DEVELOPING A CYLINDRICAL GRADING MACHINE FOR OLIVE FRUITS

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Abstract

Olive is among the popular fruits and of a high economic value. Cleaning and grading of fruits may be considered important post harvest activities that improve fruit quality. This research aimed to develop a grading unit for better marketing. The measurements include some physical and mechanical properties of olive fruits that may be used in developing the proposed grading machine. The developed machine performance was tested and evaluated under different operational factors. The effect of screen slope angles, kinematic factor (ω^2 r/g), screen mesh shape (circle cells, trapezoidal bars cells and round bars cells), specific feed rate, and spiral to screen speed ratio on grading efficiency, fruits clogging, grading capacity, energy requirements, and fruit damage were studied. Results showed that this machine is quite successful for grading olive fruits. The optimal operational conditions were 2.0 kinematic factor, 0.08 kg/m^2 s feed rate, zero degree screen slope, 1.5 spiral to screen speed ratio and using trapezoidal bars cells. At these levels, the maximum grading efficiency of 95.4% was obtained with machine grading capacity of 450 kg/h, the minimum value of energy requirements of 5.8 kW.h/Mg and fruits clogging percentage of 0.58 %. The minimum fruits mechanical damage of 1.3 % was obtained.

Results indicated that the grading machine could work properly, and the classification of olive could be done based on the fruit size. This machine has the potential to size other crops like potatoes, tomatoes, apples and citrus fruits.

INTRODUCTION

Olive is among the popular fruits and of a high economic value in Egypt. Grading is the most important process to produce high quality production and obtain fruits of similar shape and size. Therefore, cleaning and grading of olive fruits are essential for modern marketing as pricing is tied to product quality and they play an active role in the marketing attractiveness. Manual sorting is unreliable since human judgment in identifying the multiple varying parameters is inconsistent, subjective and slow. Moreover, manual grading of olive fruits is a labor-consuming and tedious operation coming with many losses, high amounts of damage fruits and impurities, which in turn reduce the price of the product.

English (1974) evaluated the effect of accumulative clogging on screen capacity. Clogging also decreases sizing accuracy and, therefore, should be taken in consideration for evaluating screen performance. Grading is defined as the process which separated the fruits into different sizes based on its dimensions, volume and weight according to the standard or marketing requirements. Grading for size and quality of fruits are important for export and local marketing, also the olives price depend on its size.

Ryall and Lipton (1983), and Michael et. al. (1983) reported that machines that grade by diameter tend to have higher throughputs, to be rather less expensive for a given throughput, than those, which grade by weight. They added that sizing operations involve passing the fruits over diverging belts having holes, wire mesh belting, drop roll sizes, or volumetric size. The belts with holes and the wire mesh sizes separate the fruit into two sizes while the others provide up to five or six sizes by gradual widening of the sizing members that support the fruit.

Pierce (1985) reported that the rotary type cleaner probably is most common for on-farm application. Rotary grain cleaners separate grain into size fractions by moving it through a trammel (revolving cylindrical screen with axis slightly inclined). As the trammel rotates, material cascades over surface, and fine material passes through the screen. Material not passing through moves out the end of the trammel. Some cleaners employ a second trammel with larger openings for scalping (removal of material layer than the grain being cleaned).

Brennan et. al. (1990) reported that, sorting and grading are terms which frequently used interchangeably in the food processing industry. Sorting is a separation based on a single measurable property of raw material units, while grading is "the assessment of the overall quality of a food using a number of attributes". Grading of fresh product may also be defined as 'sorting according to quality', as sorting usually upgrades the product.

El-Sayed (2004) developed a two grading machines for olive grading. He concluded that the grading efficiency were 93, 92, and 91% for Agiza, manzanillo and Picual at 8 rpm speed of rotating, and 3 degrees slope angle of roller sizer.

Therefore, the main objectives of the present study were to:

1- Develop a cylindrical grading machine for olive fruits.
2- Investigate physical and mechanical properties of the olive fruits related to the design of function parts.
3- Experimentally evaluate the performance of the developed grading machine at different operational factors.
4- Analyze and develop simulation models for predicting grading efficiency.

MATERIALS AND METHODS

Grading is one of the most important post harvest process to obtain fruits of similar shape and size for better marketing. Screening is a common sizing or separation process that depends upon the ability of particles to pass through the apertures of a screen. During the recent research, a cylindrical grading machine, which designed and fabricated by Abd El-Tawwab et. al. 2012 was modified, developed, and tested at the workshop of Ag. Eng. Res. Inst., ARC. This is accomplished by transmitting a particular motion to a screen medium that is made of parallel rods or perforated plate. The resulting centrifugal force made each fruit forced to be in contact with the screen perforation, enabling sorting operations to be carried out. However, some particles may enter the apertures and remain trapped, thus gradually clogging the screen. Based on the physical properties of olive fruits under this study, fruits are sized into three different categories as follow:

Category (1) < 21 mm in diameter ranked: Small.

Category (2) 21 – 24 mm in diameter ranked: Medium.

Category (3) > 24 mm in diameter ranked: Large.

1- Properties of olive fruits

The physical and mechanical properties of olive fruits (Agize variety) had been investigated to determine the main operational and developing parameters affecting the performance of the proposed grading machine.

Physical properties of olive fruits

The physical properties, had been measured of olive fruits, include length, diameter and shape index. A sample of one hundred olive fruits was taken and the shape index was studied in terms of length (L), and diameter (D) by using a digital micrometer of accuracy 0.01mm according to International olive oil council, 2000.

$$\text{Shape index} = L / D \qquad (1)$$

Where:

L = Length of olive fruits, mm; and

D = Diameter of olive fruits, mm.

The obtained data of olive fruits dimensions were statistically analyzed to get the mean value (X^{-}), , and coefficient of variance (CV). Table 1 shows olive fruits length was varied from 20.8 to 35.4 mm with average of 27.8 mm, and coefficient of variation of 13.8 %. Also, Table 1 shows the diameter of olive fruits. It was varied from 15.6 to 29 mm with average of 22.4 mm, and coefficient of variation of 11.9 %. However, smaller fruits 30 % of the fruits varied from 15 to 21 mm. Also, medium fruits 32 % ranged from 21 to 24 mm. But, the larger fruits are about 38 % ranged from 24 to 30 mm. It is obvious that, the dimensions of olive fruits are non-uniform where, the coefficient of variation (CV) of fruits was 11.9%. Table 1 shows the shape index of olive fruits. According to International olive oil council, 2000 olive fruits shape (Agize variety) is divided into two groups (Spherical group and Ovoid group). Where, the frequency distribution of fruits shape index were 54 % spherical shape (<1.2) and 46 % ovoid shape (1.2 – 1.4)

Table 1. Physical properties for olive fruits (Agize variety).

