DEVELOPMENT AND EVALUATION OF AN OLIVE OIL EXTRACTING MACHINE

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Abstract

A study was carried out to develop and evaluate an olive oil extracting machine. The developed machine included washing, crushing and hydraulic press units. The optimum operating condition, machine capacity, working efficiency and energy consumption for the machine units were measured and evaluated for different oil, dual purpose and mixed varieties of olive. The results show that, the average working capacity for the machine was 197.1 kg/h. While, the energy consumption for the washing and crushing units was 2.53 kW.h., and it was 8.13 kW.h for the hydraulic press unit. On the other hand, the extraction efficiency of the hydraulic press unit was varied from 84.49 to 98.33% for the pure varieties and from 87.96 to 91.81 % for the mixed varieties. Which means that, mixing of different varieties does not affect the extraction efficiency of the hydraulic press unit. In general the developed machine was proved to work satisfactorily for the pure and the mixed varieties considering working capacity, efficiency and energy consumption.

INTRODUCTION

Olive oil in the olive fruits presents as tiny drops of oil in the vacuoles of the mesocarp cell. The mechanical extraction of oil from olives is made possible by the right steps aimed at freeing the tiny drops of oil contained in each cell of the olive pulp.

The most important of these steps is grinding (or crushing) the olives. This causes breakage in varying degrees of depth of the olive cells by using granite grinding stone mill or metal crushers spinning at high speed.

Size reduction includes cutting, crushing and grinding is brought about by mechanical means without change in chemical properties of the material. After the grinding of the olives, mixing process is executed in order to prepare the obtained paste for the subsequent separation of the liquid phase from the solid phase. (Kiritsakis 1991, Mccabe *et al.* 1993, Di Giovacchino 1999 and Owies, 2003).

Pressure, centrifugation or combination process may be applied for the separation of olive oil from the olive paste (Bockisch 1993a).

The choice of olive grinding, mixing and separation or (extraction) methods a side from the cost of different machines, should take the following factors into consideration: the organoleptic quality of the oil, and the oil mill's processing capacity.

Kiritsakis (1991) stated that, mixing process of the olive paste is a very basic step for all extraction systems. It aids in coalescing of small oil drops into larger ones, and facilitating the separation of the oil and water phases. For better efficiency, mixers have double walls, or interior tubing for the circulation of the heating water, wherever increasing the temperature causes change in the viscosity of the oil and greater olive oil yield.

Earle (1983) mentioned that, hammer mills can deal with slab cakes and cut green crops as well as coarse grains. The hammer mill, swinging heads are attached to a rotor which rotates at high speed inside a hardened casing. The material is crushed and pulverized between the hammers and the casing, and remains in the mill until it is fine enough to pass through a screen forms the bottom of the casing.

Brennan *et al.*, (1990) reported that, in hammer mills, size reduction is mainly due to impact forces, although undercook feeding condition. Attrition forces can also play a part in the size reduction. The hammers are often replaced by cutters, or by bars as in the better bar mill.

Arambarri (1992), showed that, the oldest and most widely used procedure for extracting oil from olives in the olive oil producing countries has been the pressure separation. He also added that, from the earliest time until the present day, the equipment used has been developed very slowly due to a series of cultural, social and economic reasons.

Bockisch (1993b), reported that, traditional pressing is a discontinuous process. The olives are ground up in stone mills and the pulp is then beaten in special mills that favors the further decomposition of the cell constituents in the pulp and enlarging the oil droplets contained.

Mendosa (1999) stated that, in many countries presses still exit based on methods that are classified as manual pressure separation (traditional method), and hydraulic presses separation (modern method). The manual pressure separation methods represent about 34% of pressure systems while the hydraulic presses separation represents 66%.

The present study aims to develop and evaluate an olive oil extracting machine. The evaluation bases included, machine capacity, working efficiency and energy consumption of the machine units using different olive varieties (dual purpose, oil cultivars, and mixed varieties).

