I_z value reached 7 and indicated over-ripening. At the harvest time, mean dry material was 48.76 % with mean oil in dry material found as 39.23%. The obtained results clearly show the importance of harvesting at the best time. The FDF/FW ratio at olive harvest time is an important parameter for mechanization. When Gemlik variety olive get ripe, the fruit detachment force reduces and fruit weight increases slightly and it may be said that a reduction occurred in the ratio of detachment force to fruit weight (FDW/FW). Farinelli et al. (2012), determined that FDF/ FW ratio must be equal to or lower than 2.3 to ensure mechanical harvesting yield equal to or higher than 85%. At harvest time, the mean fruit detachment force (FDF), mean fruit weight (FW) and FDF/FW ratio were found as 3.27N ± 0.21, 4.23 g ± 0.28, 0.77 N g^{-1} ± 0.01 respectively. Mean fruit volume was measured as 4.02 cm^3 ± 0.11. At harvest time in the second year with appropriate harvest time supported by the FDF/FW ratio found as 0.94 N g^{-1} ± 0.5. In second year the mean volume of fruit was calculated 3.90 cm^3 ± 0.18.

Due to preliminary studies to identify the spring rigidity value of the tree providing a tree spring constant below 50 mm, amplitude was not taken as a separate factor but this value measured as 25 mm from previous study result. It was assumed that this value would not damage the tree.

The results of first year experiments show that fruit damage was less than 1.5%. The fruit damage was not affected by harvesting methods.

According to the randomized block design with 95% confidence interval, harvest efficiency found that hand picking variable was first rank with 99.88% ± 0.05 harvest efficiency, followed by TSM at 22 Hz with 93.93% ± 3.45 harvest efficiency (Table 4). LSM was in last place (64%) (Figure 2).

As it is shown Figure 3, the greatest amount of time as 54.96 min worker^{-1} tree^{-1} was determined for harvesting by hand. There were not any statistical differences between other harvesting methods (Table 4).

The lowest damage level (1.79%) was obtained with hand picking method. This was followed by LSM and TSM 22-18-20 Hz respectively. However, LSM values may not be considered because they have high standard deviation value. In this case, the TSM 22 Hz method can be regarded as the second rank in terms of the low level of fruit damage (2.86%) (Figure 4).

The level of frequency of trunk shaker is a very important parameter to get high level work productivity. As shown in the Figure 5, TSM 20 Hz, TSM 22 Hz, TSM 18+22 Hz methods gave the best work productivity results with 344.96 kg worker^{-1} h^{-1}, 286.22 kg worker^{-1} h^{-1} and 286.79 kg worker^{-1} h^{-1} respectively.

However, it is noteworthy that the standard deviation of work productivity is high when working with TSM 18+22 Hz. As it is known, hand picking has many difficulties such as external factors and low work productivity. The exclusively TSM 22 Hz method was used in the second year trials because of the results of first year trials and the other external factors (labor, climate condition, orchard etc.). The values of harvesting performance of TSM 22 Hz for both years were obtained, compared and evaluated.

Compared two-year variables of harvest trials made by TSM 22 Hz method. The used method's harvest efficiency levels of two years almost the same. For this reason, it is understood that Gemlik variety table olive can be harvested by TSM 22 Hz method (Figure 6).

Table 4. Damage level, duration of operation per tree, harvest efficiency and work productivity of harvesting methods.

Harvest Methods	Damage Level %			Duration of Operation min tree^{-1}			Harvest Efficiency %			Work Productivity kg worker^{-1} h^{-1}		
Harvest Method	Mean	SEM	σ	Mean	SEM	σ	Mean	SEM	σ	Mean	SEM*	σ
TSM 22 Hz	2.86^{abc}	0.38	0.85	2.51^{a}	0.18	0.40	93.93^{d}	1.55	3.45	286.22^{de}	43.22	96.65
TSM 25 Hz	5.48^{bcd}	0.97	2.18	2.33^{a}	0.60	1.33	87.71^{cd}	3.24	7.24	189.15^{bcd}	30.69	68.62
TSM 28 Hz	5.69^{cd}	1.02	2.28	2.60^{a}	0.60	1.35	89.85^{cd}	3.08	6.89	231.21^{cd}	21.50	48.07
TSM 22+25 Hz	5.93^{d}	0.97	2.18	1.74^{a}	0.16	0.36	89.50^{cd}	1.50	3.35	252.67^{cde}	33.82	75.62
TSM 22+28 Hz	14.76^{e}	0.98	2.20	2.22^{a}	0.12	0.27	89.10^{cd}	3.27	7.32	159.18^{bc}	25.08	56.08
TSM 18 Hz	3.65^{abcd}	0.39	0.96	2.77^{a}	0.12	0.29	78.81^{b}	2.93	7.18	266.50^{cde}	27.21	66.64
TSM 18+22 Hz	5.75^{cd}	0.81	1.98	2.67^{a}	0.09	0.21	84.00^{bc}	2.25	5.52	286.79^{de}	51.82	126.94
TSM 20 Hz	4.45^{abcd}	1.31	3.20	2.71^{a}	0.07	0.16	88.37^{cd}	2.48	6.07	344.86^{e}	44.38	108.71
LSM	2.67^{ab}	0.98	2.20	3.70^{a}	0.46	1.03	63.75^{a}	4.93	11.03	94.83^{ab}	16.67	37.27
By Hand	1.79^{a}	0.73	1.64	54.96^{b}	9.11	20.38	99.88^{e}	0.05	0.02	25.60^{a}	0.30	0.68

TSM, LSM $p<0.00$, *: Standars Error of Means.