Physical properties	Max.	Min.	Av.	C.V., %
Fruits length, mm.	35.4	20.8	27.7	13.8
Fruits diameter, mm.	29.0	15.6	22.4	11.9
Fruits shape index.	1.39	1.02	1.23	5.85

Mechanical properties of olive fruits

The obtained values of rolling angle for olive fruits (Agize variety) at position "A" (long axis of fruit was laid parallel to the direction of motion) were 13.41 deg. and 11.7 deg. using smooth rubber and galvanized sheet respectively. While at position "B" (long axis of fruit was laid vertical to the direction of motion) the rolling angle of olive fruits were 6.99 deg. and 6.14 deg. using smooth rubber and galvanized sheet respectively.

2- The developed grading machine

Figure 1 shows a schematic diagram of the developed grading machine for grading olive fruits. It was designed and fabricated by Abd El-Tawwab et. al. 2012. During this research, the grading machine was modified and developed to be suitable for olive fruits dividing process based on physical properties. The grading machine classify fruits into 3 grades on the basis of diameter: < 21mm (small fruits), 21 – 24 mm (medium fruits) and >24 mm (large fruits). The machine functional parts may be described as follow:

1- Frame

The frame dimensions (length, width, and height) were 140, 70, and 110 cm, respectively. It is supported on four stands distributed along the frame base. The two front stands can be adjusted by a circular motion of each stand to provide different slope angle of the grading unit.

2- The feeding device

The feeding device is consists of a simple hopper with the dimensions of 40×40×30 cm for length, width and height, respectively. It was made from iron sheet of one mm thickness with bottom slope. The hopper is fixed on the main frame. As shown in figure 2 the feeding device of the developed grading machine was modified to suit olive fruits feeding.

The modified steps were:

1- Replacing the fluted wheel by an adjustable feeding gate to permit the olive fruits to roll out slowly and uniformly. The specific feeding rate was adjusted by changing the feeding gate height.

2- The inner face of the hopper was modified by covering it with rubber to avoid the impact damage.

Calibration of the feeding mechanism

The following steps were carried out to calibrate the feeding mechanism to give the required feed rates of olive fruits:

- The hopper was filled with fruits.
- The gate opening was adjusted to control the output of the fruits.
- The machine was run for two minutes in each test. This period was measured from the instant of full dropping the fruits through the hopper opening.
- The discharged fruits were collected in plastic bags to determine the specific feeding rate of olive fruits ($kg/m^2.s$).

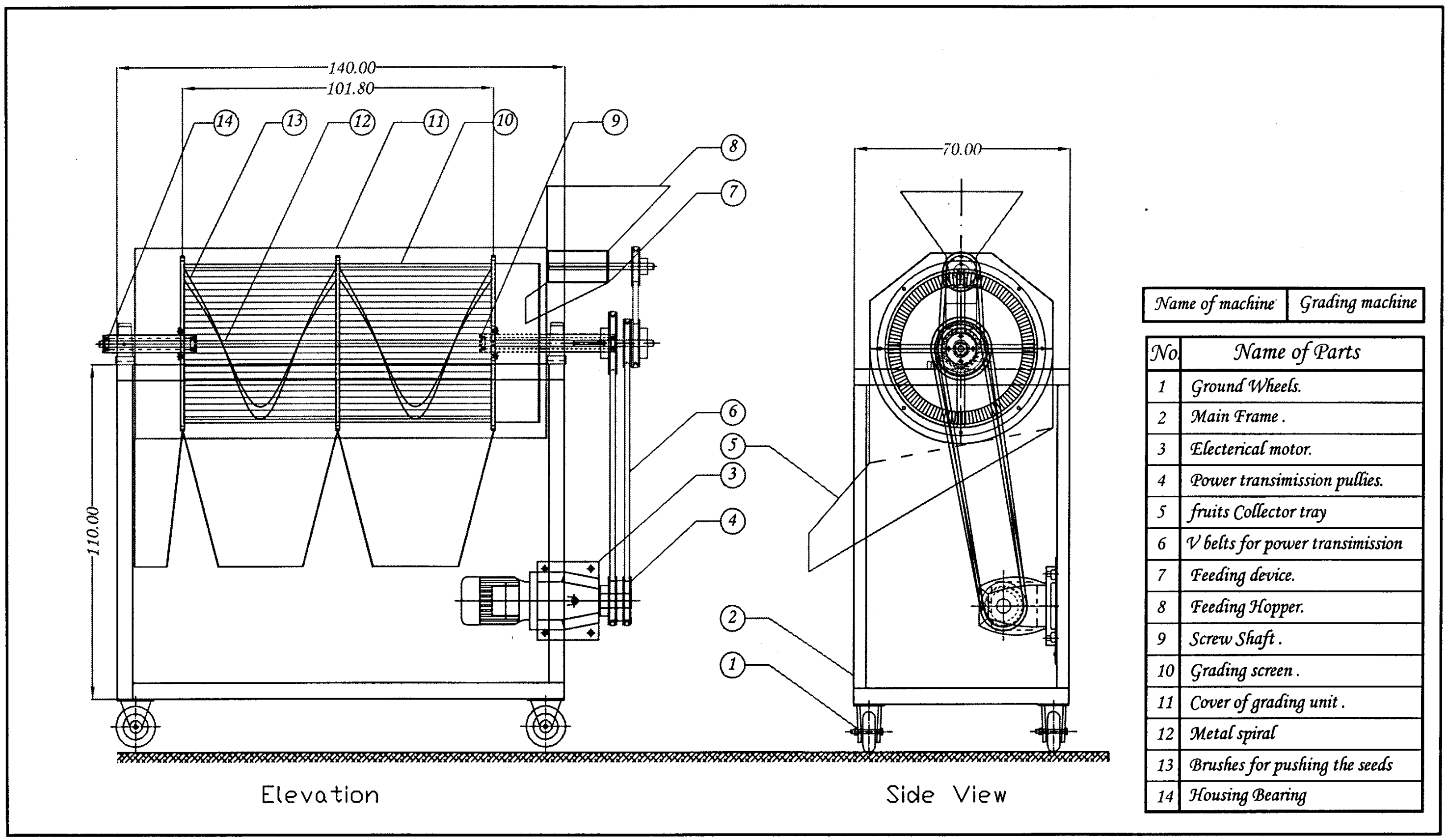

Fig. 1. Schematic diarame of cylindrical grader of olive fruits.

