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DEVELOPMENT OF OLIVE HARVESTING MACHINE FOR SMALLHOLDINGS

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Abstract

The main objective of this study was to develop and evaluate a hand held olive harvester suitable for smallholdings. The development elements were harvester head, extension rod, and electric motor. The developed harvester was evaluated at four levels of head rotating speed 1200, 1400, 1600 and 1800 rpm with three olive varieties (Grossay, Manzanillo and Shemlali). The evaluation criteria were machine productivity (Pm),fruit removal percentage (FRP) and fruit damage percentage (FDP).The results showed that the suitable Pm, FRP and FDP were achieved at 1600 rpm of head rotating speed. Also, it is deduced an equation to predict the suitability of the harvester to remove the olive fruit by multiplying the ratio of the fruit detachment force to fruit mass (F/m) and stem length (r) for different olive varieties.
Keywords: Olive, Hand-held, Harvesting, Fruit detachment, Fruit damage.

Introduction

Olive harvesting is the most important operation among all olives production operations. Manual harvesting is the traditional method widespread in Egypt. Manual harvesting has many problems like low production rate, high cost and tree damage (Deboli et al., 2014)**.** The manual harvesting cost represents between 25 and 60% of total cropping cost (IOOC, 2015). Mansour et al., (2018) mentioned that the best harvesting operation is definite as the ability to harvest more than 90% of the olive fruits, in the shortest time, the lowest number of labor, minimum damage to the olive fruits and minimum risk for labor. Zhou et al. (2016) stated that there are various methods of detachment employed with mechanical harvesting. These generally involve cutting, pulling, bending or snapping, twisting or some combination of these actions.

Ibrahim (2018) developed and tested hand-held olive harvester. This machine was evaluated at three levels of head speed (700, 1100 and 1500 rpm) and two types of head length stick length (6 cm and 17 cm). He found that the most suitable working parameters of the machine at 1100 rpm and 1500 rpm with 17 cm of head length. Solazzi et al. (2014) proposed the innovative machine for improving the olive picking from secular trees which increase the degree of mechanization and reducing the production costs. Deboli et al. (2014) evaluated the hand-arm vibration transmitted to the operator using an experimental electric labor-saving machine with rotary combs with teeth of different dimensions covered by silicon to minimize the damage to the drupes. They found that the harvest productivity of the hand held machines (pneumatic combs and electrical beater) is as much as 5 and 4.5 times that of using the hands. Ghonimy (2006) derived a mathematical relationships to predict the suitable-shaking amplitude of limb tree shaker. The derived equation correlates the pulling force to fruit mass ratio, stem length, shaking frequency and damping ratio with the shaking amplitude. The mathematical equation was experimentally checked for two citrus varieties; Valencia and Grapefruit. Ferguson et al. (2010) mentioned that the vegetative factors that affecting the mechanical olive harvesting are tree shape, canopy density, orchard density and pruning, and the cultivar. Also, Farinelli et al. (2012) reported that the factors that affecting the fruit detachment were variety, maturity, fruit weight, detachment force, the geometry of the fruit, tree pruning and specifications of the harvester. Younis et al. (2017) designed a hand-held harvester for the olives tree. This machine was tested at three levels of shaking frequency (900, 1250 and 1600 rpm) and shaking period (1, 2and 3 min.), and they found that the highest harvesting productivity was achieved at 1600 (rpm) and 3 (min). Low damage percent were evaluated at 900 (rpm) and 3 (min), machine achieved the highest productivity and the lowest damage with Kornaki variety. El-Iraqi et al.(2011) found that the modified hand-held olive harvester gave an increase in labor productivity by about 5-7 times higher compared with the manual harvesting method. Also, it can reduce the harvesting manpower requirements by about 90-130% and reduced the total harvesting cost by about 185-245% with respect to manual harvesting cost.

Thus, the aim of this study is to develop and evaluate hand-held olives harvesting machine capable to perform harvesting operation in smallholdings with minimum harvesting losses.

Material and Method

This study was carried out at the Faculty of Agriculture, Omar El-Mukhtar University, El-Beida, Libya. A hand-held olive harvester was selected for development to improve its performance and productivity to be suitable for smallholdings of olive orchards. The main considerations in the developed machine were easy to use, low weight, high productivity, and less fruit damage.

