DESIGN, CONSTRUCTION AND PERFORMANCEEVALUATION OF AN ALMOND KERNEL EXTRACTION MACHINE: 2. SEPARATING, GRADING AND CLEANING UNITS

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ABSTRACT

Separating unit performs the second operation in almond kernel extraction as almond grading is necessary to further processing. Separating, grading and cleaning units were added to almond kernel extraction machine. The separating unit was developed through consecutive stages of design, fabrication and evaluation. Some physical and mechanical properties (dimensions, mass, volume, static coefficient of friction and terminal velocity) of almond kernel that are pertinent to the mechanical processing were measured and considered in design stage of separating, grading and cleaning units. The developed units were evaluated at four levels of crank speed (C_S) (200, 225, 250 and 275 rpm), four levels of feeding rate (F_R) (173, 183, 295, 357 kg h^{-1}) and three levels of sieve angle (S_A) (5, 10 and 20 deg.). The Evaluation was based on the following parameters: grading efficiency (GE), machine capacity (P_m) and consumed energy (CE). The results recommend operating the machine at combinations of C_S =225→250 rpm, S_A =5→20 degrees at different F_R to maximize GE value of 87.97 % - 95.7%.

Keywords: *almonds, separating, grading, design, cleaning, energy, sieve.*

INTRODUCTION

Almond (*Prunus amygdalus*) is a native tree of Middle East, India and North Africa belongs to the family Rosaceae (***Potter et al., 2007***). The kernel has an important source of energy (6 kcal g^{-1}), protein (15.64%) and the oil content ranges from 35.27% to 40% (***Aydin, 2003***). Kernel of almond are widely used in desserts, candy and cooking. It's a good source of beauty, inspiration, food, medicines and anti-oxidant nutrients. The handling operations of the almond have been carried out manually.

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The most important process after almond cracking is the separating almond kernel from its cracked shell (***Aarabi and Ebrahimi, 2017***). Where the problem faced in production of nuts and similar products is the separation of the shells and husks from the kernel. Hand cracking of the nutshell and separation of the kernel was remained traditional means (***Nahal et al., 2013***).Physical and aerodynamic properties of agricultural products are essential engineering data for designing and developing post harvest handling and processing operations (***Khir et al., 2012***). (***Tado et al. 1999)*** stated that the knowledge of agricultural engineering operations and understanding the basic properties of the experimental crop product such as separation processes, determination of the terminal velocity and the evaluation of the physical and aerodynamic are also very necessary. ***Gorial and O'Callaghan (1991)*** suggested that the separation of mixed components under an air stream is possible only when the accurate air pressure and terminal velocity delivered. Aerodynamic information of shelled walnut particles is important for developing separation equipment in postharvest processing of walnut. It has been reported that physical and aerodynamic properties of grains and seeds are used for designing various types of cleaning, separating, sorting and conveying equipments (***Baryeh, 2001***). (***Klenin et al. 1985)*** stated that the agricultural product is cleaned and graded according to many criteria. The criteria are geometric size, aerodynamic properties, the shape of the surface, density and specific weight. ***(Nigrini et al. 1994)*** mentioned that the vibratory seed cleaner is considered as an efficient device to achieve cleaning and grading seeds to get higher quality. ***Amin (2003)*** mentioned that the sieving time, cell shape, and oscillating speed were the main factors that affected the separation efficiency. This efficiency increased by increasing sieving time and oscillating speed. (***Aarabi and Ebrahimi 2017)*** developed the pneumatic separation for separating the almond kernels from its cracked shells. They found that the separation efficiency decreased with increasing feed rate, angle of mixture supply into tunnel and distance between mixture inlet and kernels outlet. The highest separation efficiency was reported on 9.5 m s^{-1} air velocity while the lowest amount was reported on the 6.5 m s^{-1}.

Marey et al. (2017) designed, manufactured and evaluated a low-cost almond kernel extraction machine. Kernel extraction by the machine was conducted by first crushing the nut, and then separating kernel from a shell. But the machine need additional units include: separating, grading and cleaning units to separate the almond kernels from its cracked shells.
The objective of the present work was to develop separating, grading and cleaning units to be added to almond kernel extraction machine and introduce a combine almond separator which is suitable for the low income former.

MATERIALS AND METHODS

2.1 Sample preparation

For this study, samples (red almond) were randomly collected from different farms in Al Bydia, Libya during summer 2015, to be used for the experiments. The samples were manually cleaned to remove foreign matter and broken and immature nuts. The moisture contents of the kernel, shell, and hull were 4.5%, 8.8%, and 16.6% d.b., respectively. The moisture content measured using an oven dryer at 103°C for 24 hours ***(ASAE, 1999)***.

2.2 Physical and mechanical properties of almond kernel

The following physical and mechanical properties of almond kernel that are pertinent to the mechanical processing were measured and considered in the design of the separating, grading and cleaning units.

2.2.1 Dimensions, mass and volume

Fifty (50) kernels were selected at random from both samples, the three principal diameters; major diameter (a), intermediate diameter (b) and minor diameter (c) were measured using Vernier Calipers and the average was taken (***Mohsenin, 1986***).The properties that were used are presented in Table (1).

