Evaluation the mechanical harvesting efficiency of olive with the application of fruit loosening spray

Adnan I. Khdair[1*], Ghaida Abu-Rumman[2], Sawasn I. Khdair[3]

(1. *Mechanical Engineering Department, Jordan University of Science and Technology, 22110 Irbid, Jordan*;
2. *Deptarment of` Civil Engineering, Isra University, 11622 Amman, Jordan*;
3. *Faculty of Pharmacy, Al-Zaytoonah University of Jordan, 11733 Amman, Jordan*)

Abstract: Olive is harvested mainly by hand in the Mediterranean. This resulted in steady rising of harvesting cost due to shortage of skilled labors at harvesting time. Operation cost might be reduced and harvesting processes will be carried out on time if mechanical harvesters are used. In 2015, an experiment was performed to study the effects of mechanical harvester and use of loosening agent on harvesting productivity and efficiency. The experiment was conducted using randomized complete block with two regional olive varieties Nabali Rosie and Nabali. Harvesting productivity by hand (hand picking), pneumatic comb and branch shaker machines were evaluated. Ethrel abscission chemical was used two weeks before harvesting as an abscission and loosening agent at three concentration levels: 0, 1500 and 3000 mg L^{-1}. The results showed that harvesting techniques and Ethrel amount had significant effects on harvesting percent at $\alpha = 0.01$. The harvesting productivity increased by two and four times compared to traditional method (hand harvesting) using pneumatic comb and branch shaker machines, respectively. The fruit detachment force (FDF) was also significantly affected by abscission dosage at $\alpha = 0.01$. It was reduced from 9.35 N to 5.65 N for Nabali Rosie at Ethrel level of 3000 (mg L^{-1}). This reduction in FDF as a result of abscission application increased the removal percentage and harvesting production of olives. The percentages of injured fruits and detached leaves were acceptable with less than 10% and 12%, respectively.

Keywords: olive mechanical harvesting, abscission, harvest productivity, removal efficiency, fruit detachment force

Citation: Khdair, A. I., G. Abu-Rumman, and S. I. Khdair. 2018. Evaluation the mechanical harvesting efficiency of olive with the application of fruit loosening spray. Agricultural Engineering International: CIGR Journal, 20(4): 69–75.

1 Introduction

Olives (*Olea europaea* L.) are grown on large scale worldwide in areas of Mediterranean climate. It is estimated that there are around 1000 million olive tress throughout the word with more than 95% of the orchards are planted in the Mediterranean region (Weismann, 2009). Olive harvesting is a tedious job in olive cultivation, demanding a lot of labor at high cost. Despite its difficulties hand harvesting is the main practice because it ensures high quality product with less branches and tree injuries. To increase harvesting productivity, labors used manual comb and beat the tree branches with wooden sticks occasionally to accelerate the process. This might cause fruits injuries, foliage loss and damage to the new kindling.

Olive plantations in the region are booming because the tree is drought tolerance and required less care in the field. Usually over 75% orchards are planted in dry land at low tree densities (30-180 trees ha^{-1}). The trees have multiple trunks and wide canopies and have low yields (1.1 to 4.5 Mg ha^{-1}) (Vossen, 2007). There is no universal solution for mechanical harvesting of olive due to different olive groves varieties (Gomez-Limon et al. 2012, Rallo et al. 2013). The harvesting technique depends mainly on trees training and layout, size, cropping, land slope, and workers availability. The crop's low return and seasonal fluctuation slow harvesting innovations. Simultaneous adaptation of the trees and the harvesting machinery for the current and new groves might be a

Received date: 2017-10-29 **Accepted date:** 2017-11-09
*** Corresponding author: A. I. Khdair,** Mechanical Engineering Department, Jordan University of Science and Technology, 22110 Irbid, Jordan. Emails: akhdair@just.edu.jo; akhdair@kau.edu.sa.

solution (Ravetti and Robb, 2010).