This aim was planned to be realized through the following stages:

1. Select the hand-held olive harvester (original machine).
2. Study the force analysis affecting the olive-fruit separation.
3. Developed olive-harvesting machine and its components.
4. Testing the developed machine.

1. Original machine

A hand-held olive-harvester (*Ibrahim 2018*), fig. 1, was selected for development to improve its performance. The specifications of the original machine are shown in table (1).

Fig.1: The original machine

Table 1: Specifications of the original machine

Subsystem	Specification
Rotating head	The first head (H_1) has a diameter of 10 mm and length of 6 cm. The second head (H_2) has a diameter of 10 mm and length of 17 cm.
Motor	Electric motor (AC, 220 V – 60 watt - 2000 rpm).
Main and extension rod	telescoping rod up to a maximum length of 2.9 m.
Generator	700 W maximum power, 630 W rated power, 220 V and 2.7 A.
Operating switch	To control the speed of harvester head.

Problems of the original machine:

1. **Flexible sticks**

Selecting the flexible material, fig. (2), for the manufacturing of the sticks led to the wrapping of the sticks on the branches and leaves of the trees during harvesting, which caused an increase in the wasted time, and consequently a decrease in the performance rate of the machine.

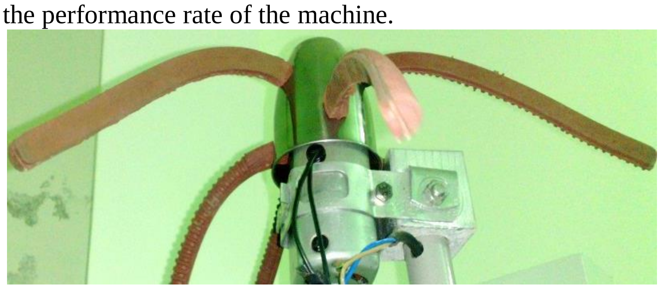


Fig. (2): Flexible sticks

2. **Flexible sticks location in the harvesting head**

Presence of the flexible sticks at the top of the main rod of the machine made the rotation surface of the sticks perpendicular on the main rod, which in turn led to difficulties in maneuvering the machine inside the trees to get the fruits required to be harvested (Fig. 3).

Fig. 3: Flexible sticks location

3. **Extension rod**

The non-straightness of the extension rod **(Fig. 4)** gave rise to the torque of the machine rod and consequently caused difficulties in controlling the machine during its operation

Fig. 4: Extension rod

2. **Force analysis affecting the olive fruit separation**

The basic principle involved in removing fruit by shaking is to accelerate each fruit so that the inertia force developed ($F = m.\ a$) will be greater than the detachment force between the fruit and the tree stem. (*O'brien et al. 1986*).

Two forces are affecting the fruit detachment:

1. The downward force of gravity (Fruit weight).
2. The tensile force which should be greater than the resultant of multiplied ultimate tensile strength of the stem by the cross-sectional area of the stem.

Fig. (5) shows that, the resulting value of *Fc* is a collection of the tensile force and the fruit weight.

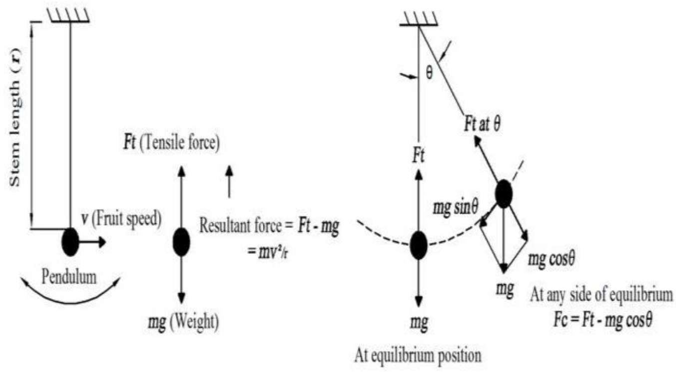


Fig. 5: Fruit motion under vibration effect**.**

At any fruit position, when the limb makes an angle θ with the vertical position, the fruit-speed (v) and centripetal force (Fc) decrease their its values compared with the equilibrium position. The centripetal force at θ position can be calculated from equation (1):

$$Fc_{\text{at}\,\theta} = Ft_{\text{at}\,\theta} - mg\cos\theta \qquad (1)$$

Where:

Fc	=	Centripetal force, N;
Ft	=	Tensile force exerted on the olive limb, N;
m	=	Mass of olive fruit, kg;
g	=	Acceleration gravity, m.sec^{-2}.