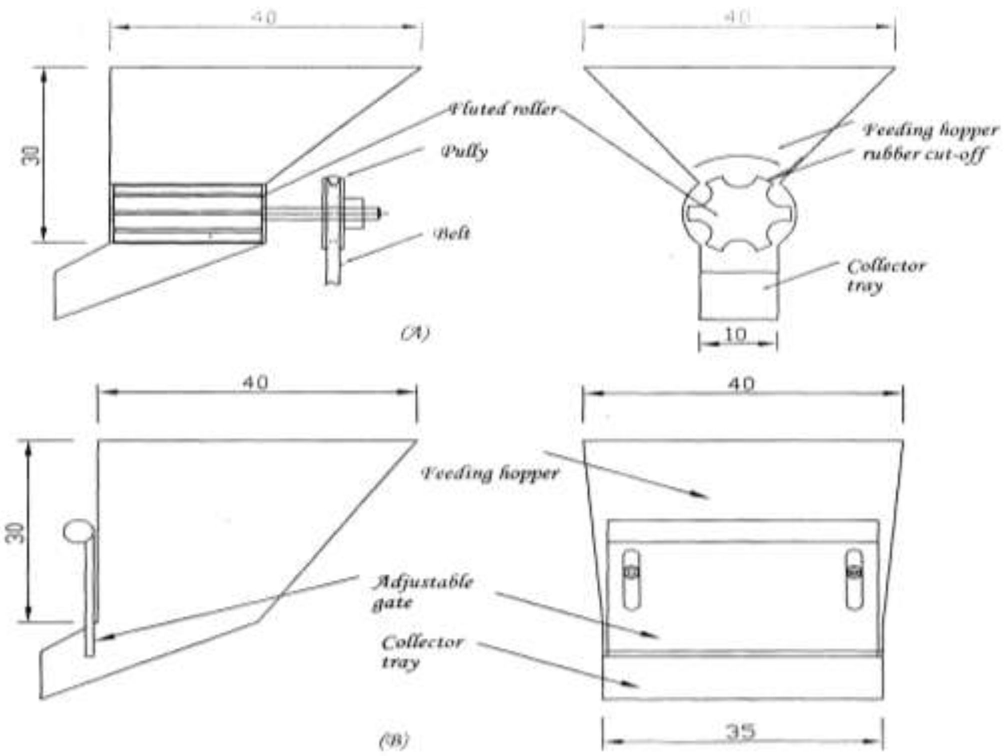

Fig. 2. Feeding device: "A" before development, "B" after development.

3- Grading cylindrical screen

A mechanism was built that consists of a cylindrical screen of 50 cm in diameter and 100cm in length. The cylindrical screen consists of two sequential screens. Three types of screen mesh shape used in the developed grading machine are:

1- Screen with circle cells (round holes):

The front screen is round holes of 21 mm diameter to separate small fruits (category 1). The rear screen of 24mm diameter round holes to separate medium fruits (category 2).

2- Screen with parallel trapezoidal bars cells:

The front screen separated small fruits; parallel trapezoidal bars are distributed in an equal distance of 21mm, on its circumference, and fixed by welding. The rear screen is parallel trapezoidal bars are distributed in an equal distance of 24mm, on its circumference, and fixed also by welding to separate the medium fruits.

3- Screen with parallel round bars cells:

Round bars of 6mm diameter are distributed in an equal distance of 21mm, and 24mm and fixed by welding on circumference of front screen and rear screen respectively.

A spiral was installed inside the cylindrical screen. During fruit's motion in the screen some of them may be become clogged. For the purpose of cleaning the surface of the screen of such fruits clogged, brushes were fixed on the spiral tip.

4- Power source

An electric variable speed motor of 2.21 kW (3 hp, 3 phase 380 v) with maximum rotating speed of 3000 rpm was installed to the grading machine.

Experimental conditions

The experiments were designed and carried out to study the effect of the following engineering factors on the machine performance:

1- Spiral to screen speed ratio, (ω_1/ω)

The performance of grading machine was evaluated at three values of (ω_1/ω) as zero (without spiral), 1, and 1.5.

2- Kinematic factor, (K)

Kinematic factor (K) is the ratio of the cylindrical screen acceleration ($\omega^2 r$) to gravity acceleration (g), therefore, $K = \omega^2 r/g$. (Kanafojski and Karwowski, 1976).

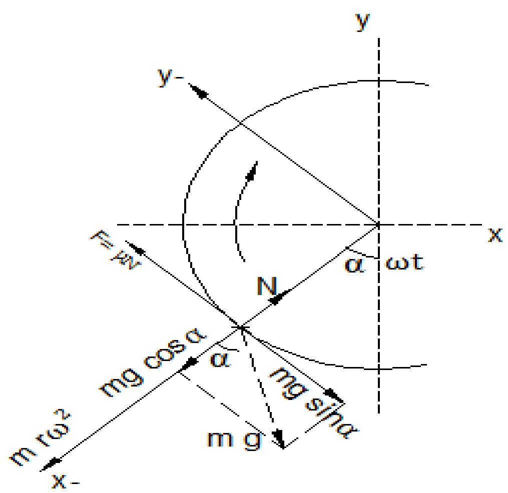

Fig. 3. Forces acting on the fruit situated on the internal cylinder surface.

The fruit, with a certain value of K, will be situated on the cylinder surface in relative rest that is it will revolve together with the cylinder. The highest value of K is as follows:

$$K_{max} = \sqrt{1 + \frac{1}{\mu^2}} \quad (2)$$

Where:

K = kinematic factor, ($\omega^2 r/ g$);

φ = rolling angle = 13.41 degree;

μ = coefficient of rolling = tan 13.41 =0.238;

In this research the determined coefficient of friction between the olive fruits and the experimental screen μ = 0.238, and substituting in equation (2), the maximum value of kinematic factor K_{max} is:

$$K_{max} = (\omega^2 r/g) = \sqrt{1+\frac{1}{\mu^2}} = \sqrt{1+\frac{1}{0.238^2}} = 4.31 \qquad (3)$$

Therefore, the critical rotating speed, $N=62/r^{1/2}$=124 r.p.m. (4)

Critical speed is the minimum rotating speed at which cascading ceases and material remains in constant screen contact, held there by centrifugal force. On other hand, to achieve actual sorting operation, it is necessary that the fruit should slide over the cylinder surface. In such a case the value of K must be appropriately reduced which means that K< 4.3. The performance of grading machine was evaluated at kinematic factor (K) of 1.5, 2.0, 2.5, and 3.0 (1.91, 2.21, 2.47, and 2.71m/s).