Currently, manual harvesting with poles is the primary harvesting method in the Mediterranean with harvest efficiency more than 95%. The productivity is low reached 15-25 kg h^{-1} per worker and expensive, averaging more than £ 0.2 kg^{-1} (Rallo et al., 2013). Incorporating hand-held machines improves productivity to 30-50 kg h^{-1} per worker and reduces the cost to £ 0.18 kg^{-1} (Jesus et al., 2014). However, the efficiency is highly dependent upon operator skill and cannot be considered a technique for mechanical harvesting as it does not eliminate the reliance on labor availability (Ferguson, 2006). Mechanical harvesting is adapted primarily because hand labor is too expensive and unavailable (Catania et al., 2017). The net return should be improved or at least maintained by adopting mechanical harvesting is required (Jesus et al., 2014). Harvesting with minimum fruit damage and processing at the proper time are the requirement for production of high-quality virgin olive oil (Clodoveo et al., 2014).

Mechanical harvesters are used to reduce labor cost and harvesting time (Farinelli et al., 2012; Zipori et al., 2014). Tree shakers are used on large scale at huge olive fields (Almeida et al., 1999, Tombesi et al., 2002), which guarantees less damage to olives fruits compared to that harvested by hand-held machines. On the contrary, mechanical harvesting of table olives is a rare practice due to its low harvesting efficiency and high fruit injuries percentages (Ferguson, 2006).

In Jordan olives are 98% hand harvested, where fruits picked one by one from the tree by the use of ladders to pick up the fruit from upper twigs on the top of the canopy. The fallen fruits were collected from nets placed underneath the trees. Hand harvesting cost accounts for 50%-70% of the product and requires 80% of the man-hours needed for the total crop operation (Ahmad and Ayoub, 2014). Slow rate of hand harvesting and higher harvesting cost makes introducing machines harvesters appealing to the olive farmers. Finding enough labors at the proper time for manual harvesting is not an easy job, which motivate the adoption of mechanical harvester techniques slowly in the market.

Studies related to mechanical harvesting assessment of olive in Jordan are rare; therefore, the objective of this research was to assess hand-held harvesting machines effectiveness relative to widely used traditional hand harvesting method. The study includes evaluation of performance factors such as yield harvest percentage, productivity percentage, fruit detachment force, detached leaves and fruits injuries for two local varieties Nabali Rosie and Nabali sprayed by abscission agent.

2 Materials and methods

The study was conducted in 2015 on 15-year-old olive trees of two olive cultivars, Nabali Rosie and Nabali on local farm located in North West of the country, where most of rain fed trees are grown. The experiment was conducted as factorial randomized complete block design in three replications, with two factors of olive cultivar (NR = Nabali Rosie, N = Nabali), three harvest method (M = harvesting by hand, P = harvesting by pneumatic combs, BS = harvesting by branch shaker) at three levels of Ethrel abscission chemical (E1 = 0, E2 = 1500 and E3 = 3000 (mg L^{-1}). The Nabali Rosie cultivar has relatively large and spherical fruits with the average weight of 4-5 g, used mainly for table olive. This cultivar is native of Jordan and oil content reached 19%. The Nabali cultivar is local variety too with small fruits and average weight of 2.7 g and oil content reaches up to 29%. Table 1 shows the average fruit physical properties and oil content for 15 olives from each cultivar. The fruit weight was obtained by digital balance, volume by using water displacement method and fruit dimension by using digital caliper.

Table 1 Fruit physical properties and oil content of the two cultivars investigated

Cultivar	Fruit mass (g)	Fruit volume (cm^3)	Fruit (span × width) (cm)	Oil content % (Based on fresh weight)
Nabali Rosie	4	2.4	2.3×1.8	19.2
Nabali	2.7	4.5	2×1.4	28.5

Two weeks before harvesting the fruits, on November 30, the Ethrel loosening agent was used at specified dosages. The fruits from each treatment were gathered and weighed at harvesting time. After harvest completed, the remaining fruits over the trees were hand collected and weighed to determine harvesting efficiency. For every treatment, fruit removal percentage was calculated by using the formula:

$$\text{Harvesting efficiency} = \frac{\text{Fruit weight obtained by ceratin method}}{\text{Tree yield}} \times 100$$

Harvesting time was recorded for every treatment and total yields were weighed. Labor productivity (kg hr^{-1}) for each treatment was calculated by

$$\text{Labor productivty} = \frac{\text{Fruit weight gathered by one worker (kg)}}{\text{Time of harvesting (hr)}} \times 100$$

