

FACTORS AFFECTING THE DESIGN OF A GRADING MACHINE FOR EGYPTIAN-LIME FRUITS

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ABSTRACT

The aim of this research is to design a grading machine according to the physical and mechanical properties of lemon fruits.

The main results in this study can be summarized in the following points: The maximum fruit damage of 4.7, 4.1 and 8.9 % for fruit sizes 35, 40 mm and total count, respectively were obtained with grading speed of 8 rpm (0.08 m/s) and fruit batch of 20 kg. Meanwhile, the minimum fruit-damage of zero % for all fruit sizes was obtained with grading speed of 11 - 14 rpm (0.12 - 0.15 m/s) and fruit batch of 5 kg. The maximum range of grading-machine productivity for lemon fruits of 220.7 - 760.9 kg/h was obtained with grading speed range of 5 - 14 rpm (0.05 - 0.15 m/s) and fruit batch of 20 kg. Meanwhile, the minimum range of grading-machine productivity for lemon fruits of 142.8 - 492.3 kg/h was obtained with grading speed range of 5 - 14 rpm (0.05 - 0.15 m/s) and fruit batch of 5 kg.

The operation and production costs were 7.37 L.E./h and 64.84, 19.8 L.E./ton at optimum conditions (grading speed of 11 rpm or 0.12 m/s and fruit batch of 10 kg).

1. INTRODUCTION

Post harvest sorting and grading of fruits is a difficult and labour intensive component of the commercial fresh fruit market.

Citrus are the major horticultural crops in Egypt. The cultivated area of citrus is 346.24 thousand feddans (145.42 thousand hectare) in 2002. The areas of orange, tangerine and lemon are about 210, 94 and 38 thousand feddans (88.2, 39.48 and 15.96 thousand hectare), respectively. The total annual production of citrus in Egypt is about 2.8 million ton, in 2002. The productions of orange, mandarin (*Citrus deliciosa*, Blanco) and lemon are about 181, 602 and 334 thousand tons respectively.

(1), (2) and (3) Chief Res. and Res., Ag. Eng. Res. Inst. Respectively.

The lemon is considered to be one of the most alkalizing foods.

In Egypt, there are various mandarin varieties different in their productivity, fruit maturity and quality. Alternate bearing is one of the most disadvantages in Baladi mandarin, beside great number of seeds per fruit and small fruit size.

Abd-Alla et al. (2000) reported that:

- 1- The grading efficiency decreased with increasing both fruit feeding speed and tilt angle of grading unit.
- 2- The grading efficiency increased with the increase of critical distance from 0.04 to 0.1 m and start to decrease at critical distance of 0.13 m.
- 3- The mass-grading machine consumes an average power of 0.0084 kW for potato varieties and 0.001 kW for orange variety.
- 4- The total cost of grading one ton of potato varieties was 13.15 L.E. in comparison with 9.05 L.E. for orange.

Mousa (1998) found that the mean values of diameter ranged from about 28.1 to 41.4; height ranged from about 26.7 to 40 mm; mass ranged from about 15 to 35 g; volume ranged from 17 to 40 mm³ for Egyptian lime. The height values limited the distance between grading lines and shape and size of the distributed buckets on the conveyor belt. According to that, the grading-pipes design was: the distances between two pipes for grading lime are 20 and 50 mm at the beginning and ending of grading line.

Mousa (1998) designed and tested a cylinders grading-machine for citrus. The optimum conditions were: grading speed of 70 rpm (0.37 m/s), and tilt angle of grading unit of 3 – 6° which gave 4.2 ton/h, grading efficiencies of 56 and 44 % for two sizes.

Amin (1994) developed and tested a grading machine consisting of rotating cylinder and perforated concave to grade potato, onion and orange crops. The obtained results showed that crop parameters such as (cell area and shape, drum speed, slope of drum axle and drum length) have a significant effect on grading efficiency. The capacity of machine at optimum drum speed of 25 r.p.m. and slope of zero degrees was 1.2 Mg/h with tuber damage of 0.23%.

Radwan (2000) reported that the grading efficiency decreased with increasing both fruit feeding speed and tilt angle of grading unit. However, the grading efficiency increased with the increase of critical distance from 0.04 to 0.1m and start to decrease at critical distance of 0.13 m.

Yehia (2001) studied the physical and mechanical properties of Ponkan mandarin and used them to give a design idea of the grading machine as a case study. The theoretical calculations were:

Revolving drums with holes are used to grade the fruits to 5 sizes.

Drum hole diameters = 40, 50, 60, 70 and 80 mm, No. of drums to suit No. of Ponkan mandarin categories = 5, Rotating drums with holes diameter and length to suit machine productivity = about 40 – 50 cm diameter and 100 cm length, Drums tilt-angle = more than maximum rolling angle between Ponkan mandarin fruits and stainless steal surface = more than 24° .

The objective of present research is to study some physical and mechanical properties of Egyptian lime, as a data base to help the design of handling machines. The physical and mechanical properties are incorporated in the development of the grading machine as a case study.

2. MATERIALS AND METHODS

2.1. Fruits.

Lemon crop "Egyptian lime" variety was considered in this study. All measurements were done using a random sample of 100 fruits. The samples were taken randomly from lemon trees (special farm in El Qanater El Khairia at acceptable harvesting date) and from "El Oboor" (سوق العبور) Market; and the measurements were taken in the same day.

2.2. Designed grading-machine.

The designed grading machine for lemon fruits consists of the following parts (fig. 1):

2.2.1. Fruit box: made of wood sheet with thickness of 6 mm, top dimensions of 350 x 330 mm and bottom dimensions of 350 x 80 mm. The rear side of hopper has the angle with horizontal plane of 60 degree (fig. 2a).