3- Screen mesh shape

During this research three types of screen mesh shape were used in the developed grading machine are: screen with circle cells (round holes), screen with parallel trapezoidal bars cells and screen with parallel round bars cells.

4- Specific feed rate, (F)

Passing of fruits though the screen depends not only the above mentioned factors, but also on the loading of the screen and to be exact on the thickness of the fruit layer. Specific feed rate is defined as the initial loading of fruits which falls over 1 m^2 of screen area in the course of 1 second. Four different specific feed rates of 0.07, 0.08, 0.10, and 0.12 $kg/m^2.s$ were studied.

5- Screen slope angle, (θ)

Slope angles (θ) of the cylindrical grading screen were selected as zero, 3, 6, and 9 degrees.

Test procedure

- Before carrying out the tests, the samples were manually cleaned to remove impurities and the unwanted materials.
- The machine was installed on level ground. The fruits were put into baskets and manually discharged into feeding hopper.
- The fruits were dropped from the feeding unit to the grading screen to grade fruits into 3 sizes. Then the fruits were discharged to the collecting baskets.

- During grading process the consumed time of operation from the moment of fruits dropping until the end time was recorded, and the mass of graded fruits was determined. Then the machine grading capacity (kg/h), machine grading efficiency (%), fruit clogging percentage, fruit mechanical damage (%), and energy requirements were calculated for each test.

Measurements

The following measurements were carried out to investigate the effect of the previously mentioned parameters on the developed grading machine performance.

1- Grading efficiency

Grading efficiency of screens determined by the percentage of actual graded particles mass that passed through it to theoretical particle mass. The results depend on the size distribution of the processed material. The grading efficiency of each screen was calculated according to the following equation:

$$\zeta_i = \frac{M_i}{M} \times 100 \tag{5}$$

Where:

ζ_i = Grading efficiency of fruits for each screen, %;

M_i =Actual mass of the graded fruits for each screen, kg; and

M = Theoretical mass of the graded fruits for each screen, kg.

The total grading efficiency was calculated as a mean efficiency for three outlet of the machine as the following equation:

$$\zeta = \frac{\zeta_1 + \zeta_2 + \zeta_3}{3} \tag{6}$$

Table 2. The variables affecting the grading efficiency.

	Variable	Symbol	Dim.
1	Grading efficiency, %	ζ	----
2	Spiral angular velocity = zero, 8.84 and 13.26 s^{-1}	ω_1	T^{-1}
3	Screen angular velocity =7.64, 8.84, 9.88, 10.84 s^{-1}	ω	T^{-1}
4	Feed rate = 0.07, 0.08, 0.10, and 0.12 $kg/m^2.s$	F	$M L^{-2}T^{-1}$
5	Fruit density = 1160 kg/m^3.	ρ	ML^{-3}
6	Screen perforation diameter = 0.024 m	d	L
7	Cylindrical screen radius = 0.25 m	r	L
8	Gravitational acceleration = 9.81 m/s^2	g	LT^{-2}
9	Screen slope angle = zero, 3, 6, and 9 degree	θ	-----

A mathematical model for predicting the grading efficiency of the developed grading machine was presented using dimensional analysis based on the Buckingham's Pi theorem **(stated by Glenn Murphy, 1950)** as follows:

$$\zeta = f\,(\omega_1,\ \omega,\ F,\ \rho,\ d,\ r,\ g,\ \theta) \quad (7)$$

$$\pi_1 = f\,(\pi_2,\ \pi_3,\ \pi_4,\ \pi_5) \quad (8)$$

$$\zeta = f\,[(\omega_1/\omega),\ (F/\rho\,\omega\,d),\ (\omega^2 r/g),\ (\theta)] \quad (9)$$

2- Fruits clogging percentage

Screening is a common sizing or separation process that depends upon the ability of particles to pass through the apertures of a screen. However, some particles may enter the apertures and remain trapped, thus gradually clogging the screen. Particles can be divided into three categories in regard to their size: particles that are too small that may not clog the screen; medium-size particles that can either pass through or remain trapped (depending on their shape and orientation relative to the apertures); and oversize particles that cannot pass through the screen. The fruits clogging percentage of each screen was calculated according to the following equation:

$$G_i = \frac{g_i}{M} \times 100 \quad (10)$$

Where:

G_i = Fruits clogging percentage, %;

g_i = Actual mass of clogging fruits for each screen, kg; and

M = Theoretical mass of the graded fruits for each screen, kg.

The total clogging percentage was calculated as a mean fruits clogging for two screens of the machine as the following equation:

$$G_T = \frac{G_1 + G_2}{2} \quad (11)$$

3- Grading capacity

The grading capacity was calculated according to the following equation Amin, 1994:

$$C = \frac{M \times 60}{T_G} \quad (12)$$

Where:

C = Grading capacity of the machine, kg/h;

M = Mass of classified fruit, kg; and

T_G = Grading time, min.

4- Energy requirements

The consumed power (kW) was estimated by using the super clamp meter-300k (Japan made) to measure the line current strength (I) and the potential difference values (V) according to **Kurt, 1979** as follow:

$$Consumed\ power\ (P) = I \times V \times \eta \times Cos\theta / 1000, kW \quad (13)$$

Where:

I = line current strength, Amperes;

V = Potential difference, Voltage;

Cos θ = Power factor assumed 0.64; and

η= mechanical efficiency assumed (80 %).

The energy requirements (E) in kW.h/Mg, was calculated by using the following equation:

$$Energy\ \ requirements, E = P/C \quad (14)$$

Where:

E = Energy requirements, kW.h/Mg;

P = Consumed power to grading seeds, kW; and

C = Grading capacity of machine, Mg/h.

5- Fruits mechanical damage

The mechanical damage was considered as the visible damage to the human eyes after each pass of the olive fruits through the grading machine. Scuffed fruits (with surface abrasion damage to skin) and those with flesh damage were separated from each fraction and their percentages based on the weights of the corresponding fractions were taken as mechanical damage.