Detached leaves percentage was calculated by using the following formula:

$$\text{Detached leaves \%} = \frac{\text{Detached leaves number}}{\text{Total number of leaves}} \times 100$$

Injured fruits percentage (according to the scratch that found on the fruit skin) was calculated by:

$$\text{Fruits injuries \%} = \frac{\text{Number of injured fruits}}{\text{Total number of harvested fruits}} \times 100$$

Three harvesting methods were evaluated (hand picking, pneumatic comb and hand held branch shaker) for each cultivar. A Randomized Complete Block Design (RCBD) was used, with three replications. For each harvesting method, Etherl (2-Chloroethylphosphonic acid - Ethephon) was used as abscission agents at three levels ET 0, 1500 and 3000 mg L^{-1}. The experiment included 27 trees from each cultivar. For means comparison, Duncan's Multiple Range test was used. All data obtained was statistically analyzed using Minitab 17 software.

3 Results and discussion

The analysis of variance (ANOVA) for the gathered data is shown in Table 2 which represents: harvesting percentage, harvesting productivity and the fruit detachment force (FDF). The results show significant difference between harvesting methods, (FDF) and Etherl concentration at level of 0.01. The interaction between cultivar and Etherl concentration on harvesting productivity was significant at α = 0.05. Also, the interaction between harvesting method and Etherl concentration was also significant at α = 0.01 for harvesting percentage and (FDF).

3.1 Mean comparison for all treatments on harvesting productivity and efficiency

Means comparison of the measured factors are shown in Table 3. Fruit harvesting percentages by hands, pneumatic comb, and branch shaking machines were significantly different. Ninety nine percentages of the fruit were harvested by hand, while 82.25% and 89.65% of the fruits were harvested by the pneumatic comb and the branch shaker machines, respectively. Tombosi et al. (1996) reported 100% manual harvesting efficiency and 80%-85% by using tree shaker. The effectiveness of harvesting machines depends on cultivar, fruit ripening and tree yield (Mannino and Pannelli, 1990, Ravetti and Robb 2010).

Table 2 Analysis of variances for harvesting and productivity percentage and FDF

Variation Source	DF	MS		
		Harvesting percentage	Harvesting productivity (kg hr^{-1})	FDF (N)
Replication	2	2.37^{ns}	2.10^{ns}	0.33^{ns}
Cultivar	1	0.673^{ns}	17.85^{**}	43.78^{**}
Harvesting Method	2	65.37^{**}	95.30^{**}	5.30^{**}
Ethrel Concentration	2	7.45^{**}	3.25*	49.87^{**}
Cultivar × Harvesting Method	2	5.68^{**}	3.74*	2.68^{ns}
Cultivar × Ethrel Amount	2	0.53^{ns}	2.96^{*}	5.68^{**}
Harvesting Method×Ethrel Amount	4	4.25^{*}	0.59^{ns}	1.39^{*}
Cultivar × Harvesting Method × Ethrel Amount	4	2.15^{ns}	2.96*	0.43^{ns}
Residual	34			
Coefficient of variation (CV %)		4.83	17.85	25.65

Note: *, ** significance difference at α = 0.05, 0.01, respectively; ns: No significance difference.

Table 3 Treatments means for all factors

Treatment		Harvesting percentage	Harvesting productivity (kg hr^{-1})	FDF (N)
Variety				
NR	Nabali Rosie	89.40 b***	53.17 a	7.48 a
N	Nabali	85.35 c	30.29 b	4.71 b
Harvesting Method				
M	Manual	99.00 a	13.25 c	4.95 b
P	Pneumatic comb	82.25 c	36.04 b	4.15 b
BS	Branch shaker	89.65 b	57.95 a	4.45 b
Ethrel amount (mg L^{-1})				
E1	0	80.35 c	35.42 b	6.50 a
E2	1500	89.50 b	40.40 d	4.95 b
E3	3000	91.50 b	43.77 d	2.77 c

Note: *** Means within each row followed by the same letter are not significantly different between treatments P<0.05.