THEORETICAL ANALYSIS

1. Calculations of The Hammer Mill (Crusher):

Dimensions and capacity of the feeding auger:

The moving quantity of olive fruits by the feeding auger should be corresponded with the capacity of the designed hammer mill which was suggested to be around 200 kg/h. The auger dimensions such as (D_5) outer diameter, (D_6) auger shaft diameter, and (P_1) auger pitch were determined based on the variations in physical properties of the investigated varieties (Matouk, 2007). These dimensions were assumed to be 8, 12.5, and 6 cm respectively. While, the feeding auger capacity (Q) was calculated according to El-Sahrigi, (1997) as follows:

$$Q = 60\frac{\pi}{4}(D_5^2 - D_6^2)P_1\,\rho\eta n \quad \text{.........................(1)}$$

where:

ρ = Average bulk density of olive fruits, kg/m^3.

η = Auger conveying efficiency, %.

n = rotating speed of the auger, rpm.

The average auger conveying efficiency for different studied varieties was laboratory estimated to be about 0.75 and the average bulk density of different studied varieties was about 611.028 kg/m^3. Therefore, both of the auger capacity or rotational speed could be estimated by knowing one of them using the following equation:

$$Q = 0.000263\,\rho\,\eta\,n \quad \text{.................... (2)}$$

Dimensions of the hammer mill unit:

As shown in fig (1) the dimensions of the hammer mill include, diameter of the crusher inlet orifice (D_4), diameter of the hammers (D_3), diameter of the concave screen (D_2), diameter of the crusher body (D_1), and the crusher width (W_h). The remaining dimensions such as hammer length (L_h) and hammer mass (m) were designed according to the force affecting the end of the hammer to reduce the size of the olive fruits (shear force or impact force which is bigger).

When the maximum shear force of the investigated fruits equal to the kinetic force at the end of the hammer, the above parameters could be calculated as follows:

$$Fs = m\,v^2/2r \quad \text{.................. (3)}$$

where:

Fs = shear force of the olive fruits, N,

m = mass of the hammer, Kg,

v = peripheral speed of the hammer, m/s,

r = radius of the hammer, m.

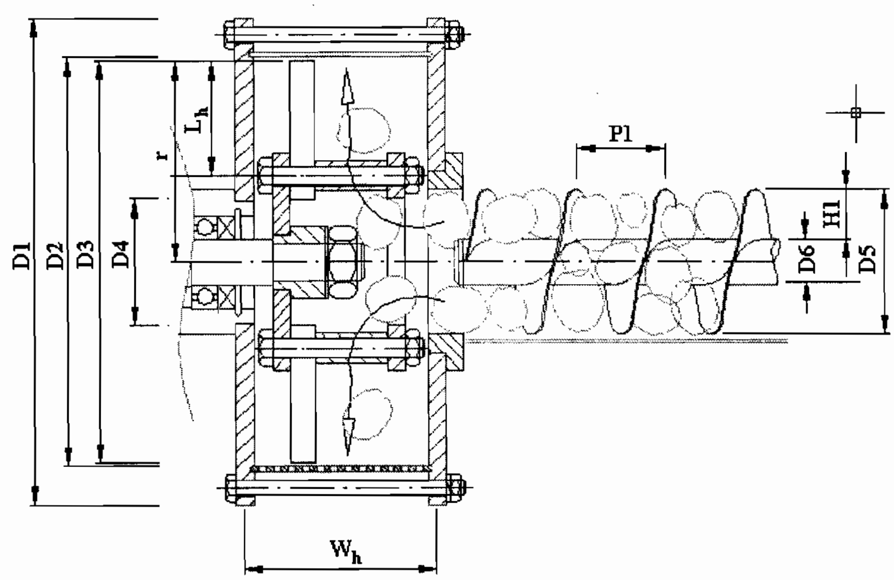


Fig. 1. Dimensions of the hammer mill unit

Also, calculations of the hammer radius and the hammer mass could be described as follow:

$$r = \frac{m\ v^2}{2\ Fs} \quad \ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots \ldots\ldots (4)$$

$$m = \frac{2\ Fs\ x\ r}{v^2} \quad \ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots \ldots (5)$$

Peripheral and rotational speed of hammers:

In the present study the proper peripheral speed of the hammers was calculated according to eq. (3). After determining the hammers dimensions, the peripheral speed of the hammer mill could be calculated using the following equation:

$$v = \sqrt{\frac{2 Fs x r}{m}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