Maximum Fc was found at the bottom of its swing because the maximum fruit-speed was found at the equilibrium position. The maximum Fc was calculated from equation (2):

$$Fc_{\text{maximum}} = Ft - mg \qquad (2)$$

The resultant centripetal force was calculated from equation (3):

$$Fc = m.r.\omega^2 = \frac{mv^2}{r} \qquad (3)$$

Where:

v	=	The linear speed of harvesting stick, m.s^{-1} = $\frac{2\pi.r.N}{60}$;
N	=	Harvester head rotating speed, rpm;
ω	=	Olive-fruit angular speed, rad.s^{-1};
r	=	Stem length, m.

From equation (3), the v^2 value can be calculated as follows:

$$v^2 = (\frac{F}{m}).r \qquad (4)$$

The olive fruit will be separated from the stem when the v^2 value of the fruit is higher than or equal the $(\frac{F}{m}.r)$ value as follows:

$$v^2 \geq (\frac{F}{m}).r \qquad (5)$$

Where:

v	=	The linear speed of harvesting stick, m.s^{-1} = $\frac{2\pi.r.N}{60}$;
N	=	Harvester head rotating speed, rpm;
F/m	=	Detachment force to fruit mass ratio, N.kg^{-1};
r	=	stem length of, m.

Thus, the v^2 of harvesting stick should be higher or equal to the value $(\frac{F}{m}.r)$ of olive fruit variety to get fruit detachment.

3. Developed olive-harvesting machine

The developed olive-harvesting machine consists of the following main functional parts: a) Harvesting head, b) Main and extension rods, c) Electrical motor, d) Generator, and **e)** Operating switch.

a) Harvesting Head

The harvesting head **(Fig. 6)** consists of two groups of the harvesting mechanism.

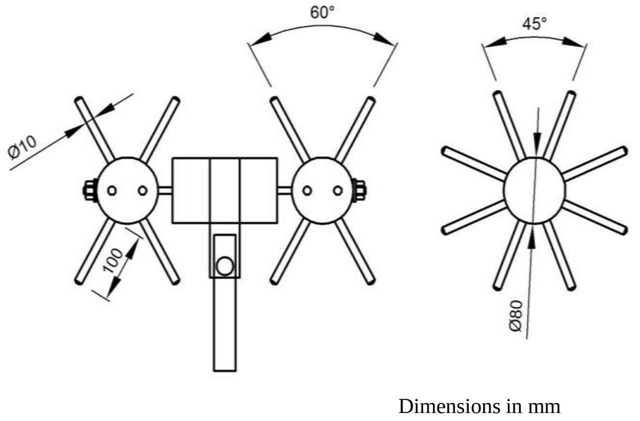


Fig. 6: Harvesting Head

Each group of harvesting mechanism consists of a ball of thermoplastic connected to 8 tips (sticks) in carbon fiber fixed to the head. The dimensions of each stick were 10 mm diameter and 100 mm length. Carbon fiber was chosen to manufacture the sticks to reduce olive fruit damage.

b) Main and extension rods

The main rod is a telescopic aluminum tube. The dimensions of the main rod, fig. (7), are 2.8 meter long and 25mm diameter. While the length of the extension rod was 1.2 m.

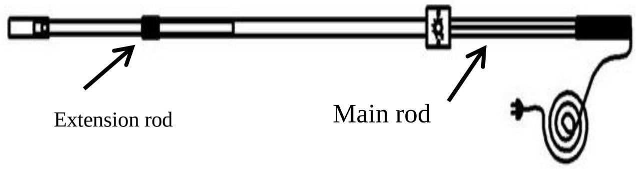


Fig. 7: Main and extension rods

c) Electric motor

The appropriate engine specifications were selected as follows:

- Using a stick length of 10 cm as shown in fig. (8).
- The number of olive fruits that can contact with the stick at the same time= stick length/ fruit diameter = 6 fruits.
- The required force (Fh) to oscillate the one fruit = 0.05 N (measured by digital force gauge).