The harvest productivity of the olive cultivars (kg of harvested fruits per hour per worker) has significant difference at α = 5% and Nabali Rosi cultivar had higher harvest productivity as shown in Table 3. Compared to hand harvesting, the productivity of pneumatic comb and branch shaker machines increased significantly by 2.7

and 4.4 fold, respectively. Vossen, (2007) reported increased in harvest productivity using hand-held pneumatic combs and branch shaking devices by 2 and 2.6 fold relative to hand harvesting. On the other hand, Yousefi et al., (2010) reported increased productivity by 1.44 and 3 times that of manual harvesting for Zarad and Koroneeki cultivar. This might be as a result of smaller fruits sizes and weights in their study. Fruit weight for single olive average 4 and 2.5 g for Nabali Rose and Nabali cultivars, respectively. So, the smallness of Nabali cultivar resulted in reduction the harvesting productivity of fruit. Nabali Rose cultivar harvesting productivity was 1.75 times that of Nabali variety productivity. Branch shaking had significantly higher harvesting productivity (57.95) kg hr^{-1} than pneumatic combs (36.04 kg hr^{-1}). The branch shaking causes intensive movements of each branch, which facilitated the fruits to be separated and drop in short time. The harvest productivities of trees sprayed by Etherl were significantly higher than those in the control. Etherl at concentration of 3000 (mg L^{-1}) gave harvest productivity of 43.77 kg hr^{-1} higher than the control 35.42 kg hr^{-1}, but no significant difference between 1500 and 3000 (mg L^{-1}) at $\alpha = 0.05$.

Table 3 shows that the fruit detachment force FDF for Nabali Rose cultivar was 7.48 N significantly higher than that for Nabali cultivar 4.71 N. This might be as a result of higher weight of Nabali Rose fruit and thicker fruit stalk. Lavee et al., (1982) reported high correlation between fruit volume, thickness of the fruits stalks and FDF. Although FDF is a significant factor harvesting efficiency, other parameters play important role during the vibration of the tree such as inertial and bending forces and fatigue action, which initiates the fruit detachment (Tsatsarelis, 1987). Canopy shaker system applied the forced vibration directly to the fruit-bearing branches.

3.2 The effect of harvesting methods and Ethrel levels on harvesting productivity

Table 4 shows the interaction between cultivars, harvesting method and Ethrel on harvesting productivity. At Ethrel level of 3000 (mg L^{-1}), the highest productivities were obtained when trees were harvested by branch shaker machine; it was 70.39 and 54.25 kg hr^{-1} for Nabali Rosie and Nabali, respectively. The harvesting hand productivity was significantly lower; it was 12.75 and 8.35 kg hr^{-1} for Nabali Rosie and Nabali, respectively. The harvesting productivities for both cultivars didn't show significant difference between Ethrel treatments levels when olive was harvested by mechanical means. Therefore, it is not recommended to increase abscission dosage beyond 1500 mg L^{-1}, to avoid extra foliage fall down. Etherl weakened the fruit stalk and reduced the FDF. The abscission agent was considered as a factor responsible for reducing the binding force between the fruit and the stem (Sessiz and Ozkan, 2006). Lavee and Hazkal, 1975 recommended Ethephon concentration of 1500 mg L^{-1} was good enough to increase the efficiency of both manual picking and mechanical harvesting for all olive cultivars.

Table 4 Interaction between cultivars, harvesting method and Ethrel amount on harvesting productivity

Cultivar	Harvesting Method	Ethrel concentration (mg L^{-1})	Harvesting productivity (kg hr^{-1})
Nabali Rosie	Hand Picking	0	12.75 d***
		1500	17.65 d
		3000	21.35 e
	Pneumatic comb	0	35.47 c
		1500	42.15 c
		3000	45.65 c
	Branch shaker	0	60.25 b
		1500	65.13 a
		3000	70.39 a
Nabali	Hand Picking	0	8.35 d
		1500	10.17 d
		3000	9.20 d
	Pneumatic comb	0	25.15 e
		1500	35.37 c
		3000	32.45 c
	Branch shaker	0	40.57 c
		1500	57.13 b
		3000	54.25 b
LSD 5%			8.85

Note: *** Means within each row followed by the same letter are not significantly different between treatments $P<0.05$.