2.2.2 Fruit bin: made of wood sheet with thickness of 24 mm and dimensions of 800 x 525 x 270 mm (fig. 2b). The fruit box was supported

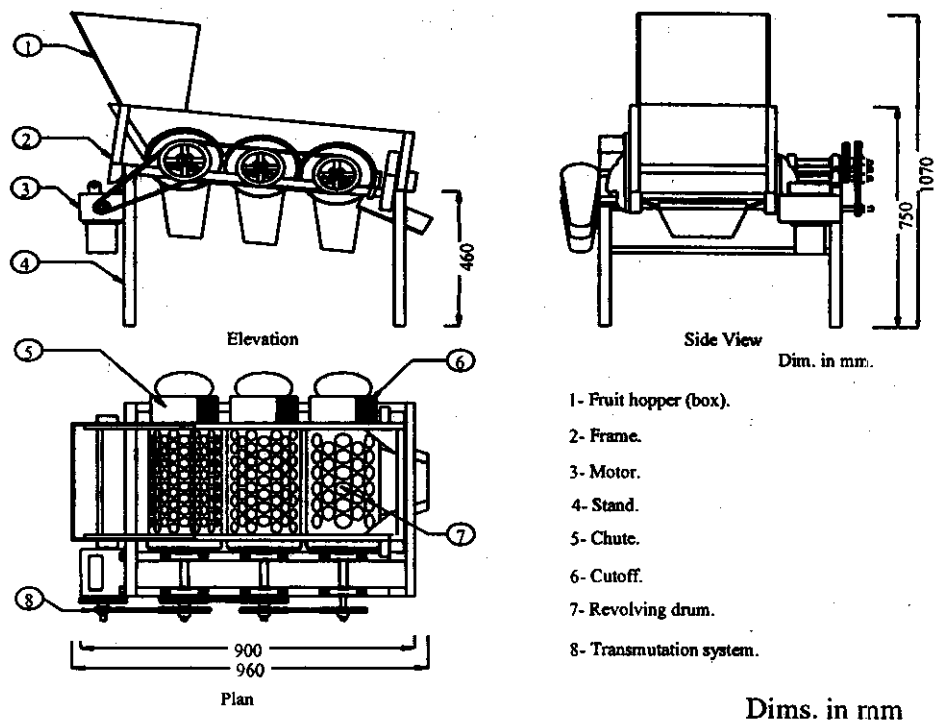


Fig. 1: Views of designed grading-machine for lemon fruits.

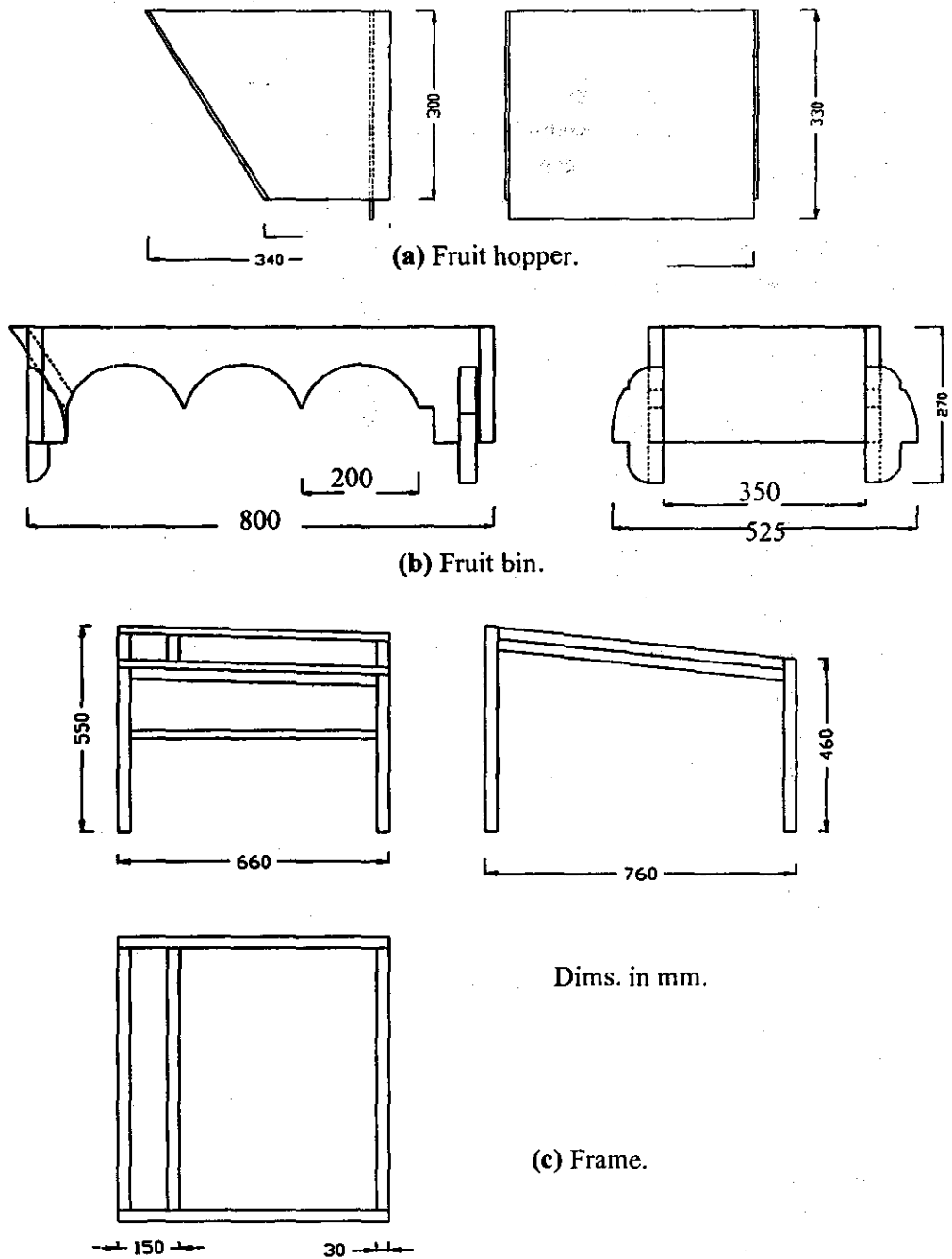


Fig. 2: Views of fruit hopper, fruit bin and machine frame.

with rear side of fruit bin by two bolts. The rear side of the fruit bin is inclined with horizontal plane by 7° .