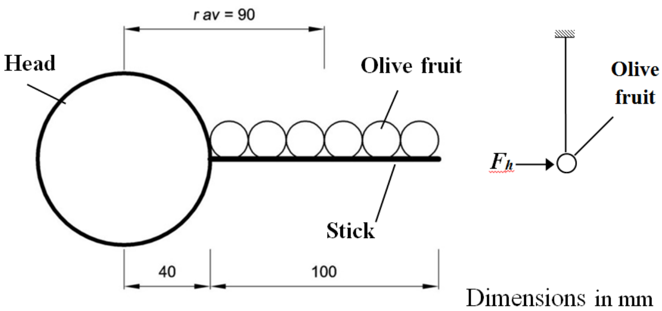


Fig. 8: Head of olives harvester.

- It can calculate the torque for one stick of the one head by the following equation:

$$T = \sum_{i=1}^{6} F_h.r_i = F_h.\, r_{av}\,.\, N_f \qquad (6)$$

Where:

T	=	Torque for one stick of the one head, N.m;
F_h	=	Required force to oscillate the one fruit, N = 0.05 N;

r_i = The distance from the center gravity of fruit and the center of head at fruit number (i);
i = Number of fruit i = 1,2,3,…..6.
r_{av} = The average distance from the center gravity of fruit and the center of harvesting head, m = 9 cm;
N_f = Number of fruits move by one stick = 6 fruit;

Total torque of the one head = 0.05 N × 0. 09 m × 6 fruit × 8 sticks = 0.216 N.m.

The required power (*P*) was calculated by the following equation:

$$P = \frac{T \times 2\pi N}{60} \quad (7)$$

Where:

P = The required power, W;
T = Torque, N.m = 0.216 N.m;
N = Harvester head rotating speed, rpm = 1800 rpm.

From equation (7), the required power for the one head (*P*) was calculated as **41** W. For the machine (two heads), the required power is 82 W.

Thus, a motor (AC, 220 V – 150 W - 2000 rpm) was used to operate the harvesting head.

d) Gasoline generator

The electric motor is driven by a gasoline generator through electrical wires passing inside pipes of the telescopic rod. The specifications of the used generator were 700 W maximum power, 630 W rated power, 220 Volt and 2.7 Ampere.

e) Regulated operating switch

The operating switch was fixed on the lower pipe of the main rod in a suitable place for the operator. The function of the regulated operating switch is controlling the speed of harvester head.

These subsystems were assembled in the compacted machine, **fig. (9)**.

4. Testing the developed machine

The developed machine was tested at four levels of harvester head rotating speed (1200, 1400, 1600 and 1800 rpm) for three olive varieties. The olive trees were chosen in a critical stage of maturity (contains full-ripe, half-ripe and full mature stage (green olive fruits)). Nylon nets were fixed on stands for receiving the removed fruits.

4.1. Tested Olive varieties

Three varieties of olives were chosen to represent all the types of fruits for table olives, oils olives, and double purpose**.** The tested varieties were Grossay, Manzanillo, and Shemlali.

4.2. Experimental and laboratory measurements:

1. Dimensions of the olive trees

Some dimensional characteristics of the tested olive trees from different varieties were measured. Fifteen olive trees for each variety were randomly selected, planted at 6 × 6 m spacing. The dimensional characteristics of olive trees are shown in table (2).

Table 2: Dimensional characteristics of the olive trees

Trunk circumference (cm)	Trunk Height (m)	Canopy Diameter (m)	Tree Height (m)
109 ± 45	0.8 ± 0.06	3.8 ± 0.6	3.0 ± 0.4

2. Physical and mechanical properties of olives fruit

Physical and mechanical properties of olive fruits for the selected varieties were determined according to their maturity levels. Three maturity levels; full-ripe, half-ripe, and full mature stage (green olive fruits) were used. For each level, 50 olive fruit for each variety were randomly selected.

Fruit physical properties were determined according to the following measurements;

Fruit length, maximum fruit diameter, volume, and mass. Also stem length was measured.

The ratio of fruit detachment force to fruit mass (R_{Fm}) is used to decide the suitability of olive fruit for mechanical harvesting. The fruit detachment force was measured by using digital force gauge (accuracy = ± 0.01 N). The digital force gauge was attached to the selected fruit and a pulling force was gradually increased until the fruit was separated. The maximum force was recorded as the static detachment force. Each detached fruit was then weighed. The ratio of the (R_{Fm}) was calculated from equation (8):

$$R_{Fm} = \frac{F}{m} \quad \textbf{(8)}$$

Where:

R_{Fm} = The ratio of the fruit detachment force to fruit mass, N.kg^{-1};
F = Fruit detachment force, N;
m = Fruit mass, kg.