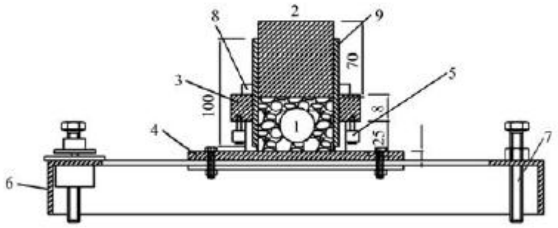
2.2.2 Coefficient of static friction

The static coefficient of friction of almond kernels against different materials, namely plywood and Galvanized metal was determined at moisture content of 4.5 % d.b. The device was used for the determination of the coefficient of static friction is shown in figure (1) according to ***Ibrahim, (2008)***. The static coefficient of friction was calculated as follows:

$$\mu = \frac{F_T - F_E}{W} \qquad \text{............ (1)}$$

Where

μ	:	Coefficient of static friction.
F_T	:	Force required to start motion of filled wooden frame (N).
F_E	:	Force required to start motion of empty wooden frame (N).
W	:	Weight of the object (N).



1- Sample　**2**- Piston　**3**- Carriage
4- Sliding surface　**5**- Rolling wheels　**6**- Base
7- Adjustable screw　**8**- Adjustable nut　**9**- Cylinder

Fig. (1): The device for measuring the friction force.

2.2.3 Breaking force of almond kernel

The rupture strength was tested to know the magnitude of force that is required to break the almond kernels. Several trails were conducted with a special press (***Bernik and Stajnko, 2009***) at the laboratories of Faculty of Engineering, Omar Al Mokhtar University, Libya. Each individual almond kernel was loaded between two parallel jaws and compressed until the kernel is ruptured. To determine the effect of the loaded kernel orientation on the rupture, nuts were positioned on the front and on the side plane (*Figure 2*). Five samples, each includes five nuts, were selected randomly and the experiment was performed on each sample and the maximum force that break the kernel was recorded.

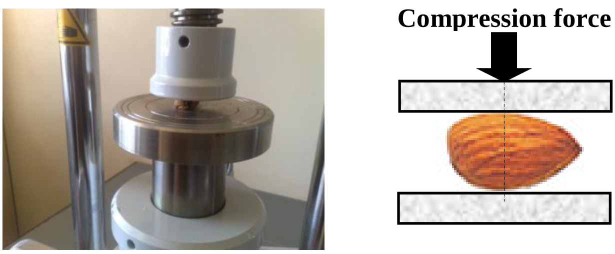


Fig. (2): Loading and compressing of almond kernel and spring between two parallel plates.

The physical and mechanical properties of the almond kernel are presented in Table (1).They were considered in the design and the development of the machine.

Table (1): Some Physical and mechanical properties of the almond kernel.

Property		Min.	Max.	Mean	Stand. Dev.
Length, L (mm)		21.31	22.09	21.83	1.51
Width, W (mm)		9.21	14.96	12.09	0.71
Thickness, T (mm)		7.52	11.45	10.43	0.50
Mass (g)		2.8	4.1	3.3	0.28
Coefficient of friction	**Metal**	0.305	0.654	0.452	0.06
	Wood	0.425	0.719	0.565	0.08
Breaking force (N)	**Length**	115.6	194.1	158.6	3.52
	Width	90.2	128.1	103.5	3.12
	Thickness	58.1	82.9	76.3	1.92

2.2.4 Terminal velocity

The terminal velocities of kernel and shell of almond samples were measured by using an air column (***Tabak and Wolf 1998***); similar to ***Awady and El Sayed (1994***). The air inlet pipe of the fan has a circular shape 90 mm diameter, the outlet of the fan has a rectangular shape 8 x 11 cm, to control the amount of air. A movable gate was placed on the inlet pipe of the fan. The gate area was adjusted to give variable air velocities. The air velocity was measured using tri-Sence digital instrument connected with a velocity probe, (range from 0.1 to 25 m s^{-1}, its accuracy 0.1 m s^{-1}). The whole almond and the individual particles of the shelled almond were considered in this measuring in order to determine the terminal velocity of each particle. The pieces of the shelled almond were then classified into: Whole almond, One-half almond, One-quarter almond, Whole kernel, One-half kernel, One-quarter kernel, One-eight kernel, One-half shell, One-quarter shell, One-eight shell. Table (2) shows the terminal velocity of different particles of the shelled almond.

2.2.5 Separation force

It is defined as the required force for loosening the shell from the cracked almond nut. The device that was used for measuring a low compression force required that used to loosening the shell from the cracked almond nut, it was used in the design separating unit. The method consisted of placing one cracked almond nut between two plates (one lower and the other upper). The lower plate (iron material) provided the oscillated motion, and the upper wooden surface plate was he compression plate, this process was repeated with different load until the shell loosening from the cracked almond nut without damage in the kernel (Fig. 3).The compression force was determine 0.25 N.

Table (2): Terminal velocity of different particles for almond

Particles	Terminal velocity (m s^{-1})	Particles	Terminal velocity (m s^{-1})
Whole almond	13.2	One-quarter kernel	7.4
One-half almond	9.74	One-eight kernel	7.7
One-quarter almond	7.6	One-half shell	6.9
Whole kernel	10.6	One-quarter shell	4.9
One-half kernel	7.9	One-eight shell	4.8

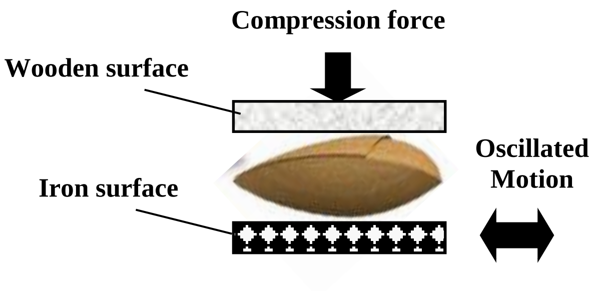


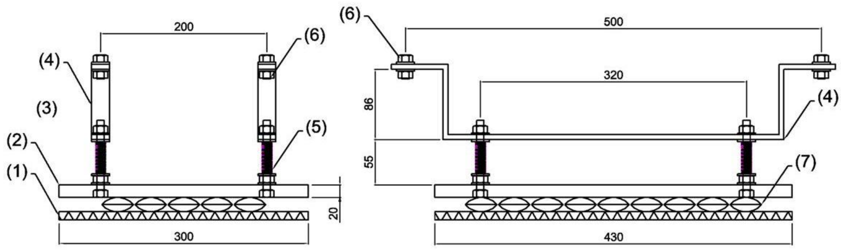
Fig. (3): Test method used for measure loosening force.