2.2.3. Frame: made of iron angles with dimensions of 30 x 30 x 3 mm (fig. 2c). The frame has length of 760 mm, width of 660 mm and rear height of 550 mm and front height of 460 mm. The frame is inclined to front direction (grading-direction) by 7° .

2.2.4. Grading revolving-drums: three revolving drums made of PVC with diameter of 200 mm and length of 430 mm, thickness of 4 mm and spacing 6 mm (fig. 3a). The three grading-drums have holes diameter of 35, 40 and 45 mm and number of holes of 111 104 and 77 respectively. Iron metal-sheet of 35 mm length, 32 mm width and 1.5 mm thickness was assembled upper grading-drums spacing and bolted on two sides of fruit bin.

2.2.5. Fruit cutoff and chute: made PVC sheet with length of 450 mm and width of 160 mm (fig. 3b). Three fruit cutoffs were passed inside the three grading drums and were hinged with left side of frame by cantilevers. The fruits roll on the concaved part of cutoff (chute) and drop into funnels. The curved part prevents the jamming of fruits. The total inclined-angle of cutoff and chute is 11.5° .

2.2.6. Transmission system and motor: consist of motor of 0.3 hp (225 kW) and chains and sprockets as shown in fig. 4.

2.6. Design steps and specifications of components of the grading machine:

Fig. 5 shows a schematic diagram of the designed grading-machine. Parameters shown on the figure are essentially those to be determined for lemon through this work, for modifying the grading machine to operate efficiently on this fruit.

The physical and mechanical properties are incorporated in the design of the fruit hopper, revolving drums with holes (length and diameters of drums, diameter of holes, and number of holes) and exit chute of the designed grading-machine as follows:

3.3.1. Fruit hopper (Fig. 5):

Hopper dimensions: to suit feeding rate and bulk density of fruits = top dimensions of 350 x 330 mm and bottom dimensions of 350 x 80 mm.

Fruit hopper side-slope = more than maximum friction angle of lemon fruits with wood surface ($> 43^\circ$) = 60° .

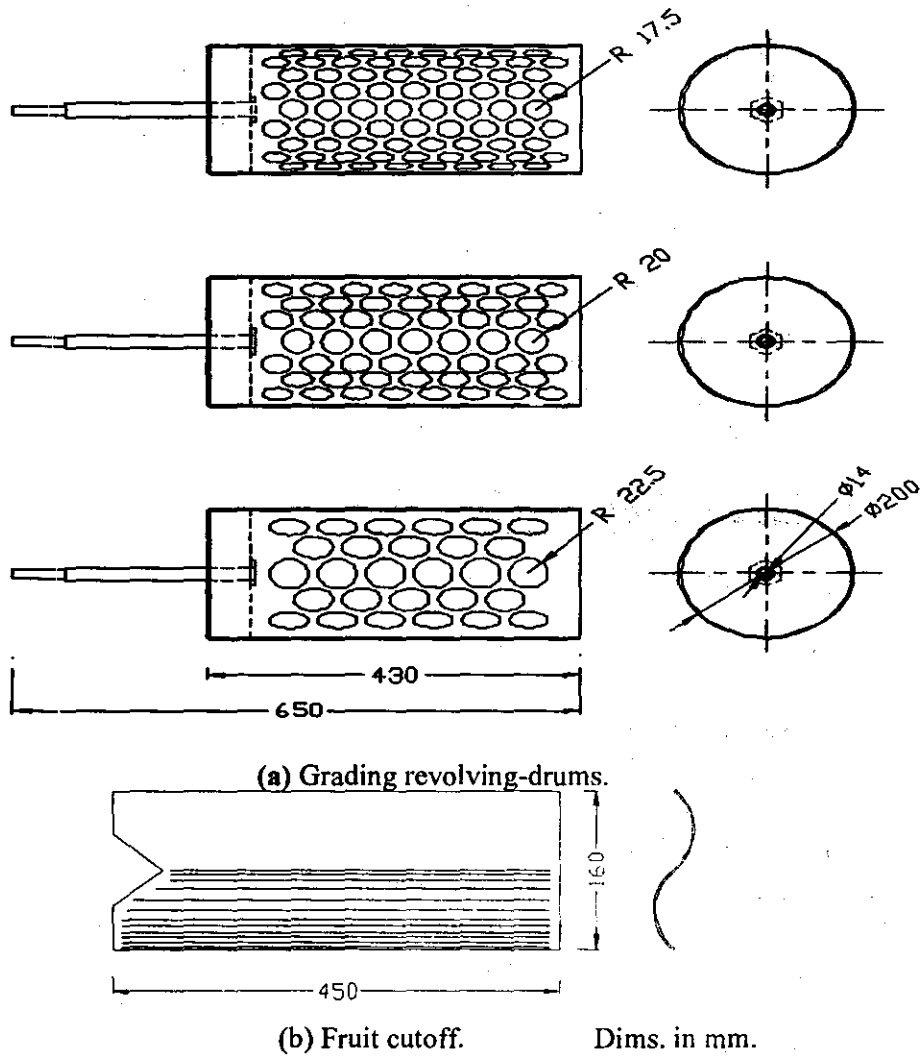


Fig. 3: Views of grading revolving-drums and fruit cutoff.