RESULTS AND DISCUSSION

The grading efficiency and fruits clogging percentage were plotted against spiral to screen speed ratio (ω_1/ω) and kinematic factor ($\omega^2 r/g$) Figure 4. If would be consider grading efficiency alone with the screen that operates at a kinematic factor of 2 and spiral to screen ratio of 0 (without spiral), it may seem to be a very efficient value. However, the screening performance points out the disadvantage of a high clogging rate of 4.7%. A screen cannot be used under such conditions without efficient means for releasing particles that clog the screen. Fig. 4 shows that clogging can be decreased by operating the screen at a kinematic factor of 2.5 and 3, but only with a decrease in the grading efficiency. At a kinematic factor of 2.5 and 3, clogging is totally eliminated but the grading efficiency is very low. This trend may be attributed to increase the fruits speed and decrease the fruit stay interval on the grading screen thus, increase the overlapping percentage which tend to decrease the efficiency.

Therefore, at 2 kinematic factor and zero spiral to screen speed ratio (without spiral) if the grading efficiency is desired, clogging should be expected.

The above considerations illustrate why in practice there are two categories of screens:

1 "Low-speed screens" —they are used for accurate sizing and require a means to release the trapped particles.

2 "High-speed screens" — the rotary motion of the screen does not allow particles to enter into the apertures and become trapped; however, it interferes with the passage of the near size particles and, therefore, is not suitable for accurate sizing. A screen of this category separates according to a size that is considerably smaller than the aperture size.

Generally, the maximum grading efficiency (95.4 %) and minimum fruits clogging (0.58) were achieved at 2 kinematic factor and 1.5 spiral to screen speed ratio. The relationship between the grading efficiency and the kinematic factor is given by the quadratic equation, $\zeta = 83.25 + 11.94\ (\omega^2 r/g) - 3(\omega^2 r/g)^2$, with coefficient of determination R^2 is 0.99.

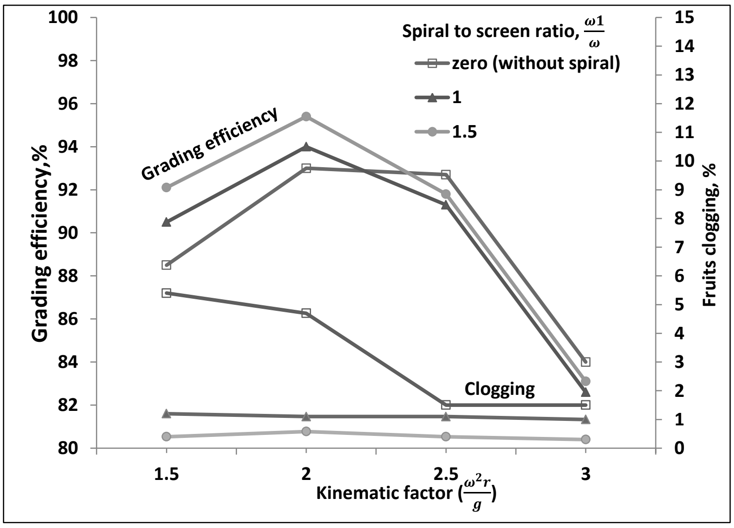

Fig. 4. Effect of kinematic factor and spiral to screen speed ratio on grading efficiency and fruits clogging percentage.

The grading capacity is governed by the optimal load on the screen. Figure (5) shows that, in general, with increase of the fruits load on the screen up to 0.1 $kg/m^2.s$, the grading capacity is directly proportional, until some limiting load after which it decreases. The grading efficiency shows the extent to which grading initially occurs remain unchanged, but with further increase of the load on the screen above 0.08 $kg/m^2.s$, the grading efficiency significantly decreases. A higher specific load on screen would mean more fruits per perforation per unit time. This would impede passage of fruit through the perforation of screen, which explains the decrease in grading efficiency and grading capacity. Significant decrease of grading efficiency always occurs earlier than the maximum grading capacity. Thus, the maximum grading capacity is always greater than that which occurs at the highest factor of grading efficiency. Therefore, the optimum value of fruit specific load is selected at 0.08 $kg/m^2.s$ to obtain 450 kg/h grading capacity and 95.4 % grading efficiency.

It can also be seen that, at specific feed rate of 0.08 kg/m^2 s, the maximum grading efficiency and grading capacity of 95.4 % and 450 kg/h respectively were achieved by using trapezoidal bars cells. On other hand, at specific feed rate of 0.08 kg/m^2 s, the minimum grading efficiency (90.4 %) and minimum grading capacity (360 kg/h) were recorded by using circle cells. The reason of depression of grading efficiency and grading capacity with circle cells may be due to the increase in clogging of screens compared with other screen mesh shape. The relationship between the grading efficiency (ζ) and the specific feed rate (F) is given by the quadratic equation, $\zeta = 89.725 + 7.705 (F) - 2.475(F)^2$, with coefficient of determination R^2 is 0.99.

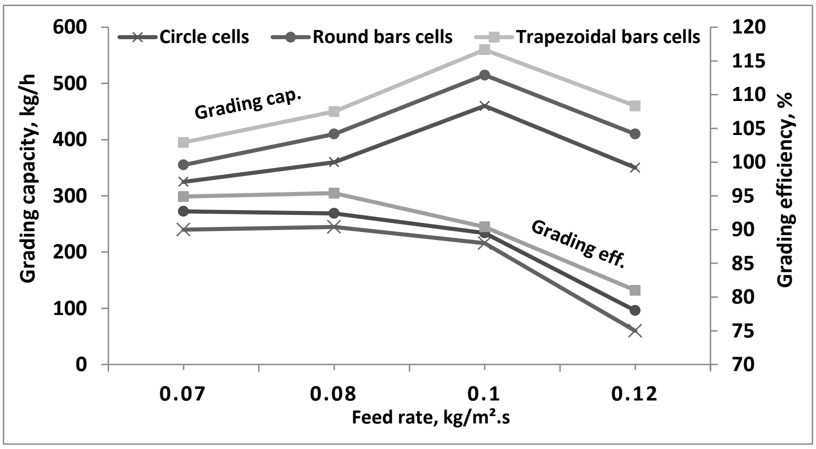

Fig. 5. Effect of screen mesh shape and specific feed rate on grading efficiency and grading capacity.