2.3 Design of separating, grading and cleaning units

The cracking machine consists of major units: the in-feed unit, the cracking unit, the discharge outlet, the separating unit, the sorting unit, cleaning and the driven unit (Fig. 5).

2.3.1 Separating unit

A wooden plate of 30 cm in length, 40 cm in width and 2 cm thickness was fixed above the sieves. This plate was mounted on the main frame by two iron bars and four springs (Fig. 4). The clearance between the wooden plate and sieves was smaller than the nuts dimensions. The separation of the seeds from the solid crust was achieved by the friction between the nuts and the wooden plate that resulted from the reciprocating motion of the sieves.



1- Sieve **2**- Compressed wooden plate **Dims. in mm**

3- Screw + nut **4**- Compressed beam **5**- Spring

6- Screw + nut for fixed with the machine frame **7**- cracked nut

Fig. (4): Scraping (separating) unit.

Compression force required to loosen one shell from the cracked almond nut without damage in the kernel = 0.25 N.

Total compression force = No. of nut × required force for one nut.

No. of nut that loosening at simultaneously = (length × width of the wooden plate) / (length, L × width, W of the nut).

No. of nut = (300 × 400) / (21.83 × 12.09) = 455 nuts.

So, the total compression force = 455 × 0.25 = **113.75** N.

Total compression force = **113.75** N = total compression force exerted by four springs. The restoring force exerted by the one spring = **113.75** N / 4 = **28.4 N**

Spring was selected and tested; the restoring force exerted by the spring (F) was determined by the following equation:

$$F = k \cdot x \qquad \text{............ (2)}$$

Where

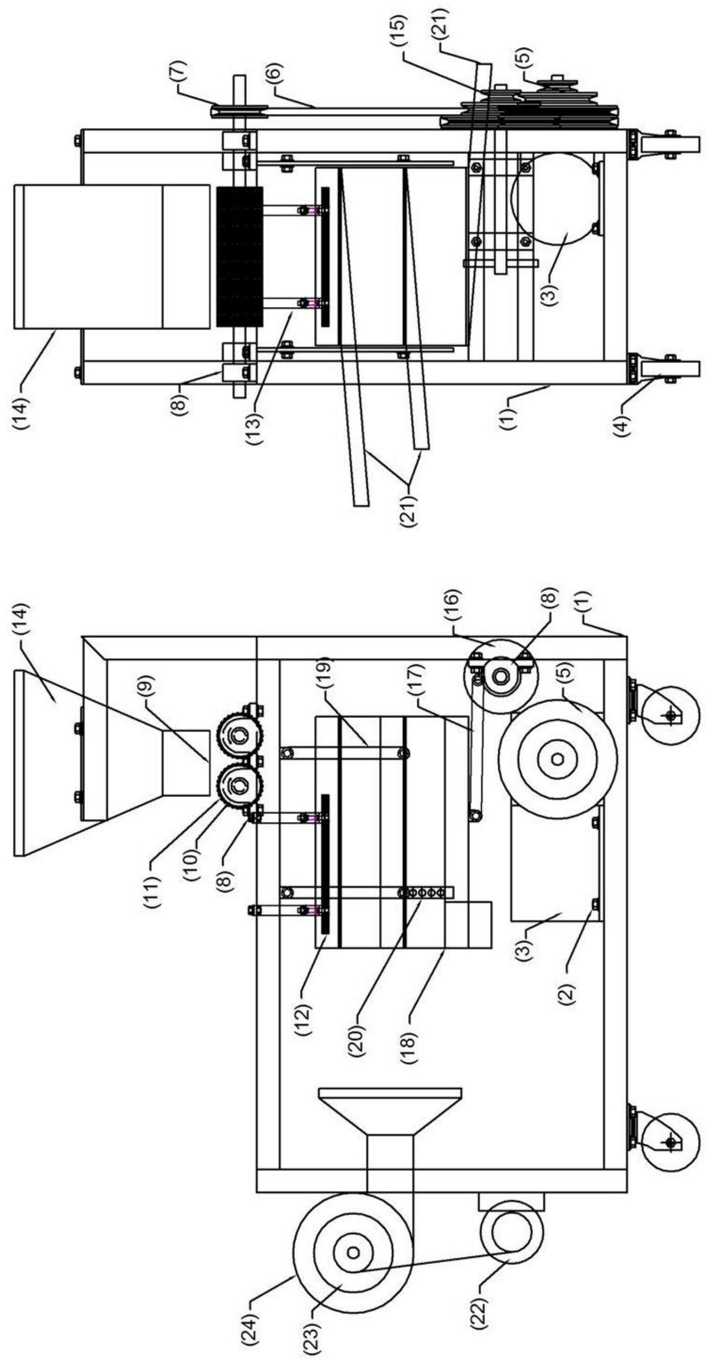
F : Exerted force by the spring on that end (N).

k : Spring constant ($N\ m^{-1}$).

x : Displacement (m)

2.3.2 Grading unit

An aggregate of two sieves and flat pan with 60 cm in length and 40 cm in width was fabricated from 3 mm thick steel sheet. A decentralized cam was used to convert the rotating motion of the electric motor to reciprocating motion. The sieve unit is composed of screen, crank mechanism and power transmission.