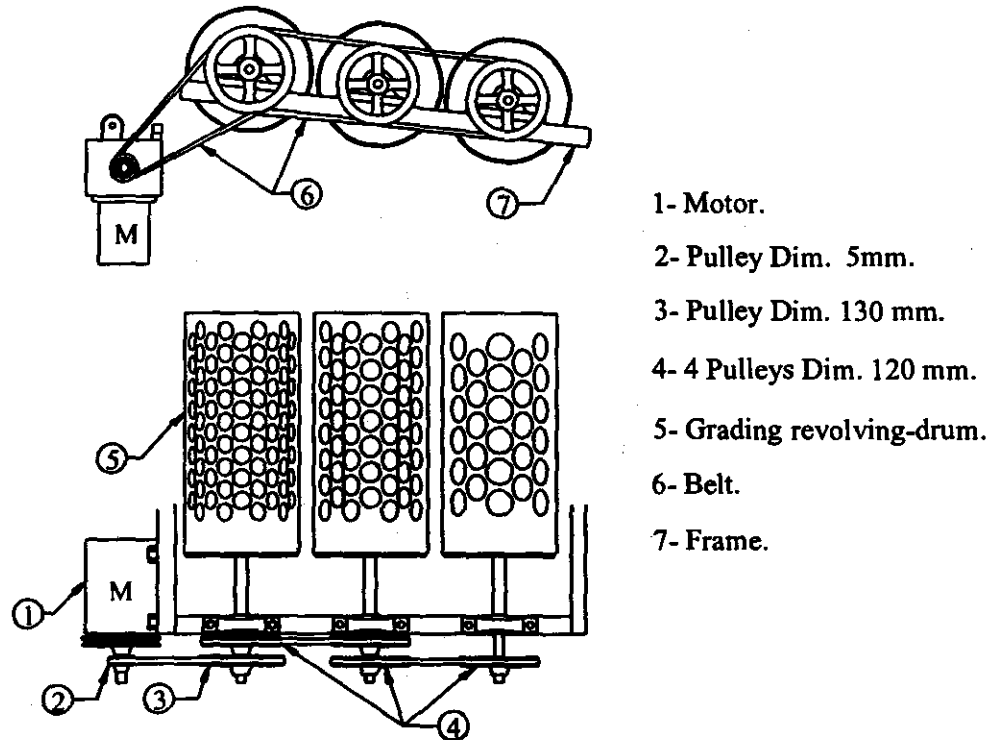


Fig. 4: Views of grading transmission system of grading machine.

3.3.2. Grading drums:

Revolving drums with holes are used to grade the fruits to 3 sizes.

Drum hole diameters = 35, 40, and 45 mm. The fruit > 45 mm exit from the end of the machine.

No. of drums to suit No. of lemon categories = 3.

Rotating drums with holes diameter and length to suit machine productivity = about 20 cm diameter and 100 cm length.

Drums tilt-angle at fruit exit direction = more than maximum rolling angle between lemon fruits and PVC surface = more than 24° .

Drums tilt-angle at drum-motion direction (found experimentally) = 7° .

3.3.3. Fruit cutoff and chute:

Fruit chute tilt-angle = more than maximum rolling angle between lemon fruits and PVC surface = more than $24^{\circ} = 25^{\circ}$.

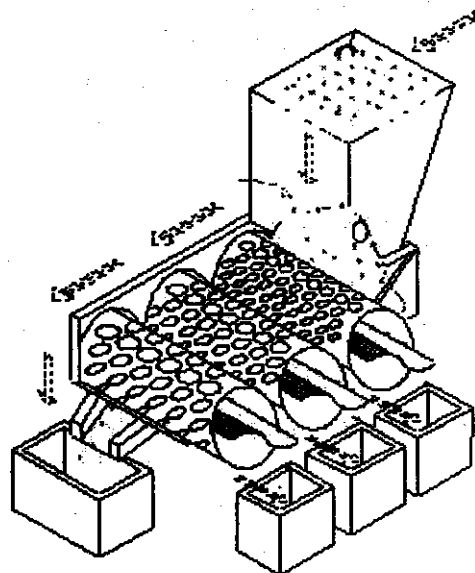


Fig. 5 : Schematic diagram of the designed grading-machine, with the numbers in brackets indicating parameters necessary for design of different parts.

Associated parameters:

(1) Fruit dimensions, (2) Bulk density, (3) Friction and rolling angles, (4) Fruit mass, and (5) Fruit firmness.

2.3. Instrumentation:

2.3.1. Digital caliper with vernier: with accuracy of 0.01 mm, to measure different dimensions of limon fruits.

2.3.2. Digital balance: with accuracy of 0.2 g, to measure mass of Ponkan-mandarin fruits and constituents (peel, seeds and juice).

2.3.3. Graduated cylinder: of 1000 mL with accuracy of 25 mL to determine the real density and volume of fruit by immersion in water.

2.3.4. Friction and rolling-angle measuring device: An inclined plane was used to measure friction and rolling angles.

2.3.5. Friction angle measurement: the fruits are placed as a group bounded together on a horizontal surface then the angle of inclination is gradually increased until the fruits begin sliding without rolling. For each fruits group of an average sample of (10), the friction angles were determined.

2.3.6. Rolling angle measurement: the fruits are placed on a horizontal surface one by one then the angle of inclination is gradually increased until the fruits begin roll. For each fruit of an average sample (50), two angles of rolling are determined: for the maximum stable (with their base down) and minimum stable positions.