The effect of screen slope on grading efficiency and grading capacity is plotted in Figure 6. Screen inclination controls the duration that the fruits stay in the grader; however, there was very little effect of the screen's inclination on grading capacity. There was no clear tendency and the differences generally were not significant. But, grading efficiency was highly affected by screen slope angle. Where, the highest grading efficiency of 94.8 % was obtained at screen slope angle of zero degree. But, the minimum grading efficiency of 84.2 % recorded at 9 degree screen slope. This can be explained as, at a greater slope each fruit stays on the screen for a shorter period therefore, lower grading efficiency can be expected. The relationship between the grading efficiency (ζ) and the screen slope angle (θ) is given by the quadratic equation, $\zeta = 92.875 + 3.325 (\theta) - 1.375(\theta)^2$, with coefficient of determination R^2 is 0.99.

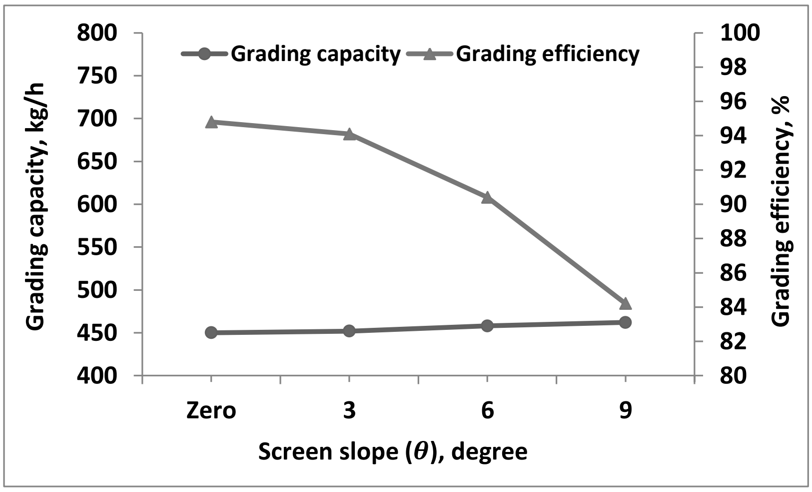

Fig. 6. Effect of screen slope angle on grading efficiency and grading capacity.

Fig. 7 shows the effect of kinematic factor on the grading capacity and energy requirements. It can be seen that increasing the kinematic factor to 2 causes a corresponding increase in grading capacity and decrease in the energy requirements. This decrease in energy may be attributed to the increase in grading capacity. Generally, the maximum value of grading capacity (450 kg/h) and the minimum value of energy requirements (5.8 kW.h/Mg) were achieved at kinematic factor of 2. While the minimum value of grading capacity (340 kg/h) and maximum value of energy requirements (6.5 kW.h/Mg) were performed at 3 kinematic factor.

The capacity of the screen increases with increasing speed of rotation until a critical speed is achieved. At speeds greater than this, the material does not cascade over the surface but is carried around by centrifugal force, and separation is seriously impaired. The critical speed of the screen was previously given as:

Critical rotating speed, $N = 62/ r^{1/2}$ = 124 r.p.m (6.49 m/s).

where N is the number of revolutions of the screen per minute and r is the radius of the screen in meters.

Experimentally, the maximum grading capacity and minimum energy requirements was achieved at 2 kinematic factor ($\omega^2 r/g$). Therefore:

Optimum rotating speed, $N = 42.2/ r^{1/2}$ = 84.5 r.p.m (4.4 m/s).

Thus, the optimum screen speed was 68 % of critical speed.

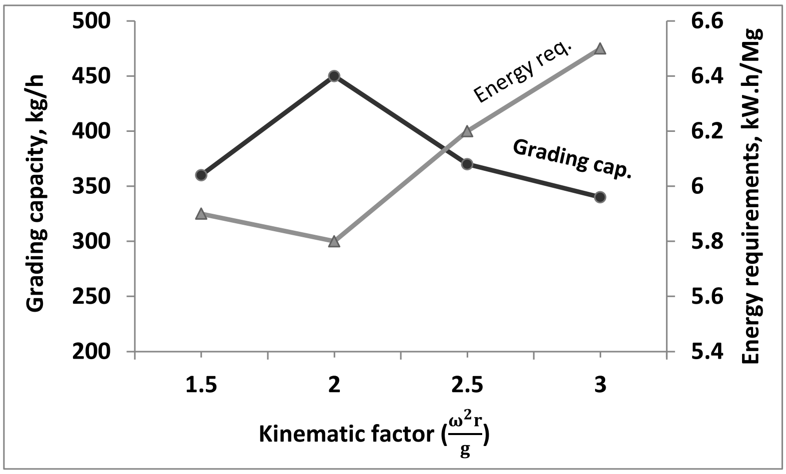

Fig. 7. Effect of kinematic factor on grading capacity and energy requirements.

The effect of feed rate on energy requirements is given in Figure 9. At screen trapezoidal bars cells, there was a decrease in energy requirements with increasing feed rate within the range of 0.07 and 0.1 $kg/m^2.s$. When the feed rate was 0.07 $kg/m^2.s$, energy requirements was 6.4 kW.h/Mg and when feed rate was 0.10 $kg/m^2.s$, energy requirements decreased to 5.1 kW.h/Mg. But with further increase of feed rate to 0.12 kW.h/Mg, energy requirements increased to 6 kW.h/Mg .

Fig. 9 also shows that the screen mesh type had a significant effect on energy requirements. Where, at feed rate of 0.08 $kg/m^2.s$, the energy requirements was 5.8, 6.2, and 6.7 kW.h/Mg by using trapezoidal bars cells, round bars cells, and circle cells respectively.

At the three screen mesh type, the fruit clogging percentage remained unchanged up to feed rate equal 0.08 $kg/m^2.s$, but with further increase of feed rate, it increased. In practice, the feed rate is so selected to be 0.08 $kg/m^2.s$ that is corresponds to the desired requirements, that is, fruits clogging of 0.4 % and 5.8 kW.h/Mg energy requirements.

It can be seen from Fig. 9 the minimum fruits clogging were achieved by using screen trapezoidal bars cells compared to the other screen mesh type. This may be due to with use screen circle cells the passing hole area is close to fruits projected area. Also, with use of screen round bars cells fig. 8 the cross section of the sifting slits decreases toward the direction of sifting ($\alpha > \alpha_1$), while with a trapezoidal cross section of the rods the cross section of the sifting slits increases toward the sifting direction ($\alpha < \alpha_1$). In the first case, sifting is inhibited; in the other, on the other hand, facilitated.

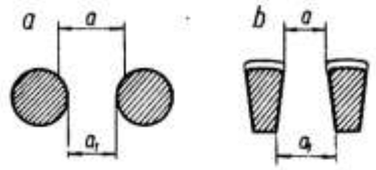

Fig. 8. Clearances between the grids: a - with round bars; b - with trapezoidal bars.