Itemref	Quantity	Title/Name	Material	Itemref	Quantity	Title/Name	Material	Itemref	Quantity	Title/Name	Material
1	1	Machine base	St37	10	2	Roller	St37	19	2	Oscillating rod	St37
2	28	Bolts and nut M10	St37	11	2	Coating material	Rubber, st 37	20	2	Oscillating rod to change tilt angle	St37
3	1	Motor + Worm reducer		12	1	Compressed plate	wood	21	2	Collector orifice for grading garlic	St37
4	4	Rotary caster single bearing wheel		13	2	Compressed beam	St37	22	1	Cleaning motor	
5	1	Malti-pulleys blok	Al	14	1	Feed hopper	St37	23	1	Single-pulleys blok	Al
6	1	V-belt = 16mm	Rubber	15	1	Malti-pulleys blok	Al	24	1	Blower housing	St37
7	2	Single-pulleys blok	Al	16	1	Crank - eccentric	St37				
8	4	Bearing housing UCP205-100		17	1	Connecting rod	St37				
9	1	Adjusted gate	St50	18	2	Oscillating sieves (upper - middle)	Rubber				

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Fig. (5): Diagrammatic sketch of the separator, cleaning and grading machine.

1) Screen characteristics

Screens are characterised by parameters such as hole shape and the co-efficient of opening (Co). The axial dimension of almond kernel was used to calculate the estimated average sphericity as suggested by ***Mohsenin (1986)***.

$$S_{ph} = D_g / L \qquad \textbf{............ (3)}$$

Where

S_{ph} : Sphericity.

D_g : Geometric mean diameter ($Dg = \sqrt[3]{LWT}$).

Sphericity of almond kernel ranged from 53.43 % to 70.54 %. So the materials have low sphericity. An oblong shape screen must be used according to ***Okunola and Igbeka (2009***).

The sieve consists of two sieves; the upper one was used for separating the large kernel. The second sieve is used for separating the medium kernel. The lower sheet is to collect the small kernel. The proper mesh-size of the sieves was determined from physical properties of almond kernels (Table 1). The sizes of the screen are 25 × 10 mm (upper screen) and 20 × 8 mm (lower screen). For efficient screening, coefficient of opening (Co) was calculated by applying the following equation and was found to be taken as 40 % according to ***Okunola and Igbeka (2009)***. It can calculate the (***Co***) for oblong opening as follows (Fig. 6):

$$Co = \frac{\text{Open area}}{\text{Total area}} = \frac{L_s W_s}{(L_s + d_2 + \frac{d_2}{n_2})(W_s + d_1 + \frac{d_1}{n_1})} \times 100 \qquad \textbf{............ (4)}$$

Where

L_s : Length of opening (mm).

W_s : Width of opening (mm).

d_1, d_2 : Distance between adjacent lateral and elongated sides (mm).

n_1,n_2 : Number of holes in the lateral and elongated side

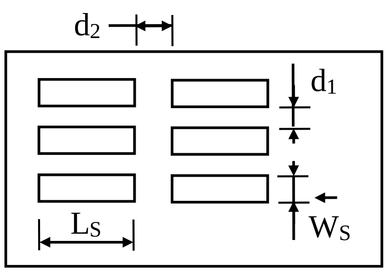

Fig. (6): An elevation view of screen to calculate the coefficient of opening.

The sieves were made from steel sheet metal of 1.5 mm thickness with drilled oblong holes. The sieve was 500 mm long, 350 mm wide. By using try and error method in equation (3), d_1 and d_2 were calculated taking in account that Co equals 40 %. Table (3) shows the characteristics of the sieves.

Table (3): Characteristics of the sieves.

	L_s	W_s	d_1	d_2	n_1	n_2
Upper sieve	25	10	8	8	15	20
Lower sieve	20	8	7	6	16	20

2) Sieve mechanism

A vibrated sieve is used to grade almond kernels. The screens were fixed inside screen casing which is suspended by hangers. They consist of upper and lower sieves and hang on four links (2 adjustable rods in the front and 2 fixed in the rear to alter the sieve tilt angle – 250 mm length). The tilt angle can be varied from 0 to 30^o (Fig. 5). The crank mechanism was used to produce the reciprocating motion of sieve. Radius of crank is 50 mm and connecting rod is 300 mm long.

Design crank mechanism: Agitation of the sieve results in displacement of the almond kernels over its surface. The resultant force on a particle must be higher than the friction force between the almond kernels and the surface. Particle velocity on the sieve surface must not be too high, or the almond kernels will pass by the sieve openings instead of falling through. The sieve is agitated by multiple system linkage taking linear motion that are given by applying the following equations (***klenin et al, 1985***):

$$X = r\,(1 - \cos \omega t)$$

$$\bar{X} = \omega r \sin \omega t \qquad \text{............ (5)}$$

$$\bar{\bar{X}} = \omega^2 r \cos \omega t$$

Where

X	:	Instantaneous displacement (m).
$\bar{X}$	:	Motion velocity (m s^{-1}).
$\bar{\bar{X}}$	:	Acceleration of motion (m s^{-2}).
ω	:	Angular velocity (rad s^{-1}).
r	:	Crank shaft length (m).