2.3.7. Penetrometer: Penetrometer, made in Italy, with accuracy of 0.1 N was used to measure penetration force of lemon fruits. The firmness of fruit was obtained by dividing the penetration force by the area (0.28 cm²) of cylindrical probe, which had 0.6 cm diameter.

2.4. Studied factors and measurements:

The studied factors of designed grading-machine were:

(1) **Grading speed:** Four different grading speeds 5, 8, 11 and 14 rpm (0.05, 0.08, 0.12 and 0.15 m/s).

(2) **Fruit batch:** Four different feed rates of 5, 10, 15 and 20 kg.

The measurements were: (1) grading efficiency, (2) fruit damage and (3) grading productivity.

2.5. Equations and calculations:

The following equations were used to calculate sphericity, projected area and real density according to **Mohsenin, 1986**.

Sphericity ratio = fruit height (H) / fruit diameter (D) ----- (1)

Projected area = 4/π (D * H) ----- (2)

Real density = Mass / Volume ----- (3)

Grading productivity: Was calculated by using the following formula according to **Amin (1994)**:

$$P = \frac{3600 * M}{T} \text{ ----- (4)}$$

Where: P = Grading productivity, kg/h.

M = Mass of sample, kg and

T = Time in seconds.

Grading efficiency: The grading efficiency (μ) of each outlet has been calculated according to Amin (1994) as follows:

$$\mu_1 = M_{o1}/M_{i1}, \mu_2 = M_{o2}/M_{i1}, \mu_3 = M_{o3}/M_{i1}, \text{ and } \mu_4 = M_{o4}/M_{i1} \text{ -----(5)}$$

Where: μ_1, μ_2, μ_3 and μ_4 : Grading efficiency of fruits for each outlet in the machine, %.

M_{i1}, M_{i2}, M_{i3} and M_{i4} : Mass of each class inside fruit hopper, kg and

M_{o1}, M_{o2}, M_{o3} and M_{o4} : Mass of the fruit for each outlet in the machine, kg .

Total grading efficiency: The total grading efficiency machine (μ) has been calculated using the following equation:

$$\mu = (\mu_1 + \mu_2 + \mu_3 + \mu_4) / 4 \text{ -----(6)}$$

Mechanical damage: Percentage of mechanical damage was calculated by using the following formula:

$$Df = \frac{N_d}{N_t} \times 100 \text{ -----(7)}$$

Where: N_d = Number of damaged fruits and

N_t = Total number of fruits.

Estimating the costs of using the machine: The operation cost of washing machine was calculated according to the following equation given by Awady, 1978 (updating 1998) modified for electrical motor drive:

$$C = P/h(1/a + I/2 + t + r) + (w.e) + m/144 \text{ ----- (8)}$$

Where: C = hourly cost, P = price of machine, h = yearly working-hours, a = life expected of machine, I = interest rate/year, t = taxes and overhead ratio, w = power of motor in kW, e = hourly cost/kW.h, and m/144 = monthly wage ratio.

Notice that all units have to be consistent to result in "C = LE/h".

Operating cost (L.E./ton) = machine cost (LE/h) / machine productivity (ton/h)

3. RESULTS AND DISCUSSION

3.1. Physical properties of lemon fruits.

Table 1 shows dimensions, sphericity, mass, volume, real density and projected area, lemon fruits. These data were measured on 100 fruit sample, according to the standards set in (Mohsenin, 1986).

Table 1: Physical properties of lemon fruits.

Physical properties	Max.	Min.	Average	S. D. ⁽¹⁾	C. V. ⁽²⁾
Height, mm	43	27	36	4.36	12.12
Diameter, mm	49	28	38.3	5.73	14.93
Sphericity	1.1	0.9	0.9	0.06	5.97
Mass, g	50	15	29.7	10.32	34.75
Volume, cm ³	45	17	28	8.51	29.83
Bulk density, g/cm ³	0.59				
Real density, g/cm ³	1.1	0.7	0.9	0.15	16.62
Projected area, cm ²	27	4.7	10	4.68	26.17

(1) S. D. is standard deviation.

(2) C. V. is coefficient of variation.

3.1.1. Dimensions of fruit:

Fig. 6 indicates that the fruit diameter and height ranges of sample were 30 - 50 mm (average 38.35 mm) and 30 - 45 mm (average 36.01 mm) respectively. The most frequent percent (80 %) of lemon fruits in the sample have 40 - 50 mm diameter and (90 %) of lemon fruits in the sample have 35 - 45 mm height.

3a2. Shape and size of fruit:

If sphericity is less than 0.9, the fruit belongs to oblate group; if sphericity is greater than 1.1, it belongs to oblong group. The remaining fruits with intermediate index values are considered to be round (Buyanov and Voronyuk, 1985). Fig. 7 indicates that the fruit sphericity ranged in sample between 0.9 and 1.1. The most frequent percent (100 %) of lemon fruits in the sample was round (sphericity 0.9 - 1.1).

3a3. Mass and volume of fruit:

Fig. 8 indicates that the fruit mass and volume ranges of sample were 15 - 50 g (average 29.7 g) and 17 - 45 cm³ (average 28 cm³) respectively. The most frequent percent (70 %) of lemon fruits in the sample had 30 - 40 g mass and (80 %) had 20 - 40 cm³ volume.