While, the rotational speed of the hammers (n), was calculated using the following equation:

n = 60/2πr .... (7)

Capacity of the mixture tank:

The capacity of the mixture tank should be proportional to the productivity of the hammer mill. Therefore the capacity of the mixture tank (Mc) was calculated as follows:

$Mc = V\,\rho$ .... (8)

Where:

V = total volume of the tank, m^3

ρ = average real density of olive fruits, Kg/m^3

The total volume of the mixture tank is divided into two volumes [volume of the rectangular portion (V_1), and volume of the semicircle portion (V_2)]. The volume of the semicircle portion could be calculated as follows:

$V_2 = \frac{1}{2}\,\pi\,r^2\,L$ .... (9)

where:

r = radius of the mixture tank, m

L = length of the mixture tank, m

2. Calculations of The Hydraulic Press Unit:

The applied force (F_2) during the extraction process was affected by the pressure (P_2) on the mat tray area (A_2) as follows:

$F_2 = P_2 \, . \, A_2$ .... (10)

As shown in fig. (2), the force (F_2) should be equal to the pressure (P_1) acting on the cylinder piston area (A_1) according to the following equations:

$F_1 = F_2$

$F = P \, . \, A$

$P_1 \, . \, A_1 = P_2 \, . \, A_2$ .... (11)

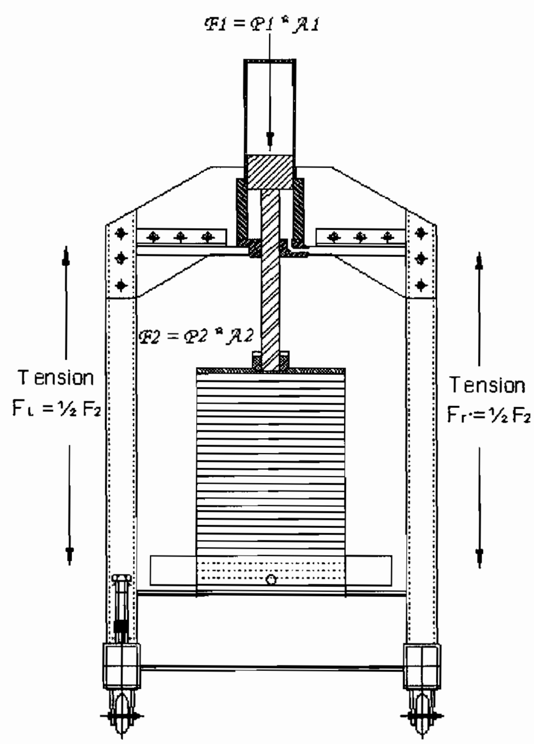


Fig. 2. Forces and pressure actions applied during the extraction process

Knowing the pressure acting on the mat tray (P_2), the mat tray area (A_2) and the piston surface area (A_1). The required pressure for the oil pump was calculated as follows:

$P_1 = P_2 \cdot A_2/A_1$ ....(12)

where:

P_1 = pressure inside the piston surface, kg/cm^2

A_1 = area of piston surface, cm^2

P_2 = pressure on the mat tray, kg/cm^2

A_2 = area of the mat tray, cm^2.

The cross section area and the tensile strength of the used material were selected to be equivalent to the external forces acting on the mat tray as follows:

1- The mat cross section area was calculated using the following equation:

$A = \pi/4\ (D^2 - d^2)$ .... (13)

where:

D = diameter of the fruit mat, cm

d = diameter of the mat opening, cm.

2- The proper applied pressure (P_a) over the mat surface was calculated according to the maximum efficiency of the extracting process using equation (11).

3- The maximum force influences the mat tray was calculated using eq. (10) and (13).

4- From the calculation of the maximum force acting on the mat tray, the specification of the hydraulic cycle was selected.

5- To calculate the cross section area for the two arms of the pressing frame, the total force acting on the mat tray should be equivalent to the tensile strength of the selected material as follows:

$F \cdot f_s = \delta \cdot a$ .... (14)

$\delta = P/a$ .... (15)

Where:

F = total force acting on the mat tray, N,

f_s = factor of safety,

δ = tensile strength N/cm^2,

P = normal load, N,

a = cross section area of the used material, cm^2.