4.3. Evaluation criteria

1. Machine productivity (P_m)

The P_m of the developed machine was calculated from equation (9):

$$P_m = \frac{W}{T} \quad \textbf{(9)}$$

Where:

P_m = Machine productivity, kg.h^{-1};
W = The weight of harvested fruit, kg;
T = Total operating time, h.

2. Fruit removal percentage (*FRP*)

FR was calculated from equation (10) (***Polat et al. 2007***):

3. Fruit damage percentage (*FDP*)

FDP was calculated by equation (11): (***Srivastava et al., 2006***)

$$FRP = \frac{M1}{M1 + M2} \times 100 \quad \textbf{(10)}$$

Where:

FRP = Fruit removal percentage, %;
$M1$ = The weight of harvested olive fruit, kg/tree;
$M2$ = The weight of olive fruit which are remaining stay on the tree, kg/tree.

$$FDP = \frac{Wd}{Wt} \times 100 \qquad \textbf{(11)}$$

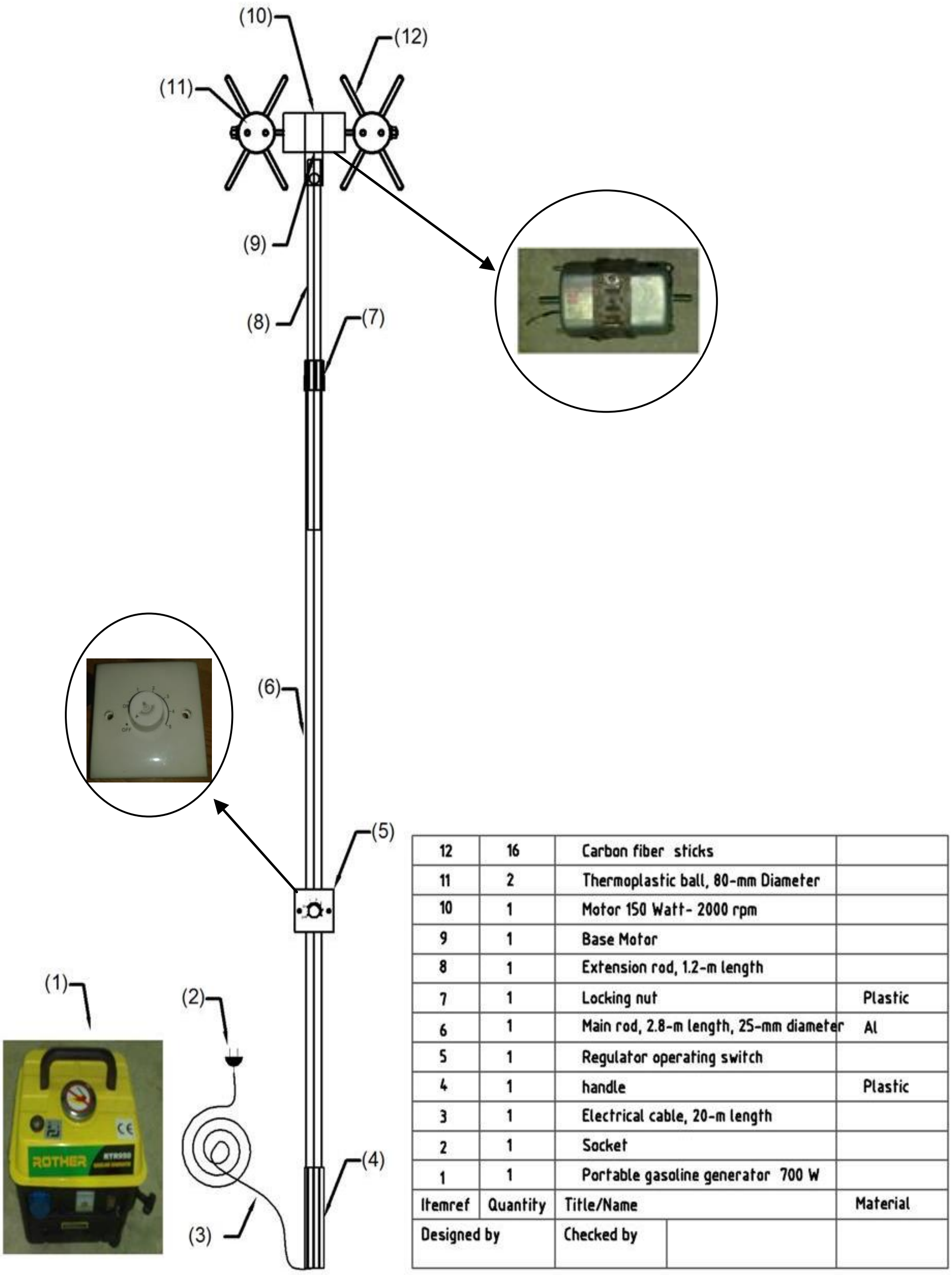
Where:

FD = Fruit damage percentage, %;

P

Wd = The total weight of damage harvested fruit, kg;

Wt = The total weight of harvested fruit, kg.



12	16	Carbon fiber sticks	
11	2	Thermoplastic ball, 80-mm Diameter	
10	1	Motor 150 Watt- 2000 rpm	
9	1	Base Motor	
8	1	Extension rod, 1.2-m length	
7	1	Locking nut	Plastic
6	1	Main rod, 2.8-m length, 25-mm diameter	Al
5	1	Regulator operating switch	
4	1	handle	Plastic
3	1	Electrical cable, 20-m length	
2	1	Socket	
1	1	Portable gasoline generator 700 W	
Itemref	Quantity	Title/Name	Material
Designed by		Checked by	

Fig. 9: The hand-held olives harvester

Results and Discussion

The averages values of olive fruit mass, fruit length, fruit width, bulk density, and stem length are shown in table (3).

It is clear that, for the tested varieties, higher values of CV (more than 11%) were accompanied with the properties of fruit mass, fruit length and fruit detachment force, while lower values of CV (less than 8%) were accompanied with the fruit width, fruit volume, stem length and fruit detachment force to mass ratio of olive fruit. A statistical analysis (ANOVA at 5% level) showed significant differences for every property except the fruit detachment force and stem length.

1. Operating parameters of the harvesting machine

Fig. (10) shows the effect of calculated value of ($v^2 = F/m \,.\, r$) on the harvester head rotating speed of harvesting machine.

Fruit detachment was simply expected to occur as the inertial force due to vibration exceeds the static tensile force required for fruit detachment ranged from 2.39 to 6.78 N for all olive tested varieties, as listed in Table 2).

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Table 3: Physical properties of the olive fruit-stem system

Variety	Property	Full mature stage (Green olive)		Half-ripe olive		Full-ripe olive	
		Mean value[a]	CV[b]	Mean value[a]	CV[b]	Mean value[a]	CV[b]
Grossay	*L*, mm	26.51A	10.84	26.46B	11.90	26.50C	12.56
	W, mm	18.40A	8.21	18.42B	7.66	18.51C	9.13
	V, cm^3	4.90A	4.71	4.95B	4.90	4.95C	5.00
	r, cm	17.32A	6.18	17.40A	4.55	17.36A	4.00
	m, kg	0.00504A	13.53	0.00508B	12.83	0.00506B	12.99
	F, N	6.78A	12.54	6.76A	14.21	6.65A	11.76
	R_{Fm}, $N.kg^{-1}$	1360.1A	4.44	1330.7B	8.10	1314.2C	5.00
Manzanillo	*L*, mm	20.89A	17.21	21.42B	18.15	21.50C	18.00
	W, mm	16.87A	7.30	17.23B	6.84	17.24C	7.95
	V, cm^3	2.95A	7.21	3.15B	6.18	3.06C	5.44
	r, cm	15.04A	3.66	15.08A	3.82	15.08A	3.41
	m, kg	0.00309A	11.46	0.00318B	14.65	0.00319B	13.54
	F, N	5.90A	16.38	5.81A	17.37	5.80A	18.34
	R_{Fm}, $N.kg^{-1}$	2024.8A	5.44	1930.6B	6.11	1880.3C	3.56
Shemlali	*L*, mm	13.60A	16.56	13.92B	16.23	14.01C	17.59
	W, mm	11.12A	6.84	11.15B	3.67	11.20C	4.79
	V, cm^3	0.95A	6.45	0.97B	6.00	0.99C	6.56
	r, cm	9.88A	6.00	9.88A	4.67	9.88A	3.22
	m, kg	0.00101A	14.00	0.00102B	12.70	0.00102B	11.00
	F, N	2.51A	14.13	2.44A	15.23	2.39A	14.87
	R_{Fm}, $N.kg^{-1}$	2490.2A	3.00	2390.1B	6.99	2340.1C	5.17