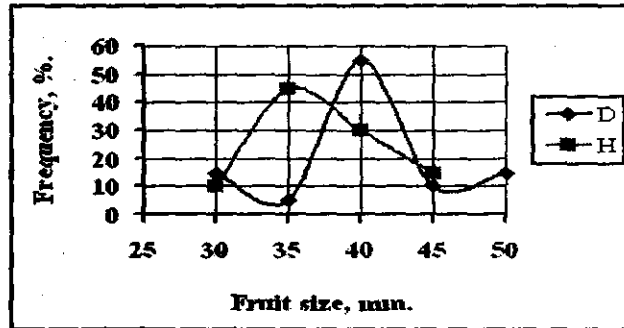


Fig. 6 : Frequency curves distribution of fruit dimensions (diameter "D" and height "H").

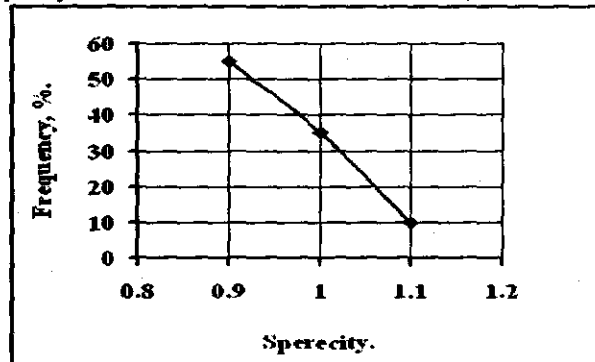


Fig. 7: Frequency curves distribution of fruit sphericity of lemon fruits.

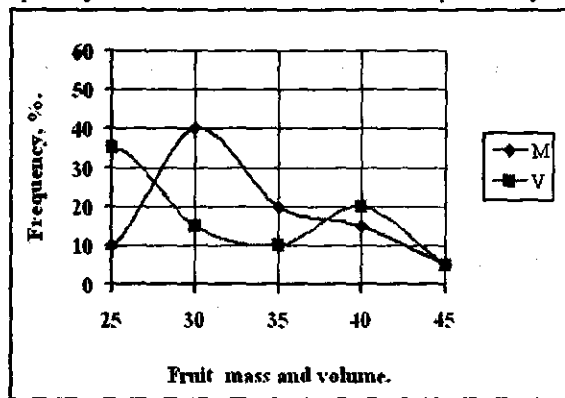


Fig. 8: Frequency curves distribution of fruit mass and volume of lemon fruits.

3.2. Mechanical properties of lemon fruits:

3.2.1. Friction, rolling and repose angles of lemon fruits:

Table 2 shows friction and rolling angles of lemon fruits. The maximum friction angle (38 - 43 degree) and rolling angle ranges (23 - 32 degree) were obtained with wood surface. Whereas, the minimum range of friction angle of 14 - 16 was obtained with PVC surface and minimum rolling angle of 10 - 24 was obtained with aluminium surface.

Table 2: Friction and rolling angles for lemon fruits with different surface types.

Surface type	Friction angle, degree			Rolling angle, degree					
	Max.	Min.	Av.	Maximum			Minimum		
				Max.	Min.	Av.	Max.	Min.	Av.
Wood	43	38	40	32	23	28	22	17	20.5
Metal	17	15	15.2	24	23	22.4	14	11	12.5
Galv. I.	17	15	14.6	24	23	22.6	14	11	12.7
Alum.	17	14	14.4	24	21	22.2	14	10	12.3
SS	17	15	14.5	24	23	21.3	14	11	12.4
PVC	16	14	14.0	24	23	21.1	14	11	12.4

Wood: wood sheet No. 2; Galv. I.: Galvanized iron; Alum.: Aluminium; and SS.: Stainless steel.

The average repose-angle was about 38.8 degree.

3c. Effect of grading speed and fruit batch on grading efficiency:

Fig. 9 shows the effect of grading speed and fruit batch on grading efficiency of four fruit-sizes.

The maximum grading efficiencies of 91.8, 93, 94.4, 100 and 94.8 % for fruit sizes 35, 40, 40, > 45 mm and total respectively were obtained with grading speed of 11 rpm (0.12 m/s) and fruit batch of 5 kg. Mean while, the minimum grading efficiencies of 76, 81.3, 82.7, 100 and 81.1 % for fruit sizes 35, 40, 40, > 45 mm and total respectively were obtained with grading speed of 14 rpm (0.15 m/s) and fruit batch of 20 kg. The

decreasing of grading efficiency by increasing grading speed and fruit batch is due to decreasing the time of grading and accumulating of fruits on drum holes respectively.

3.4.Effect of grading speed and fruit batch on fruit damage:

Table 3 shows the effect of grading speed and fruit batch on fruit damage of four fruit-sizes. The maximum fruit damage of 4.7, 4.1 and 8.9 % for fruit sizes 35, 40 mm and total respectively were obtained with grading speed of 8 rpm (0.08 m/s) and fruit batch of 20 kg. Meanwhile, the minimum fruit-damage of zero % for all fruit sizes was obtained with grading speed of 11 - 14 rpm (0.12 - 0.15 m/s) and fruit batch of 5 kg.

The caused fruit-damage by using grading speed of 5 and 8 rpm (0.05 and 0.08 m/s) is due to fruit jamming between fruit cutoff and grading drum.

3.4. Effect of grading speed and fruit batch on machine productivity:

Fig. 10 shows the effect of grading speed and fruit batch on grading-machine productivity. The maximum range of grading-machine productivity for lemon fruits of 220.7 – 760.9 kg/h was obtained with grading speed range of 5 - 14 rpm (0.05 – 0.15 m/s) and fruit batch of 20 kg. Meanwhile, the minimum range of grading-machine productivity for lemon fruits of 142.8 – 492.3 kg/h was obtained with grading speed range of 5 - 14 rpm (0.05 – 0.15 m/s) and fruit batch of 5 kg. The increasing of grading-machine productivity by increasing grading speed and fruit batch is due to decreasing the time of grading and fruit mass respectively.