The following forces act on a sieve due to almond kernel:

1- Force due to the weight (W= m g) of the almond kernels directed downward.

2- Inertia force (F_i) acting in a direction opposite to that of the mass acceleration force. The magnitude of the force F_i is obtained as follows:

$$F_i = m\ddot{X} = m\,\omega^2\, r\cos\omega t \qquad \text{............ (6)}$$

Where

m : Mass of almond kernels.

g : Gravity acceleration.

3- Friction force (F_f) between the almond kernels and the sieve surface acting in a direction opposite to motion direction.

4- Reaction force (R) of the working surface on the almond kernels acting in a direction normal to the surface.

The sieve is set horizontal or inclined to the horizontal plane, the angle of inclination selected from the condition $\alpha \le \phi$

Where

α : Angle of sieve with the horizontal.

ϕ : Friction angle between the almond kernel and the sieve surface.

Motion of material over the sieve surface at the delivery end from A to B: Motion is possible when the resultant of all forces acting the material is greater than the friction force (Fig.7):

$$W\sin\alpha + F_i.\cos\alpha \ge F_f$$
$$F_f = R\tan\phi = \mu R \qquad \text{............ (7)}$$

Where

μ : Coefficient of friction.

To determine force (R) projecting all the forces in a direction normal to the sieve:

$$R = W\cos\alpha - F_i\sin\alpha \qquad \text{............ (8)}$$

Then motion of the almond kernels at the exit may be expressed by the following inequality:

$$W\sin\alpha + F_i\cos\alpha \ge \mu W\cos\alpha - \mu F_i\sin\alpha$$
$$mg\sin\alpha + m\,\omega^2 r\cos\alpha \ge \mu\, mg\cos\alpha - \mu\, m\omega^2 r\sin\alpha \qquad \text{............. (9)}$$

$$\omega_1 = \sqrt{\frac{g\,(\mu\cos\alpha - \sin\alpha)}{r\,(\cos\alpha + \mu\sin\alpha)}}\ ,\quad \text{rad s}^{-1} \qquad \text{............. (10)}$$

$$N_1 = \frac{60}{2\pi}\sqrt{\frac{g(\mu\cos\alpha - \sin\alpha)}{r(\cos\alpha + \mu\sin\alpha)}}\ ,\ \text{rpm} \qquad \text{............ (11)}$$

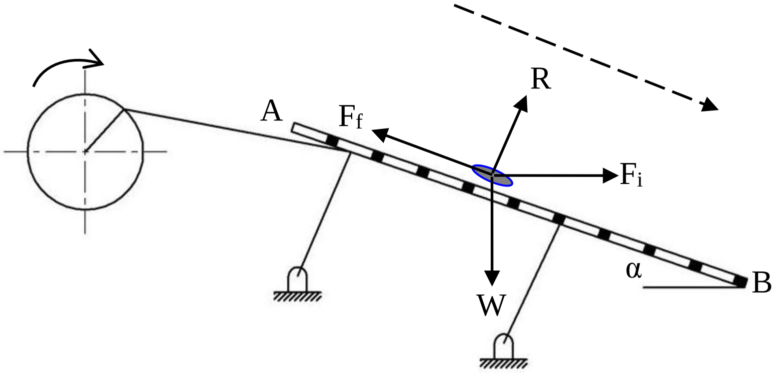

Fig. (7): Motion of material over the sieve surface at the delivery end from A to B.

Sliding motion of the material up and down the sieve surface from B to A: Fig. (8) shows the movement of material from B to A is possible when:

$$F_i \cos\alpha - W \sin\alpha \geq F_f \qquad \text{............ (12)}$$

Where $R = W \cos\alpha + F_1 \sin\alpha$

Then the motion of material in this case may be expressed by the following inequality:

$$F_i \cos\alpha - W \sin\alpha \geq \mu W \cos\alpha + \mu F_i \sin\alpha$$

$$m\,\omega^2 r \cos\alpha - mg \sin\alpha \geq \mu\, mg \cos\alpha + \mu\, m\,\omega^2 r \sin\alpha \qquad \text{............ (13)}$$

$$\omega_2 = \sqrt{\frac{g(\mu\cos\alpha + \sin\alpha)}{r(\cos\alpha - \mu\sin\alpha)}}\ ,\ \text{rad s}^{-1} \qquad \text{............ (14)}$$

$$N_2 = \frac{60}{2\pi}\sqrt{\frac{g(\mu\cos\alpha + \sin\alpha)}{r(\cos\alpha - \mu\sin\alpha)}}\ ,\ \text{rpm} \qquad \text{............ (15)}$$

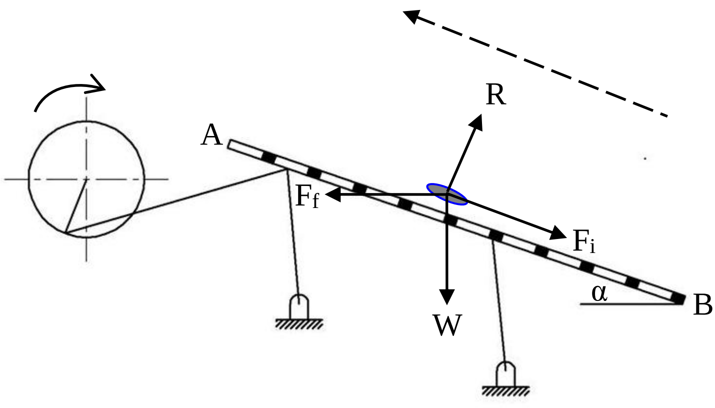

Fig. (8): Sliding motion of the material up and down the sieve surface from B to A.