L = Fruit length, *W* = Fruit width, *V* = Fruit volume, *rj* = Stem length, *m* = Fruit mass, *F* = Fruit detachment force, *RFm* = Fruit detachment force to mass ratio.
(a) Mean values with different letters are significantly different (Duncan test 5% level).
(b) CV Coefficient of variation (Standard deviation divided by the mean value).

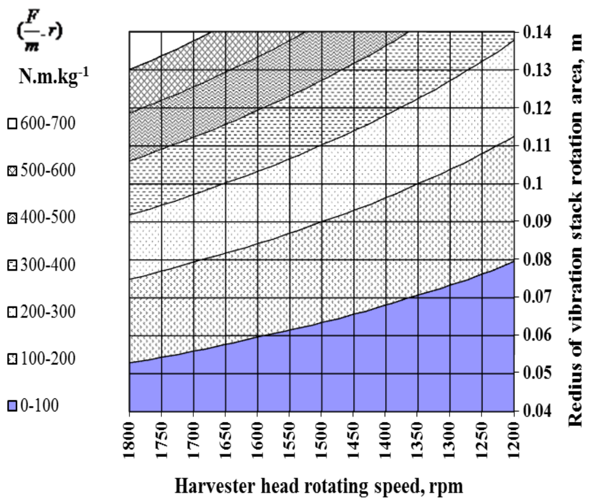

Fig. 10: Operating parameters of the harvesting machine

When the head of the machine is rotated, the sticks gain a kinetic energy related to the value of (*F/m. r*) can be sufficient for fruit detachment.

Also, fig. (10) can be used to predict the operating parameter (Harvester head rotating speed) of the developed harvester by calculating the value, *F/m. r*, of any olive variety.

2. Machine productivity (P_m)

The average values of machine productivity are shown in fig. (11). It's clear that the maximum value of machine productivity, 120 $kg.h^{-1}$, was achieved at harvester head rotating speed 1800 rpm for *Grossay* variety. While the minimum value of P_m, 80.5 $kg.h^{-1}$, was found at harvester head rotating speed 1200 rpm for *Shemlali* variety. Also, the results showed that the P_m was increased by increasing of harvester head rotating speed for all tested varieties. This is due to increasing the impacted fruit by increasing the harvester head rotating speed. The results in fig. (11) indicated that the suitable harvester head rotating speed ranged from 1600 to 1800 rpm.

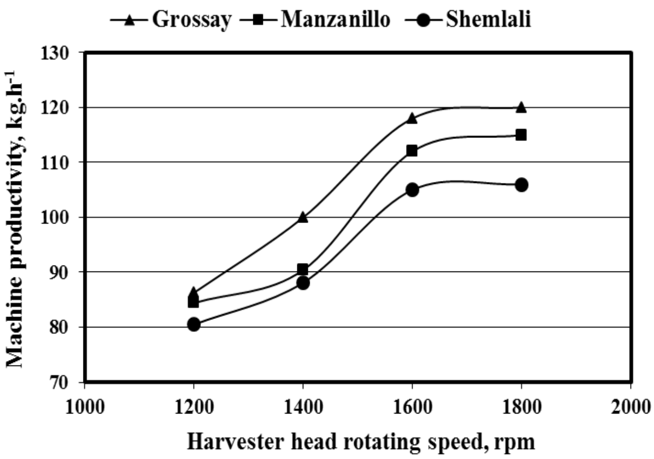

Fig. 11: Effect of harvester head rotating speed on machine productivity.

3. Fruit removal percentage (*FRP*)

Fig (12) shows the fruit removal percentage (*FRP*) of olives fruit. It's clear that the maximum value of fruit removal percentage, 100 %, was achieved at harvester head rotating speed 1800 rpm for *Grossay* variety. While the minimum value of *FRP*, 80.5 %, was found at harvester head rotating speed 1200 rpm for *Shemlali* variety. Also, the results showed that the *FRP* was increased by increasing of harvester head rotating speed for all tested varieties. This is due to increasing the impacted fruit by increasing the harvester head rotating speed. From fig (12) and table (3) it's clear that the *FRP* increased by decreasing of fruit detachment force to mass ratio. From figures (11) and (12) it's clear the maximum values of *Pm* and *FRP* were achieved at harvester head rotating speed ranged from 1600 to 1800 rpm.