By solving equations (14) and (15) the cross section area of each arm could be estimated as follows:

$a = F \cdot f_s / \delta$ .... (16)

The cross section area of the two arms of the hydraulic press unit should be equivalent to insure that the stresses are distributed uniformly through the two arms.

MATERIALS AND METHODS

The present study was conducted to develop, and evaluate a small oil extraction machine suitable for small Egyptian olive farms.

The working capacity, extracting efficiency and energy consumption of the machine units were measured and calculated for different oil cultivars, dual purpose, and mixed varieties of olives.

Materials:

Olive Varieties:

The investigated olive varieties were collected from different private farms dispread in Cairo-Alexand Road, Arish, and Siwa areas. The investigated varieties included Kronaki, Coratina, Arabqueen, Maraky, Picual, Manzanillo, Watiken, and mixtures of (Picual, Manzanillo and Watiken), (Kronaki and Maraky), and (Picual and Maraky) at a mixing ratio of 1:1 from each variety.

Before each experimental run, the olive leaves and impurities were removed using air stream blown by an electrical blower.

Structure of the machine components:

The developed machine consists of washing unit, crushing and mixing unit, and liquid extracting unit (hydraulic press). All parts of the machine units were manufactured in the workshop of Mansoura University and a private workshop in Damanhour (Behera governorate). The structure details of different machine units and over view of the crushing and the hydraulic press units are shown in figures (3) and (4).

1- Cleaning Washing, Crushing and Mixing units:

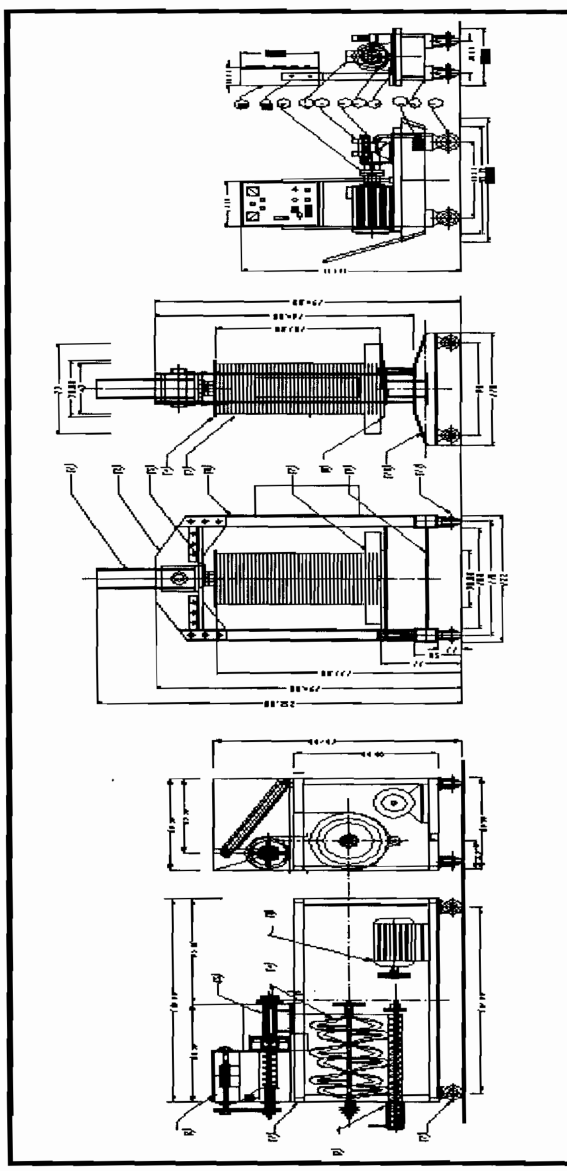
The main parts of the cleaning washing, crushing and mixing units were assembled in one frame, while the power transmission for both units was fixed in a secondary attached frame. The main frame constructed from (iron steel 42) with dimensions of 180 x 90 x 90 cm. While the secondary frame constructed from (iron steel 37). The two frames were carried out on four wheels (φ21 cm) for smooth moving of the machine during transportation.