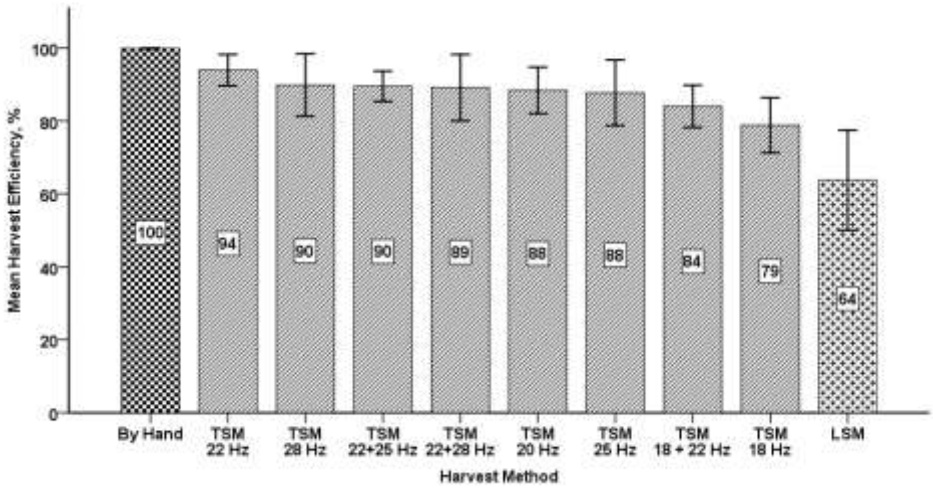

Figure 2. Harvest efficiency of methods and standard deviations.

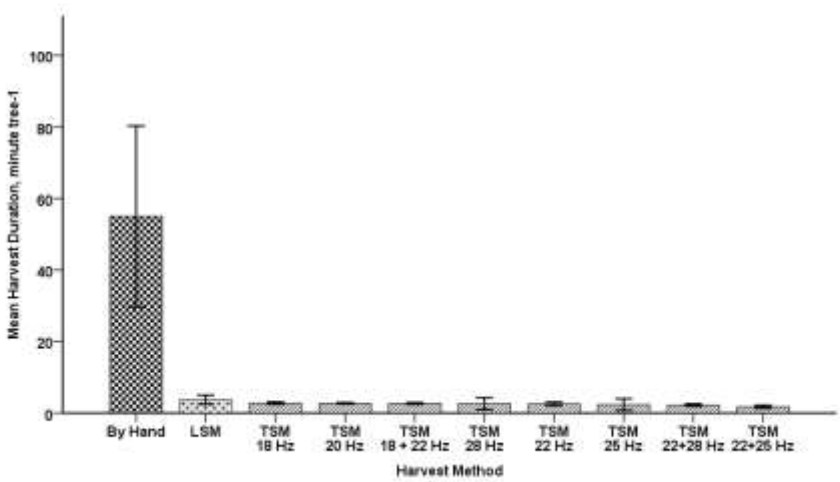

Figure 3. Duration of operation per tree and standard deviations.

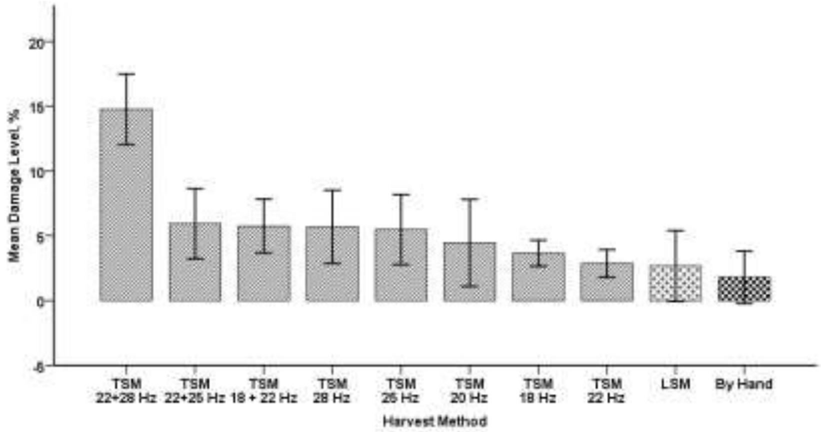

Figure 4. Damage levels (percentacge of leaf, branch and shoots mass) of harvest methods and standard deviation.