3f. Cost of using the designed grading-machine.

Table 4 shows the components of the Awady equation. The operation and production costs were 7.37 L.E/h and 64.84, 19.8 L.E./ton at optimum conditions (grading speed of 11 rpm or 0.12 m/s and fruit batch of 10 kg).

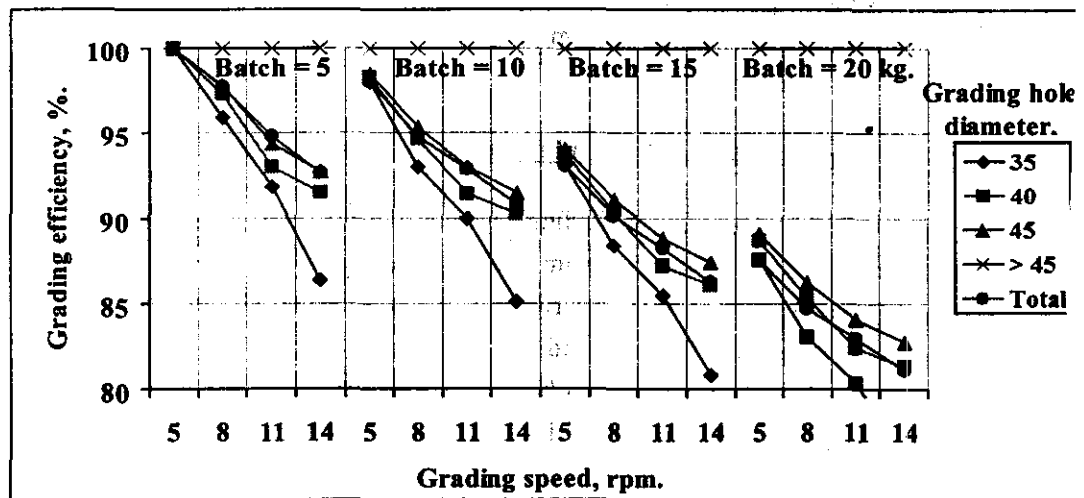


Fig 9 : Effect of grading speed, hole diameter of grading drums and fruit batch on machine grading-efficiency.

Table 3: Effect of grading speed, fruit batch-mass and fruit size on fruit damage.

Fruit batch, kg	Grading speed, rpm.	Fruit damage, %.				
		Fruit diameter, mm.				
		35	40	45	> 45	Total
5	5	3.1	3.5	0.0	0.0	6.6
	8	4.1	3.5	0.0	0.0	7.6
	11	0.0	0.0	0.0	0.0	0.0
	14	0.0	0.0	0.0	0.0	0.0
10	5	3.2	3.6	0.0	0.0	6.8
	8	4.2	3.6	0.0	0.0	7.8
	11	0.0	0.0	0.0	0.0	0.0
	14	0.0	0.0	0.0	0.0	0.0
15	5	3.4	3.8	0.0	0.0	7.2
	8	4.4	3.9	0.0	0.0	8.3
	11	0.0	0.0	0.0	0.0	0.0
	14	0.0	0.0	0.0	0.0	0.0
20	5	3.6	4.1	0.0	0.0	7.7
	8	4.7	4.1	0.0	0.0	8.9
	11	0.0	0.0	0.0	0.0	0.0
	14	0.0	0.0	0.0	0.0	0.0

Table 4: The components of Awady equation.

p, L.E.	h, h	a, year	i	t	r	Ec, kW.h/h	Ep, L.E.	m, L.E.
2000	1500	10	0.075	0.05	0.03	0.4	0.25	1000

$$C = 2000/1500 * (0.1 + 0.035 + 0.05 + 0.06) + 0.4 * 0.25 + 1000/144$$

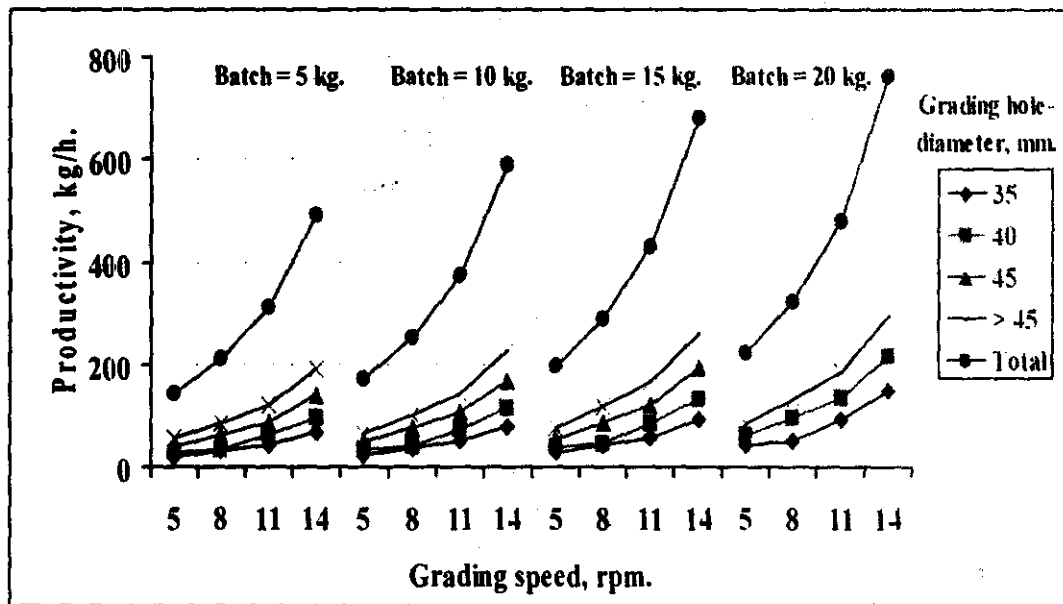


Fig. 9: Effect of grading speed, hole diameter of grading drums and fruit batch on machine grading-productivity.