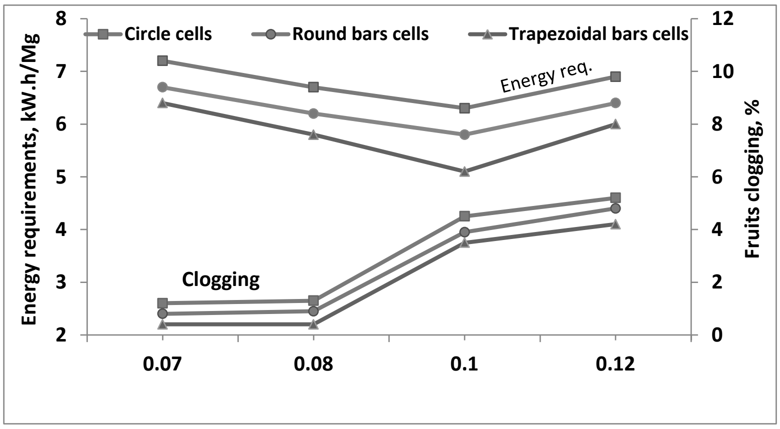

Fig. 9. Effect specific feed rate and screen mesh type on energy requirements and fruits clogging percentage.

The effect of kinematic factor on Fruits damage is presented in Figure 10. There was an increase in fruits damage with increasing kinematic factor ranged between 1.5 and 3. At 1.5 kinematic factor, the fruits damage is 1.2 % but at 3 kinematic factor, the damage increased to 3.8 %. The relationship between the fruits damage and the kinematic factor ($\omega^2 r/g$) is given by the quadratic equation, fruits damage = $1.575 - 0.735 (\omega^2 r/g) + 0.325(\omega^2 r/g)^2$, with coefficient of determination R^2 is 0.99.

Fig. 10 also shows that the screen mesh type had a significant effect on fruits damage. Where, at kinematic factor of 2, the fruits damage was 1.3%, 2.05 %, and 4.1 % by using trapezoidal bars cells, round bar cells, and circle cells, respectively.

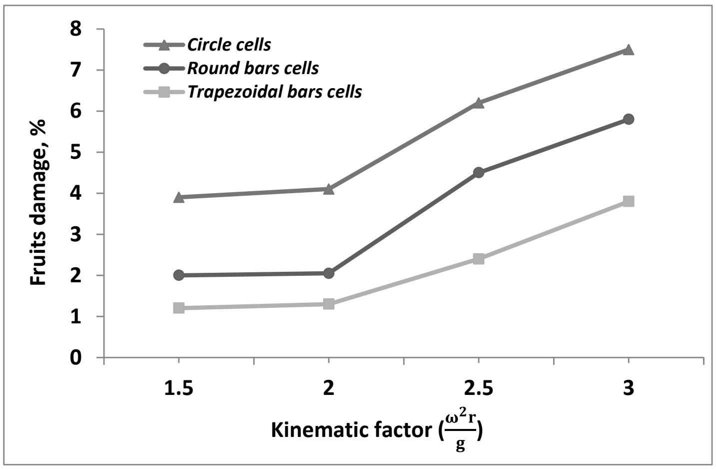

Fig. 10. Effect of kinematic factor and screen mesh type on fruits damage.

The analysis of variance (ANOVA) for the grading efficiency is presented in table 3. It is clear that the grading efficiency was highly correlated to the independent variables used. The determination factor, R^2 was found to be 0.723. The general form of the equation used in this analysis was a function of spiral to screen speed ratio (ω_1/ω), feed rate ($F/\rho\omega d$), kinematic factor ($\omega^2 r/g$), and screen slope angle (θ). A model that can be used for predicting grading efficiency (ζ) was performed according to Buckingham Pi theorem (Glenn, 1950). According to Table 4, the developed model can be expressed as follows:

$$\zeta = 122.47 + 1.54\,(\omega_1/\omega) - 49848.5\,(F/\rho\omega d) - 7.677\,(\omega^2 r/g) - 1.07\,(\theta)$$

Where:

ζ = Grading efficiency, %;

ω_1 = Spiral angular velocity, (zero, 8.84 and 13.26 s^{-1});

ω = Screen angular velocity, (7.64, 8.84, 9.88, 10.84 s^{-1});

F = Feed rate, (0.07, 0.08, 0.10, and 0.12 $kg/m^2.s$);

ρ = Fruit density, (1160 kg/m^3);

d = Screen perforation diameter, (0.024 m);

r = Cylindrical screen radius, (0.25 m);

g = Gravitational acceleration, (9.81 m/s^2); and

θ = Screen slope angle, (zero, 3, 6, and 9 degree).

The advantage of this model is that it can be used to generate numerous of predicted data for grading efficiency under the effect of many independent variables. It may be noticed from the equation the grading efficiency (ζ) was positively related to spiral to screen speed ratio (ω_1/ω). But, it was negatively related to feed rate ($F/\rho\omega d$), kinematic factor ($\omega^2 r/g$), and screen slope angle (θ). Based on the experiment results, an optimum combination of independent variables can be summarized for spiral to screen speed ratio (ω_1/ω), feed rate, ($F/\rho\omega d$), kinematic factor ($\omega^2 r/g$), and screen slope angle (θ) as 1.5, 3.25×10^{-4}, 2 and zero, respectively.

As shown in Figure 11, the relationship between the observed grading efficiency (y) and predicted grading efficiency (x) is given by the quadratic equation, $y= - 0.0354 x^2 + 6.8563 x - 240.73$, with coefficient of determination R^2 is 0.7893.

Table 3. Analysis of variance for grading efficiency.

ANOVA					
S.V.	df	SS	MS	F	Significance F
Regression	4	9087.075	2271.769	122.1277	4.82E-51
Residual	187	3478.496	18.60158		
Total	191	12565.57			

R-square = 0.723

Table 4. Multiple regression analysis of grading efficiency.