The washing unit consists of a stainless steel tank with upper rectangular cross section and a lower semicircular base. The remaining olive leaves and impurities floated at the surface of the washing tank were manually remover using a perforated screen. A rubber belt conveyor (14 cm width and 3 mm thick) was assembled inside the stainless steel tank for conveying the washed olive fruits from the washing tank to the hammer mill as shown in figure (5).

The crushing and mixing unit was fabricated from edible grade stainless steel. It was consists of feeding auger revolving at about 27 rpm and a hammer mill constructed from two stainless steel flanges (23 cm diameter and 10 mm thick) with housing ball bearing assembled on the center hole of each flange. Four crushing hammers of triangle shape were fixed on a stainless steel shaft and revolving at speed range of (2000 to 3000 rpm) as recommended by (Matouk *et al.,* 2006)

A crushing screen made of perforated stainless steel sheet convolutes to form a circular shape rounded the hammers revolving zone for passing the crushed olives to the olive paste mixture. The mixture consists of stainless steel tank with double plates mixing auger (49 cm spiral diameter) for homogeneous mixing of the olive paste at 35 rpm for 60 minutes.

The power supply for both washing and crushing units consists of 20 hp electric motor (220V – 3 phases) transmitting the power through a set of bullies, belts and reducer gear box as shown in fig. (6).



a- Washing, Crushing, mixing unit. *b- hydraulic press unit.*

Fig. 3. Schematic diagram for different units of the developed olive extracting machine.

2- The hydraulic press unit:

A hydraulic extraction unit constructed of (iron steel 52) was used for pressing the olive paste. The unit consists of two main circular plates with diameter of 50 cm and a thickness of 3 cm. The upper plate was assembled on the main shaft of the hydraulic piston for moving up and down, while the lower plate was welded to the lower base of the unit frame for accommodating a 70 cm diameter mat trays of olive past as shown in fig (7). The hydraulic pump used for the pressing unit was a standard pump with 5 L/min discharge and 400 bar pressure, while the power unit consists of 20 hp electric motor with 1500 rpm operated with automatic control circuit as presented in fig (8).