Sieving and separating are more successful under the following conditions: $N > N_2$ and $N_2 > N_1$.

Where

N : The optimum sieve speed (rpm).

Under the above conditions and by using the previous equations (11,15) the separator was adjusted as follows:

1- Angle of sieve (α) with the horizontal is determined to be less than the friction angle (ϕ) between the almond kernels and the sieve surface ($\phi = \tan \mu$), ∴ $\alpha \leq$ 34 deg.

2- Sieve motion was adjusted from an eccentric with a radius of 50 mm.

3- N_1 and N_2 were calculated from the above equations with the angle of sieve from 0 to 34 deg. The maximum values were 109.84 and 172.53 rpm respectively, so optimum sieve speed was calculated to be as follows $N \geq 172.53$ rpm.

The machine will be evaluated at three levels of crank speed: 200, 225, 250 and 275 rpm.

Power transmission by V-belts and pulley was according to ***Khurmi and Gupta (2005)***:

$$N_{s1} D_1 = N_{s2} D_2 \qquad \text{............ (16)}$$

Where

N_{s1}, N_{s2} : Speeds of driving and driven pulleys respectively (rpm).

D_1, D_2 : Diameters of driving and driven pulleys respectively (mm).

Substituting the required speeds at the crank shaft N_1 are 200, 225, 250 and 275 rpm, knowing the rated speed of the electric motor (N_2 = 70 rpm), D_1 and D_2 were calculated as shown in table (4).

Table (4): The values of D_1 and D_2.

	Pulley of machine		Pulley of motor	
	N_{s1} (rpm)	D_1 (mm)	N_{s2} (rpm)	D_2 (mm)
1st	200	105	70	300
2 nd	225	93	70	300
3 rd	250	84	70	300
4 th	275	76	70	300

3) Power requirement

Theoretical power requirement for oscillation can be approximately calculated by summation of power required for the movement in the vertical and horizontal directions (***Okunola and Igbeka, 2009***).

For vertical, $$Hp_1 = \frac{2.\, W_{SC} \,.\, N \,.\, Y}{4500}$$

For horizontal, $$Hp_2 = \frac{2.\, W_{SC} \,.\, N \,.\, X \,.\, \mu_h}{4500}$$ **............ (17)**

Where

- W_{SC} : Weight of reciprocating unit along with almond kernel on it (it was determined = 25 kg).
- N : Speed in rpm, (275 rpm was used).
- Y : Vertical displacement of the reciprocating assembly per stroke, (it was determined from the drawing = 0.0046 m).
- X : Horizontal displacement of reciprocating assembly per stroke, (it was determined from the drawing = 0.095 m).
- μ_h : Coefficient of friction between hinge points (0.3).

Total power for oscillation was 0.1 Hp (0.075 kW), adding 20% for safe performance, so the required power is 0.12 Hp (0.09 kW).

2.3.3 Cleaning unit

The air velocity needed to separate the hell from almond kernel were 4.8 – 6.9 m s^{-1} (Table 2), greater than the terminal velocity of the almond kernels. A centrifugal fan with straight blades was used with an airflow rate of 0.4 m^3 s^{-1} to supply an airflow velocity of up to 7 m s^{-1}.

An air stream was supplied by a centrifugal blower operated by an electric motor of 0.65 kW with V-shape belt bully. The blower has 6 straight blade impeller with a square duct.

2.4 Performance evaluation

The developed machine was evaluated at four different levels of crank speeds, four levels of feed rate and three levels of sieve tilt angle (Table 5). The performance of grading mechanisms was possibly measured by grading efficiency; machine capacity and consumed energy were evaluated at each combination of variables.

Table (5): Experimental values of performance parameter for evaluation modified machine.

Variables	Levels
Crank speed sieve oscillation, C_S (rpm)	200, 225, 250, 275
Feed rate, F_R (kg h^{-1})	173, 183, 295, 357
Sieve tilt angle, S_A (deg)	5, 10, 20

2.4.1 Machine capacity (*P_m*)

Time of grading process was measured by means of a stop watch, the capacity of the machine was calculated as follows:

$$P_m = \frac{W}{T} \qquad \textbf{............ (18)}$$

Where

P_m : The grading capacity (kg h^{-1}).

W : The mass of sample (kg).

T : Grading time (hour).

2.4.2 Grading efficiency (*GE*)

The ratio of well-classified almond kernel to total number of almond kernel for the same outlet was computed. The grading efficiency of the outlet was calculated according to the following equation (***Mostafa and Bahnasawy, 2009***):

$$\eta_1 = \frac{n_{C1}}{N_C} \qquad \textbf{............ (19)}$$

Where

η_1 : The grading efficiency (%).

n_{C1} : The number of the well-classified almond kernel for an outlet.

N_C : The total number of cloves passing through the metering gap of the considered outlet.

2.4.3 Consumed energy (*CE*)

The required electric power was measured for cleaning and grading process. The required electric power was calculated as ***Chancellor (1981)*** by the following equation:

$$RP = V \times I \times \cos\ \theta \qquad \textbf{............ (20)}$$

Where

RP : The required power (W).

V : Potential difference, Voltage (I phase = 220 voltage).

I : Line current strength (Amperes).

$\cos\theta$: Power factor, equal 0.64.

A digital clamp meter and Voltmeter were used for measuring current intensity and voltage respectively.