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	122.4751	2.064904	59.31274	3.3E-123	118.4016	126.5486
ω_1/ω	1.548437	0.499128	3.102288	0.002218	0.563793	2.533082
$F/\rho\omega d$	-49848.5	3994.71	-12.4786	2.16E-26	-57728.9	-41968
$\omega^2 r/g$	-7.67708	0.5568	-13.7879	2.69E-30	-8.7755	-6.57867
θ	-1.07049	0.0928	-11.5354	1.35E-23	-1.25356	-0.88742

R-square = 0.85

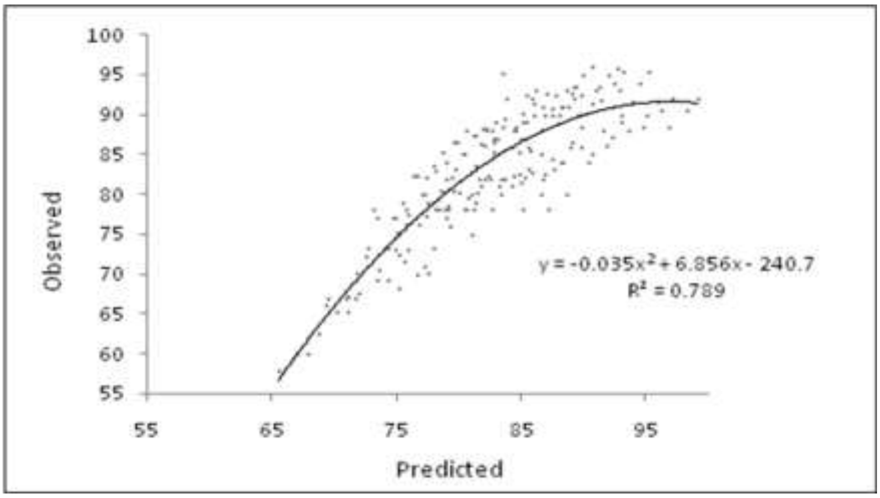

Fig. 11. The relationship between predicted grading efficiency (x) and observed grading efficiency (y).

CONCLUSION

The obtained data can be concluded as the following:

1- The maximum grading efficiency (95.4 %) and minimum fruits clogging percentage (0.58 %) were achieved at 2 kinematic factor, screen slope angle of zero degree. and 1.5 spiral to screen speed ratio.

2- The optimum value of fruit specific load is selected at 0.08 kg/m^2.s to obtain 450 kg/h grading capacity and 95.4 % grading efficiency.

3- Experimentally, the maximum grading capacity (450 kg/m^2s) and minimum energy requirements (5.8 kW.h/Mg) were achieved at 2 kinematic factor ($\omega^2 r/g$). **Optimum rotating speed, N = 42.2/ $r^{1/2}$ = 84.5 r.p.m (4.4 m/s).** Thus, the optimum screen speed was 68 % of critical speed.

4- In practice, the feed rate is so selected to be 0.08 kg/m^2.s and using screen trapezoidal bars cells that is corresponds to the desired requirements, that is, fruits clogging of 0.4 % and 5.8 kW.h/Mg energy requirements.

5- At kinematic factor of 2, the fruits damage was 1.3%, 2.05 %, and 4.1 % by using trapezoidal bars cells, round bar cells, and circle cells respectively.

Recommendation

1- The developed grading machine can be manufactured with local material in the small workshops.

2- The developed grading machine must be used under optimum operational condition as 2 kinematic factor, 0.08 kg/m^2.s feed rate, zero degree screen slope angle, 1.5 spiral to screen speed ratio and screen mesh of trapezoidal bars cells.

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تطوير آلة تدريج اسطوانية لثمار الزيتون

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تعتبر عملية التدريج من اهم العمليات اللازمة لتصنيف الاحجام المختلفة لثمار الزيتون ، مما يؤدى الى المحافظة على جودة المحصول وزيادة القدرة التسويقة والتصنيعية وزيادة الفائدة. وتجرى عملية التدريج إما يدويا او ميكانيكيا.

يهدف هذا البحثالى تطوير وإختبار آلة تدريج إسطوانية الشكل لتدريج ثمار الزيتون على اساس القطر. وكانت معاملات الدراسة: معدل تغذية الثمار لوحدة مساحة الغربال (0,07, 0,08، 0,1، 0,12 كجم/م^2 ثانية)، معامل الحركة للغربال $\omega^2 r / g$ (1,5، 2، 2,5، 3)، شكل خلايا الغربال (قضبان شبه منحرفة متوازية، قضبان دائرية متوازية، خلايا دائرية)، زاوية ميل الغربال (صفر، 3، 6، 9 درجة)، معامل سرعة الحلزوني إلى الغربال (صفر، 1، 1.5) والتي تؤثر بدورها على انتاجية الآلة، الطاقة المستهلكة، كفاءة التدريج، والتالف الميكانيكى للثمار.

لذلك كان الهدف من هذا البحث هو:

1- دراسة بعض الخواص الطبيعية والميكانيكية لمحصول الزيتون.

2- تطوير آلة تدريج اسطوانية محلية الصنع لتلائم تدريج محصول الزيتون.

3- دراسة اهم العوامل الهندسية والتصميمية على آلة التدريج المطورة.

4- الحصول على النموذج الرياضى بحيث يمكن ان نتنبأ بكفاءة التدريج تحت تأثير هذه العوامل.

أهم النتائج المتحصل عليها:

1- كانت أعلى كفاءة تدريج للآلة (95.4 ٪) عند معاملات التشغيل المثلى (الموصى بها): معامل الحركة للغربال (2.0)، معامل سرعة الحلزوني إلى الغربال (1.5)، زاوية ميل الغربال (صفر درجة)، معدل تغذية الثمار لوحدة مساحة الغربال (0.08 كجم/م^2 ثانية)، باستخدام شكل خلايا الغربال (قضبان شبه منحرفة متوازية).

2- بلغت الإنتاجية الكلية عند معاملات التشغيل الموصى بها حوالى 450 كيلوجرام/ساعة.

3- اوضحت الدراسة ان حسابات الطاقة المستهلكة عند معاملات التشغيل الموصى بها كانت 5.8 كيلوات.ساعة/ميجاجرام.

4- أثبتت التجارب ان اقل نسبة تالف ميكانيكى للثمار المدرجة بلغت 1.3 % عند معاملات التشغيل الموصى.

5- امكن الحصول على النموذج الرياضى للتنبؤ بكفاءة التدريج تحت تأثير العوامل التى تم دراستها خلال هذا البحث.

6- ثبت من التجارب ان اداء الآلة كان جيدا بصفة عامة وقد حققت الهدف المطلوب ويمكن استخدامها على المستوى التطبيقى والعملى، كما يمكن استخدامها لتدريج بعض المحاصيل الاخرى مثل البطاطس، الطماطم، التفاح، الموالح.