CONCLUSION

The main results in this study can be summarized as follows:

The maximum fruit damage of 8.9 % was obtained with grading speed of 8 rpm (0.08 m/s) and fruit batch of 20 kg. Meanwhile, the minimum fruit-damage of zero % was obtained with grading speed of 11 - 14 rpm (0.12 - 0.15 m/s) and fruit batch of 5 kg. The maximum range of grading-

machine productivity for lemon fruits of 220.7 – 760.9 kg/h was obtained with grading speed range of 5 - 14 rpm (0.05 – 0.15 m/s) and fruit batch of 20 kg. Meanwhile, the minimum range of grading-machine productivity for lemon fruits of 142.8 – 492.3 kg/h was obtained with grading speed range of 5 - 14 rpm (0.05 – 0.15 m/s) and fruit batch of 5 kg. The operation and production costs were 7.37 L.E./h and 64.84. 19.8 L.E./ton at optimum conditions (grading speed of 11 rpm or 0.12 m/s and fruit batch of 10 kg).

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الملخص العربي

عوامل مؤثرة في تصميم آلة لتدريج الليمون

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تمثل الموالح في مصر المرتبة الأولى من حيث الأهمية والمساحة المنزرعة، ويعتبر الليمون المصري من أهم وأكثر أصناف الموالح نجاحاً تحت ظروف الأراضي الرملية الحديث الاستصلاح

تهدف هذه الدراسة إلى تصميم آلة لتدريج ثمار الليمون باستخدام الخواص الطبيعية لها، وتتكون الآلة من صندوق للثمار، ثلاث أسطوانات تدريج ذات تقوَب على محيطها (أقطار التقوَب ٣٥، ٤٠، ٤٥ مم)، وموانع حشر للثمار ومنحدرات لتجميع الثمار. وتم دراسة تأثير سرعة التدريج (٥، ٨، ١١، ١٤ لفة/د) وكمية وجبة ثمار (٥، ١٠، ١٥، ٢٠ كج) على الإنتاجية والتلف وكفاءة التدريج. وتم الحصول على النتائج التالية:

(١) تأثير سرعة أسطوانات التدريج وكمية الثمار على كفاءة التدريج: تأثير السرعة وكمية الفاكهة على كفاءة تدريج الثمار لأربعة أحجام للثمار.

وجد أن كفاءات تدريج الثمار القصوى ٩١.٨، ٩٣، ٩٤.٤، ١٠٠، ٩٤.٨ و ٩٤.٨ % لحجوم الفاكهة ٣٥، ٤٠، ٤٥، < ٤٥ ملليمتر والمجموع على التوالي حُصلاً عليه بتصنيف سلع السرعة من ١١ لفة/د. (٠.١٢ م/ث) وكمية فاكهة ٥ كج. في هذه الأثناء، كفاءات تدريج الثمار الدنيا ٧٦، ٨١.٣، ٨٢.٧، ١٠٠، ٨١.١ و ٨١.١ % لحجوم الفاكهة ٣٥، ٤٠، ٤٥، < ٤٥ ملليمتر ومجموع على التوالي حُصلاً عليه بتدريج الثمار بسرعة من ١٤ لفة/د. (٠.١٥ م/ث) وكمية ثمار ٢٠ كج. كفاءة تدريج الثمار تنقص بزيادة سرعة تدريج الثمار ومعدل التغذية.

(١)، (٢)، (٣) أستاذ دكتور بقسم الهندسة زراعية ك. زراعية - ج. القاهرة . ورئيس بحوث، و باحث على الترتيب، معهد بحوث الهندسة الزراعية.

(٢) تأثير سرعة أسطوانات التدريج وكمية الثمار على التلف: وجد أن أقصى ضرر للفاكهة من ٤.٧، ٤.١ و ٨.٩ %، للحجوم الفاكهة، ٤٠٣٥ ملليمتر، حُصِلَ عليه بالسرعة من ٨ لفة/د. (٠.٠٨ م/ث) ودفعة فاكهة من ٢٠ كج. في هذه الأثناء، أقل ضرر للفاكهة صفر % لكل الاحجام، بحجم حُصِلَ عليه بالسرعة من ١١ لفة/د. (٠.١٢ م/ث)، ودفعة فاكهة م ٥ كج

(٣) تأثير سرعة أسطوانات التدريج وكمية الثمار على الإنتاجية: وجد أن الحد الأقصى لتصنيف ملع معدل إنتاجية الآلة للثمار ٢٢٠.٧ - ٧٦٠.٩ كج/س على التوالي، حُصِلَ عليه بمدى سرعة ٥ - ١٤ لفة/د. (٠.٠٥ - ٠.١٥ م/ث) ودفعة فاكهة من ٢٠ كج. في هذه الأثناء، الحد الأدنى لتدريج الثمار بمعدل إنتاج للثمار الليمون ١٤٢.٨ - ٤٩٢.٣ كج حُصِلَ عليه لتدريج الثمار بمدى سرعة ٥ - ١٤ لفة/د. (٠.٠٥ - ٠.١٥ م/ث) ودفعة فاكهة ٥ كج.

(٣) تكاليف استخدام الآلة: وجد أن تكلفة الإنتاج والعملية كانا ٧.٣٧ جنية/س و ٦٤.٨٤، ١٩.٨ جنية/طن في الشروط القسوية (تصنيف ملع سرعة من ١١ لفة/د. أو ٠.١٢ م/س ودفعة فاكهة من ١٠ كج).