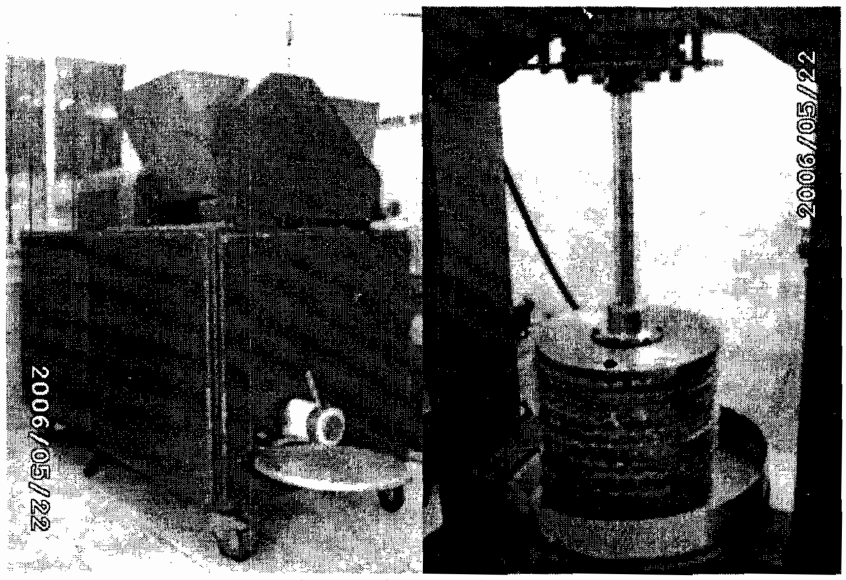
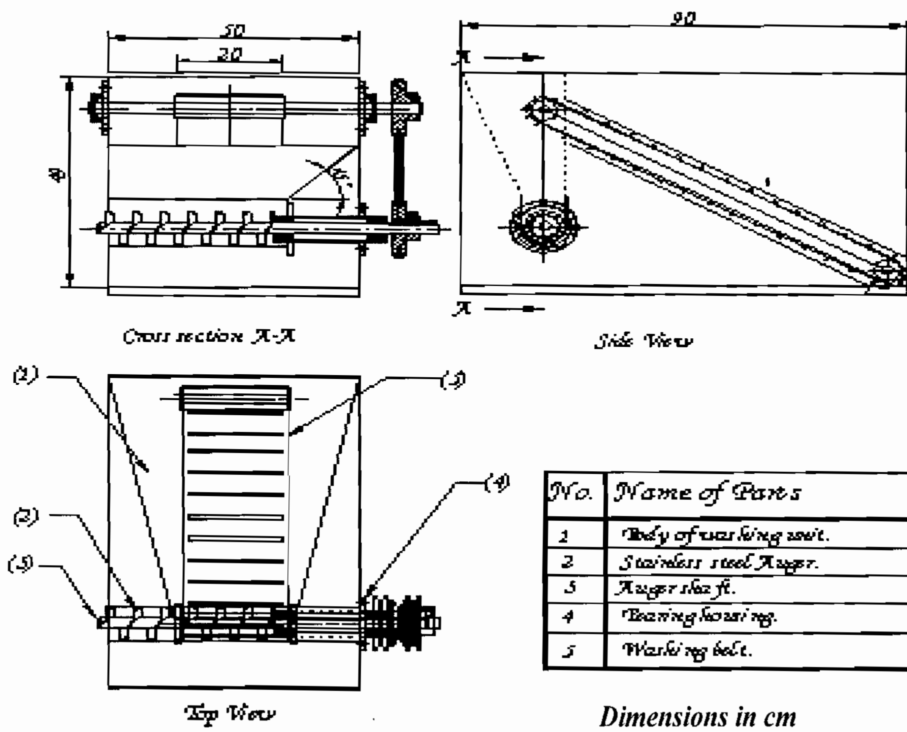


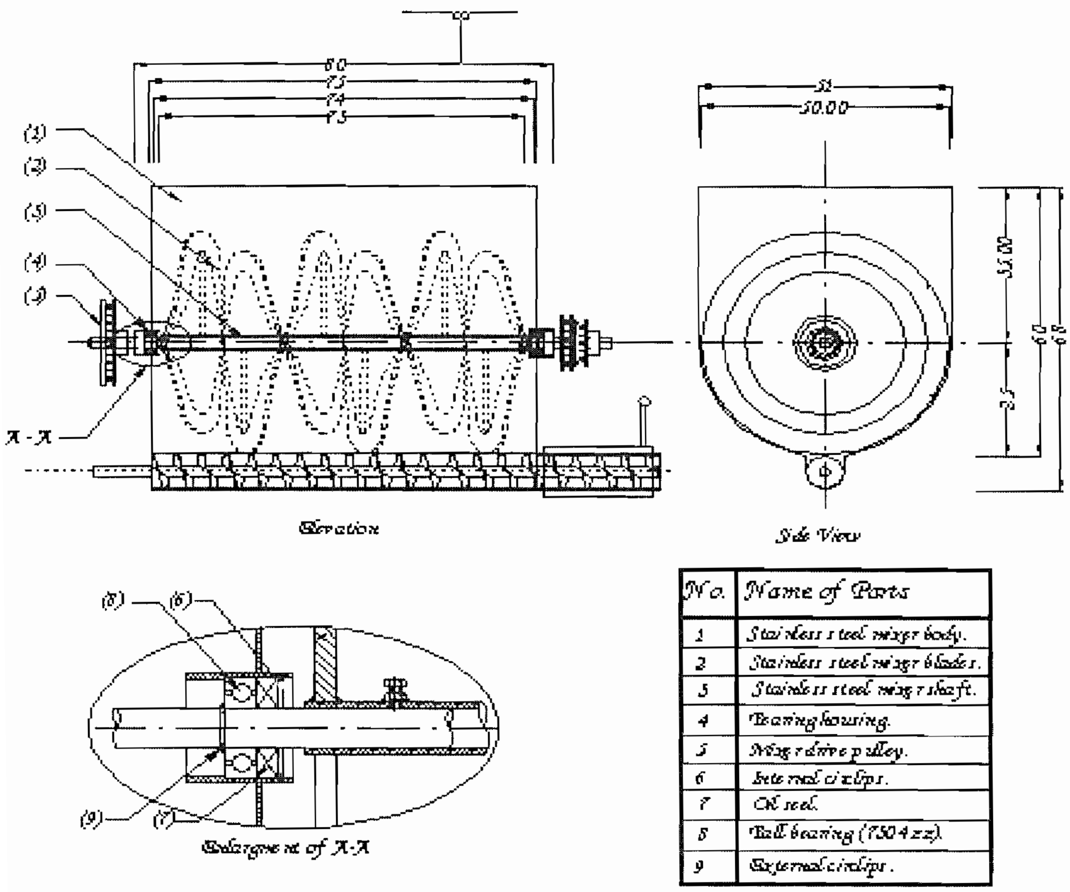
Fig. 4. Overview of the crushing and the hydraulic press units.