3.3 Effect of Ethrel levels on harvesting productivity and FDF

For all harvesting methods, the interaction between cultivar and Ethrel amount, Nabali Rose variety showed the highest productivity of 45.80 kg hr^{-1} at concentration of 3000 ppm of abscission material as shown in Table 5. There was no significance difference between the two levels of loosening agent, so it is not recommended to increase the loosening dosage behind 1500 mg L^{-1}. To promote harvesting productivity using shaking and pneumatic devices, Ozguven et al., (1998) recommended the usage of Ethrel at 2000 mg L^{-1} concentration one month before the olive harvesting. On the other hand, Sessiz et al., (2006), reported that harvesting productivity (using one stem shaking device) increased by 46% and 103%, at Ethrel levels of 3.125 and 6.25 mL lit^{-1}, respectively. They found also that the fruit-removal-force (FRF) decreased significantly as Ethrel concentration increased.

Table 5 The Interaction between cultivar and Ethrel level on harvesting productivity (kg hr^{-1}) and FDF

Cultivar	Ethrel concentration	Harvesting productivity (kg hr^{-1})	FDF (N)
NR	E1	36.16 c***	9.35 a
	E2	41.64 a	7.75 b
	E3	45.80 a	5.35 c
N	E1	34.69 c	6.25 b
	E2	39.15 b	4.63 c
	E3	41.75 ab	3.25 d
LSD 5%		3.57	1.5

Note: *** Means within each row followed by the same letter are not significantly different between treatments P<0.05.

The abscission agent significantly reduced the FDF in the sprayed trees relative to the control. These forces were maximum at 9.35 and 6.25 N for Nabali Rosie and Nabali control cultivars, respectively. The minimum FDF was observed on olive trees sprayed by 3000 mg L^{-1} of Etherl, Nabali Rose cultivar had 5.35 N and Nabali cultivar had the lowest FDF of 3.25 N. The FDF affect harvest productivity and might be used as an indicator of the best time to use mechanical harvesters (Martin, G. C. 1994; Kouraba et al., 2004).

3.4 The effect of harvesting methods and cultivar on harvesting productivity

The interaction between cultivars and harvesting methods showed a significant effect on harvest productivity at $\alpha = 0.05$ as shown in Table 6. Branch shaker gave the highest productivity of 65.26 and 50.65 kg hr^{-1} for Nabali Rosie and Nabali, respectively. The lowest productivity obtained by hand picking 17.25 kg hr^{-1} for Nabali Rosie and 9.24 kg hr^{-1} for Nabali. The harvest productivity of Nabali Rosie was greater than Nabali for all harvesting methods. Branch shaker gave the highest harvesting percentage followed by pneumatic comb for both cultivars similar to what reported by Rafael et al., (2014).

Table 6 Interaction between cultivars and harvesting method on harvesting productivity

Cultivar	Harvesting Method	Harvesting productivity (kg hr^{-1})
Nabali Rosie	Hand Picking	17.25 d***
	Pneumatic comb	41.09 c
	Branch shaker	65.26 a
Nabali	Hand Picking	9.24 e
	Pneumatic comb	30.99 d
	Branch shaker	50.65 b

Note: *** Means within each row followed by the same letter are not significantly different between treatments P<0.05.

3.5 Effects of treatments on detached leaves and fruits injuries percentage

For the two cultivars, the percentages of detached leaves in manual harvesting were significantly lower than those from harvesting machines (Table 7). The highest percentages of detached leaves were 15.2% and 12.3% when harvested by branch shaker machine for Nabali Rosie and Nabali, respectively. Percentages of detached leaves were minimal at 2.75% for Nabali Rosie and 1.2% for Nabali when trees were harvested by hand. Percentages of detached leaves were 12.1% and 10.1 for Nabali Rosie and Nabali when pneumatic comb was used in harvesting (Table 7), which is close to what reported, by Ahmad and Salam, (2014).