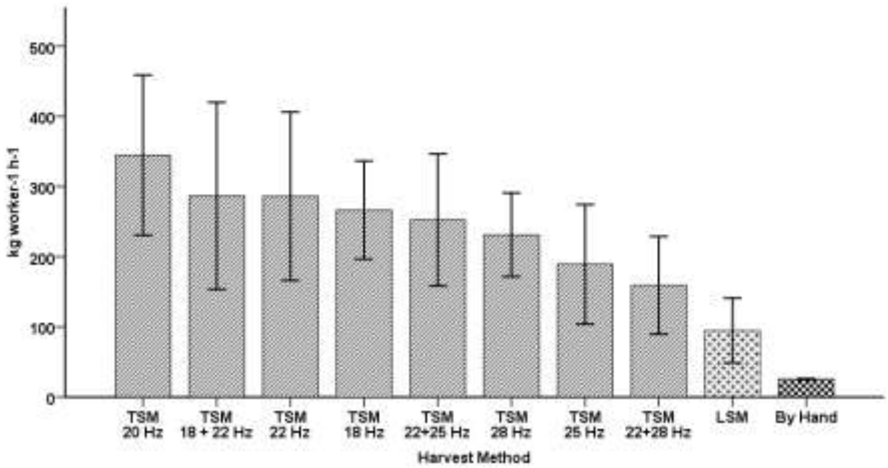

Figure 5. Work productivity of methods and standard deviation.

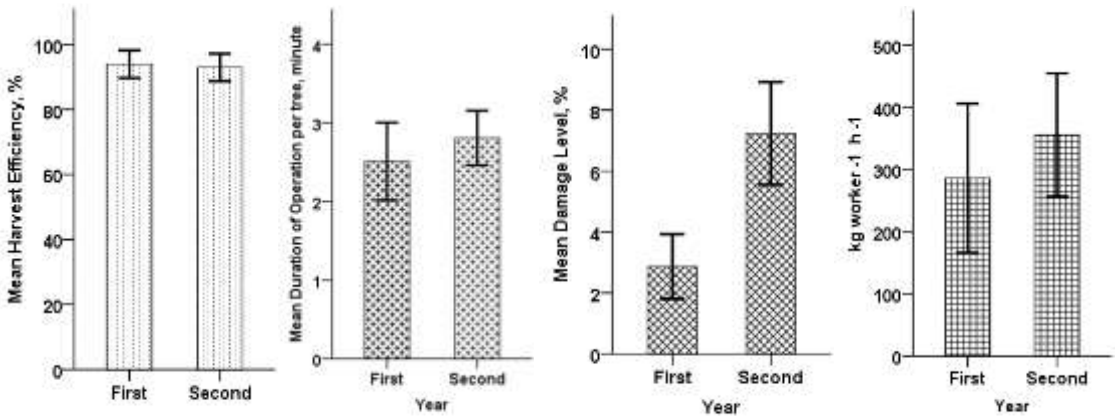

Figure 6. The comparison of first and second year harvest variables values of TSM 22 Hz method.

4. Conclusion

Comparing olive harvest with TSM, LSM and traditional hand-picking, in each situation trunk shaking should be chosen. However, sloped fields where trunk shakers cannot be operated, or for young trees or trees with structure inappropriate for trunk shakers, limb shakers may be used.

According to the result obtained in first year trials, shock vibration use caused the problem of greater leaf shedding and in situations such as when the operator is not confident in transitioning from one frequency to another and/or machine design does not allow this, it may not be practical under current conditions. Plantation should be suitable designed for mechanical harvesting. It is considered that design development studies are recommended to make this transition applicable. Castro-Garcia (2015) also expressed that trunk shakers with high acceleration improve harvesting efficiency, but it causes more damage to the harvested fruit. During the operation, it is very important to have minimum fruit and tree damage as much as high harvesting efficiency. According to results of harvesting trials, trunk shakers with low frequencies such as TSM 20 Hz and TSM 22 Hz for 8 s may be recommended.

In harvest time, while TSM includes approach, vibration and retreat from the tree, with LSM all branches were easily reached using the hook on the end of the branch pole extension and quickly vibrated. However, as all sides of the tree were not reached with LSM, some branches could not be gripped and thin branches may be broken. The harvest efficiency may be decreased in this situation. The operator of the LSM carries the machine by hand and may experience problems and difficulties due to the weight of the machine and vibration during working. The extension pole of the machine and the controls must be continuously held tightly causing discomfort. Due to misuse of mechanical limb shakers during harvest, severe peeling of bark and detachment of branches and shoots may occur.

Another criterion in the choice of harvest machine is the number of trees. Rather than large-scale production facilities using hand - held harvest machines, using TSM for harvesting assisted by hand- held harvest machines will be the correct choice. Also, time, tree numbers are so important for mechanical harvesting system (Çiçek 2011). If we have more than 100 hectares plantation, mechanical system would be economic. Otherwise cooperative system may be suggested.

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