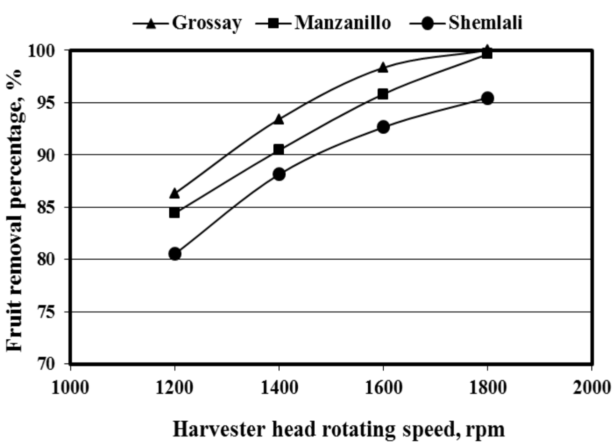

Fig. 12: Effect of harvester head rotating speed on fruit removal.

4. Fruit damage percentage (*FDP*)

Fig. (13) shows the olive fruit damage percentage (*FDP*). The *FDP* increased from 3.1 to 16.8 % with the increasing of harvester head rotating speed from 1200 to 1800 rpm. The increase of *FDP* by increasing the harvester head rotating speed is due to the increase in the number of shocks to the fruits during the work of the machine, which may lead to damage to the fruit. Also, fig. (13) showed that the *FDP* increased by 2.0 to 4.2 % with the harvester head rotating speed increased from 1200 to 1600 rpm for all tested varieties. The *FDP* increased by 9.4 to 10.0 % with the harvester head rotating speed increased from 1600 to 1800 rpm for all tested varieties. From fig. (13) and table (3) it's clear that the *FDP* increased by increasing of fruit detachment force to mass ratio.

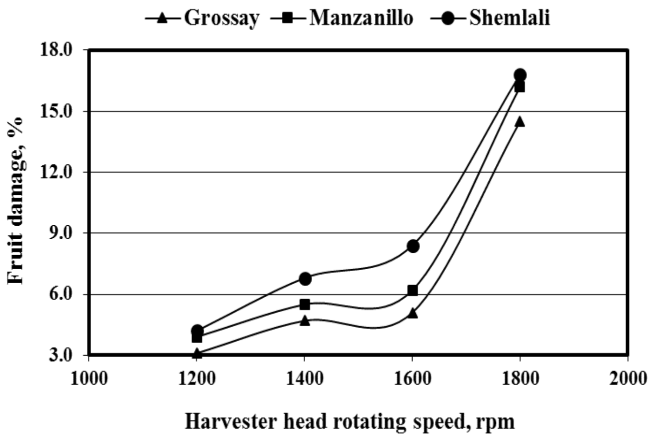

Fig. 13: Effect of harvester head rotating speed on fruit damage.

This agrees with the results found by Younis et al. (2017) who reported that fruit damage of olive fruits (Manzanillo Variety) ranged from 5.15 to 7.13 % with the machine velocity ranged from 900 to 1250 rpm.

From figures (11) to (13) it's clear that the suitable criteria of the developed machine (machine productivity, fruit removal percentage and fruit damage percentage) were achieved at 1600 rpm of harvester head rotating speed.

Conclusion

From this investigation the following conclusions can be made:

1. The operating parameters (Harvester head rotating speed) of the developed machine can be predicted by calculating the value, *F/m. r*, of any olive variety.
2. The maximum value of machine productivity, 120 $kg.h^{-1}$, was achieved at harvester head rotating speed 1800 rpm for *Grossay* variety.
3. The maximum value of fruit removal percentage, 100 %, was achieved at harvester head rotating speed 1800 rpm for *Grossay* variety.
4. Fruit damage percentage increased by increasing of harvester head rotating speed for all tested varsities.

The suitable machine productivity, fruit removal percentage, and fruit damage percentage of the developed machine were achieved at 1600 rpm of harvester head rotating speed.

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