Table 7 Detached leaves and injured fruits percentages as affected by harvested method

	Detached leaves percentages (%)		Injured fruits percentages (%)	
Harvesting Methods	Nabali Rosie	Nabali	Nabali Rosie	Nabali
Hand	2.75 a***	1.2 b	0.70 a	0.85 a
Pneumatic comb	12.1 c	10.1 c	7.20 b	6.50 b
Branch Shaker	15.2 d	12.3 e	10.5 c	7.85d

Note: *** Means within each row followed by the same letter are not significantly different between treatments P<0.05.

Table 7 also showed the effect of harvesting method on injured fruits percentage. The percentages of injured fruits from manual method were significantly lower than those from pneumatic comb and branch shaker machines for the two cultivars (Table 7). The highest percentage of injured fruits 10.5% and 7.85 % obtained from branch shaker machine harvesting for Nabali Rosie and Nabali cultivars, respectively. The percentages of injured fruits using harvesting machines are still within the reasonable limit and coming within the (5%-10%) commercially acceptable values (Zipori et al., 2014). Mechanical harvesting of table olives is a rare practice due to low harvesting efficiency and high fruit scratch (Ferguson, 2006; Jimenez-Jemenz et al., 2015) found that table olive trees were very sensitive to mechanical harvesting with trunk shakers. They reported that the fruit-fruit and fruit-branch collisions in addition to friction of the fruit during movement in the tree canopy as a result of vibrations were the main causes of fruit damage.

4 Conclusions

The harvest productivities of olive increased by 2.7 and 4.4 times that of the manual harvesting, when using the pneumatic comb and branch shaking machines, respectively. Harvesting by mechanical means greatly increased labor productivity and reduced harvesting time and cost. This was more noticeable for larger fruit size like Nabali Rosie cultivar. The harvesting productivity using branch shaking was higher than that using pneumatic comb by 160%. Thus, the branch-shaking machine can be recommended as a good harvesting tool to the olive growers. Application of chemical loosening agent is advised to reach the ripeness stage and increase the harvesting efficiency with harvesting machines aids. The agent reduced FDF by weakens the fruits stalk, thus promoting harvesting processes. In addition to increase number of detached leaves during harvesting operation, the side effects of using loosening agent on oil quality should be studied.

References

Ahmad, R., and S. Ayoub. 2014. A comparative study of hand-held harvesting machine with traditional methods used for olive harvesting in Jordan. In *Proc. of the 5th International olive Conference. Olivebioteq,* 206–211. Amman, Jordan, 3-6 November.

Almeida, A., B. A. D. Oliveira, L. S. Santos, S. D. Reynolds, and J. Lopes. 1999. Mechanical olive harvesting systems. *Acta Horticuture*, 474: 209–213.

Catania, P., F. Bono, and M. Vallone. 2017. Evaluation of the vibrations transmitted to the hand-arm system in the use of portable harvesters for olives. *Agricultural Engineering International: CIGR Journal*, 19(2): 129–138.

Clodoveo, M. L., R. H. Hbaieb, F. Kotti, G. S. Mugnozza, and M. Gargouri. 2014. Mechanical strategies to increase nutritional and sensory quality of virgin olive oil by modulating the endogenous enzyme activities. *Comprehensive Review in Food Science and Food Safety*, 13(2): 135–154.

Farinelli, D., M. Ruffolo, M. Boco, and A. Tombesi. 2012. Yield efficiency and mechanical harvesting with trunk shaker of some international olive cultivars. *Acta Horticulture*, 949: 379–384.

Ferguson, L. 2006. Trends in olive harvesting. *Grasas Aceites*, 57(1): 9–15.

Gomez-Limon, J. A., A. J. Tadeo, and E. R. Martı´nez. 2012. Eco-efficiency assessment of olive farms in Andalusia. *Land Use Policy,* 29(2): 395–406.

Hartmann, H. T., W. Reed, J. E. Whisler, and K. W. Opitz. 1975. Mechanical harvesting of olives. *California Agriculture*, 29(6): 4–6.

Jesus, A., R. Gil, L. Ferguson, S. Castro-Garcia, and L. Gregorio. 2014. How agricultural engineers develop mechanical harvesters: the university perspective. *Horticulture Technology*, 24(3): 270–273.