The consumed energy (*CE*) is specific energy requirements per unit output; it was calculated by using the following equation:

Consumed energy = (RP/P_m), kW h ton^{-1} .... **(21)**

RESULTS AND DISCUSSIONS

3.1 Grading efficiency (GE)

The results are shown in Fig. (9), the grading efficiency ranged from 75.15 % to 95.7 % with crank speed of 200 to 275 rpm, sieve angle of 5^o to 20^o and the feeding rate of 173 to 357 kg h^{-1}. It could be noticed that the lowest values of grading efficiency were obtained at (C_S) 275 rpm and (F_R) 357 kg h^{-1}, however the highest values of grading efficiency were obtained at (C_S) 200 rpm and (F_R) 173 kg h^{-1} at different sieve angle.

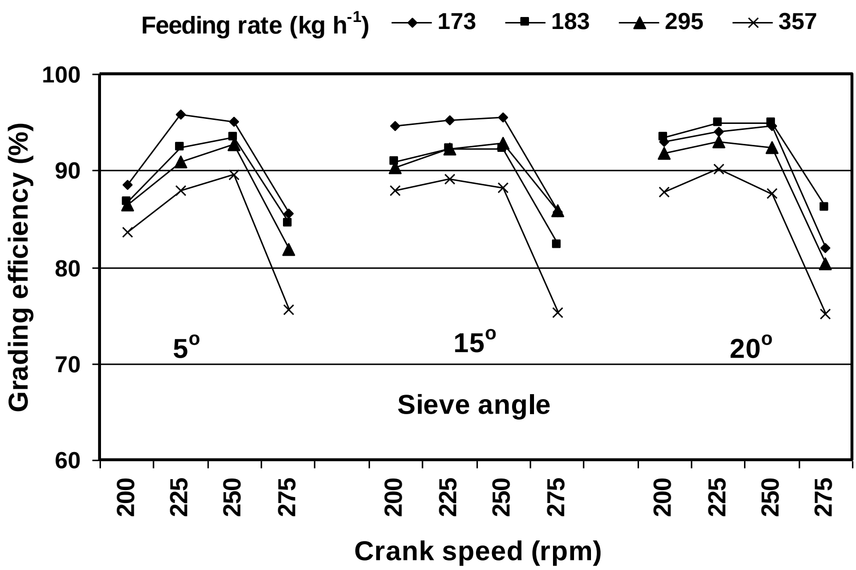

Fig. (9): The effects of crank speed, sieve angle and feeding rate on the grading efficiency.

As shown in Fig. (9), as the crank speed increased from 200 to 250 rpm the grading efficiency increased. These results may be due to increasing sieve oscillating that facilitate the material to pass through the sieve opening, but with increasing crank speed to 275 rpm the grading efficiency decreased due to the strong air front forced to pass over the sieve to outlet. It was found that the grading efficiency decreased as the feed rate increased at different sieve angles. Also, as the sieve angle increased from 5 to 15 degrees the grading efficiency increased. But increasing this angle to 20 degrees decreased the grading efficiency due to that the material rolling over the sieve to outlet.

3.2 Machine capacity (P_m)

The results are shown in Fig. (10), the machine capacity ranged from 114 to 335 kg h^{-1} with crank speed of 200 to 275 rpm, sieve angle of 5^o to 20^o and the feeding rate of 173 to 357 kg h^{-1}. It could be noticed that the lowest values of machine capacity were obtained at (C_S) 200 rpm and (F_R) 173 kg h^{-1}, however the highest values of machine capacity were obtained at (C_S) 275 rpm and (F_R) 357 kg h^{-1} at different sieve angles.

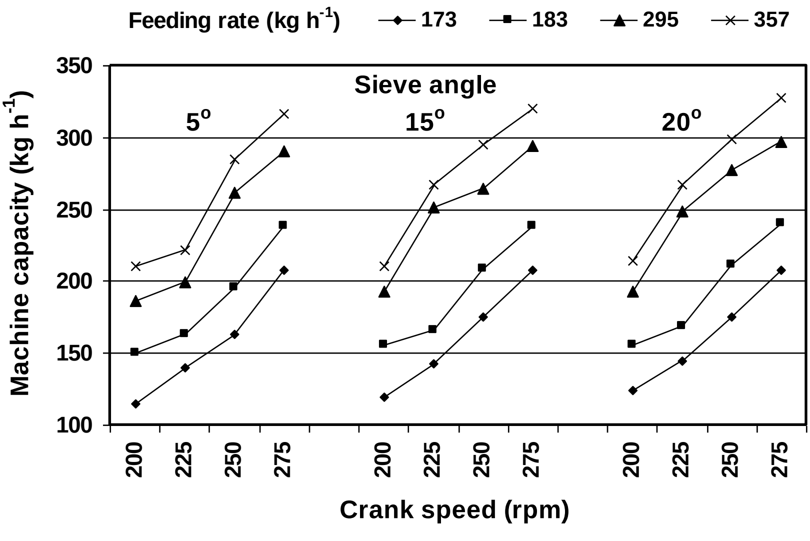

Fig. (10): The effects of crank speed, sieve angle and feeding rate on the machine capacity.

As shown in Fig. (10), as the crank speed decreased, the machine capacity increased. These results may be due to increasing of oscillating movement of sieve that facilitated the material to pass through the opening sieve.

It was found that the machine capacity increased as the feed rate increased at different sieve angles. Also by increasing the sieve angle the machine capacity increased.