Jimenez. J. F., G. L. B. Roldan, F. J. C. Ruiz, S. C. Garcia, R. R. S. Guirado, and J. A. G. Ribes. 2015. Table olive mechanical harvesting with trunk shakers: orchard adaptations and machine improvements. *Chemical Engineering Transactions*, 44: 271–276.

Jimenez. J. F., S. C. Garcia, G. L. B. Roldan, E. G. Sanchez, and J. A. G. Ribes. 2013. Isolation of table olive damage causes and bruise time evolution during fruit detachment with trunk shaker. *Spanish Journal of Agricultural Research*, 11(1): 65–71.

Kouraba, K., J. G. Ribes, G. B. Roban, M. D. Revuelta, and D. B. Navero. 2004. Suitability of olive varieties for mechanical harvester shaking. *Olivae*, 101(39): 39–43.

Lavee, S., and A. Haskal. 1975. Studies with ethephone for facilitating olive harvest. *Scientia Horticulturae*, 3(2): 163–171.

Lavee, S., B. Avidan, and Y. B. Tal. 1982. Effect of fruit size and yield on the fruit-removal-force within and between olive cultivars. *Scientia Horticulturae*, 17(1): 27–32.

Mannino, P., and G. Pannelli. 1990. Fully mechanized harvesting of olive fruit, technical and agronomical preliminary evaluations. In *International Symposium on Olive Growing,* 437–440. Cordoba, Spain: 1 December.

Martin, G. C. 1994. Mechanical olive harvest: use of fruit loosening agents. *Acta Horticulturae*, 356: 284–291.

Minitab Statistical Software, Release 17. State College, PA.: Minitab Inc.

Özgüven, A. I., F. Özgüven, O. Gezerel, H. Tath, and C. Yilmaz. 1998. The effects of ethrel on the ripening and harvesting of olive. *Acta Horticulturae*, 463: 359–364.

Rafael, R., S. Guirado, S. C. Garcı´a, L. Gregorio, B. Rolda´n, F. Jime´nez, J. Francisco, C. Ruiz, A. Jesu´s and J. Gil-Ribes. 2014. Traditional olive tree response to oil olive harvesting technologies. *Biosystems Engineering*, 118(1): 186–193.

Rallo, L., D. Barranco, S. Castro-Garcia, D. J. Connor, M. Go´mez del Campo, and P. Rallo. 2013. High-density olive plantations. *Horticulturae Review*, 41: 303–384.

Ravetti, L., and S. Robb 2010. Continuous mechanical harvesting in modern Australian olive growing systems. *Advance Horticulturae Science*, 24(1): 71–77.

Sessiz, A., and M. T. Ozcan. 2006. Olive removal with pneumatic branch shaker and abscission chemical. *Journal of Food Engineering*, 76(2): 148–153.

Tombesi, A., M. Boco, M. Pilli., and D. Farinelli. 2002. Influence of canopy density on efficiency of trunk shaker on olive mechanical harvesting. *Acta Horticulture*, 586(1): 291–294.

Tombesi, A., F. Famiani, P. Proietti, and P. Guelfi. 1996. Efficiency of different olive harvesting methods and effects on the trees and oil quality. *Revue Ezzaitouna*, 2(1-2): 93–101.

Tsatsarelis, C. A. 1987. Vibratory olive harvesting: the response of the fruit-stem system to fruit removing actions. *Journal of Agriculture Engineering Research*, 38(2): 77–90.

Vossen, P. 2007. Olive oil: history, production, and characteristics of the world's classic oils. *HortScience*, 42(5): 1093–1100.

Weismann, Z. 2009. *Desert Olive Oil Cultivation: Advanced Bio Technologies.* 1st Ed. New York, USA: Elsevier Publications.

Yousefi, Z., M. Almassi, A. Zeinanloo, R. Moghadasi, and M. B. Khorshidi. 2010. A comparative study of olive removal techniques and their effects on harvest productivity. *Journal of Food Agriculture and Environment*, 8(1): 132–135.

Zipori, I., A. Dag, Y. Tugendhaft, and R. Berger. 2014. Mechanical harvesting of table olive harvest efficiency and fruit quality. *HortScience*, 49(1): 55–58.