3.3 Consumed energy (CE)

The results are shown in Fig. (11), the consumed energy ranged from 1.9 to 5.42 kW h ton^{-1} with crank speed of 200 to 275 rpm, sieve angle of 5^{o} to 20^{o} and the feeding rate of 173 to 357 kg h^{-1}. It could be noticed that the lowest values of consumed energy were obtained at (C_S) 275 rpm and (F_R) 357 kg h^{-1}, however the highest values of consumed energy were obtained at (C_S) 200 rpm and (F_R) 173 kg h^{-1} at different sieve angles.

As shown in Fig. (11), as the crank speed increased, the consumed energy decreased. These results may be due to increasing the grading capacity.

It was found that the consumed energy decreased as the feed rate increased at different sieve angles. Also, as the sieve angle increased, the consumed energy decreased.

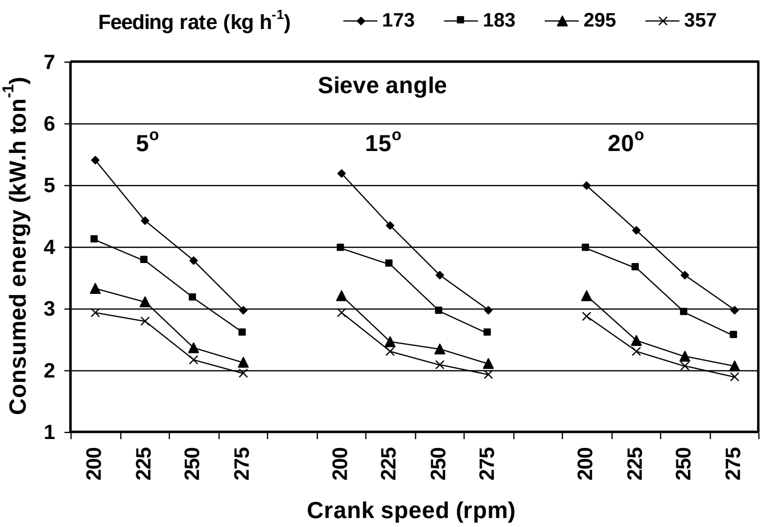

Fig. (11): The effects of crank speed, sieve angle and feeding rate on consumed energy.

The most suitable conditions for machine realizing the best performance that take the best grading efficiency value of 87.97 % - 95.7% were observed at combination of crank speed =225→250 rpm; sieve angle =5→20 degree at different feeding rates.

CONCLUSION

The obtained results can be summarized as follows:

1. Crank speed, feeding rate and sieve angle affected the grading efficiency and capacity of the machine.
2. Grading efficiency increased with the increase of crank speed from 200 to 250 rpm after that decreased, but decreased with increasing in feeding rate and sieve angle.
3. Machine capacity increased with the increase of crank speed, feeding rate and sieve angle.
4. Consumed energy decreased with the increase of crank speed, feeding rate and sieve angle.
5. It is recommended to get the maximum grading efficiency at combination of crank speed = 225→250 rpm and sieve angle = 5→20 degree at different feeding rate.

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الملخص العربى

تصميم وتصنيع وتقييم آلة لإستخلاص اللوز: ٢. وحدة الفصل والتدريج والتنظيف

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عمليات الفصل والتدريج والتنظيف من العمليات المهمة للآلات التي تقوم بإستخلاص اللوز، حيث تم إضافة وحدة خاصة بفصل وتدريج وتنظيف اللوز من أجل إستخدامها فى العمليات التصنيعية، حيث إن الطريقة اليدوية لتنظيف اللوز تحتاج إلى مجهود ومكلفة. تم تقدير بعض الخواص الطبيعية والميكانيكية لحبة اللوز: الأبعاد، الكتلة، الحجم، معامل الاحتكاك الاستاتيكى، السرعة الحرجة والمتعلقة بالعمليات الميكانيكية لعمية التدريج والتنظيف واللازمة لعملية التصميم. تم تصميم وتصنيع وحدة التدريج، والتى تتكون من غرابيل إهتزازية (٢ غربال) تعمل بنظرية عمود المرفق وذراع التوصيل ومجموعة لنقل الحركة بالإضافة إلى محرك كهربائي قدرته ٣ حصان (٢,٢ كيلووات)، والوحدة الأخرى وحدة التنظيف والتى تتكون من مروحة طاردة مركزية تعمل بمحرك خاص بها.ُاختبرت الآلة عند أربعة سرعات مختلفة لعمود المرفق (٢٠٠ ، ٢٢٥ ، ٢٥٠، ٢٧٥ لفة د-١) وأربعة معدلات تغذية (١٧٣ ، ١٨٣ ، ٢٩٥، ٣٥٧ كجم ساعة-١) وثلاثة ميول للغرابيل (٥ ، ١٥ ، ٢٠ درجة). وقدرت كفاءة التدريج، السعة الإنتاجية، والطاقة المستهلكة.

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وقد بينت الدراسة ما يلي:

١. كفاءة التدريج تزداد مع زيادة سرعة عمود المرفق من ٢٠٠ الى ٢٥٠ لفة د$^{-١}$، وتقل مع زيادة معدل التغذية وميل الغرابيل.

٢. إنتاجية الآلة تزداد مع زيادة كلا من سرعة عمود المرفق ومعدل التغذية وميل الغرابيل.

٣. الطاقة المستهلكة تقل بزيادة كلا من سرعة عمود المرفق ومعدل التغذية وميل الغرابيل.

٤. ينصح بتشغيل الآلة على مدى سرعات عمود المرفق من ٢٠٠ الى ٢٥٠ لفة د$^{-١}$ وميل الغرابيل فى المدى من صفر الى ٢٠ درجة عند معدلات التغذية المختلفة.