No.	Name of Parts
1	Body of washing unit.
2	Stainless steel Auger.
3	Auger shaft.
4	Bearing housing.
5	Washing belt.

Dimensions in cm

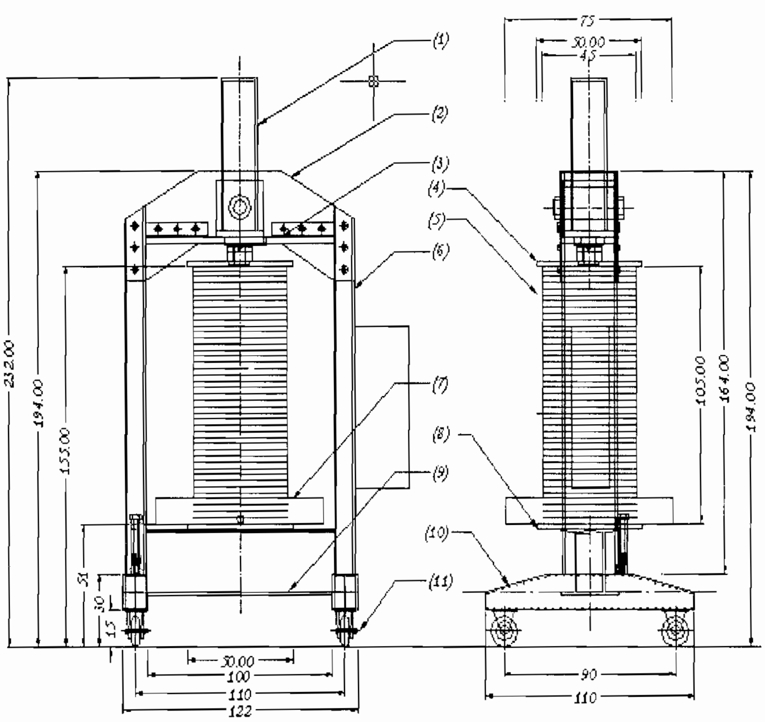
Fig. 5. Schematic diagram for the washing unit and the feeding auger.



No.	Name of Parts
1	Stainless steel mixer body.
2	Stainless steel mixer blades.
3	Stainless steel mixer shaft.
4	Bearing housing.
5	Mixer drive pulley.
6	Internal circlips.
7	Oil seal.
8	Ball bearing (7304 zz).
9	External circlips.

Dimensions in cm

Fig. 6. Schematic diagram for the crushing and mixing unit.



No.	Name of part
1	Hydraulic Piston with 15.2cm inside diameter.
2	Vertical plate to fix the piston with 1cm thick.
3	Horizontal plate with 3 cm thick.
4	Upper plate used for pressing.
5	Fabricated discs from date palm fiber
6	Press vertical arms (two sides).
7	Stainless steel tray for collecting the liquid phase.
8	Lower pressing plate with 30 cm Diam.
9	Press lower base
10	Press balance legs.
11	Rubber wheels

Dimensions in cm

Fig. 7. Schematic diagram for the hydraulic press unit.

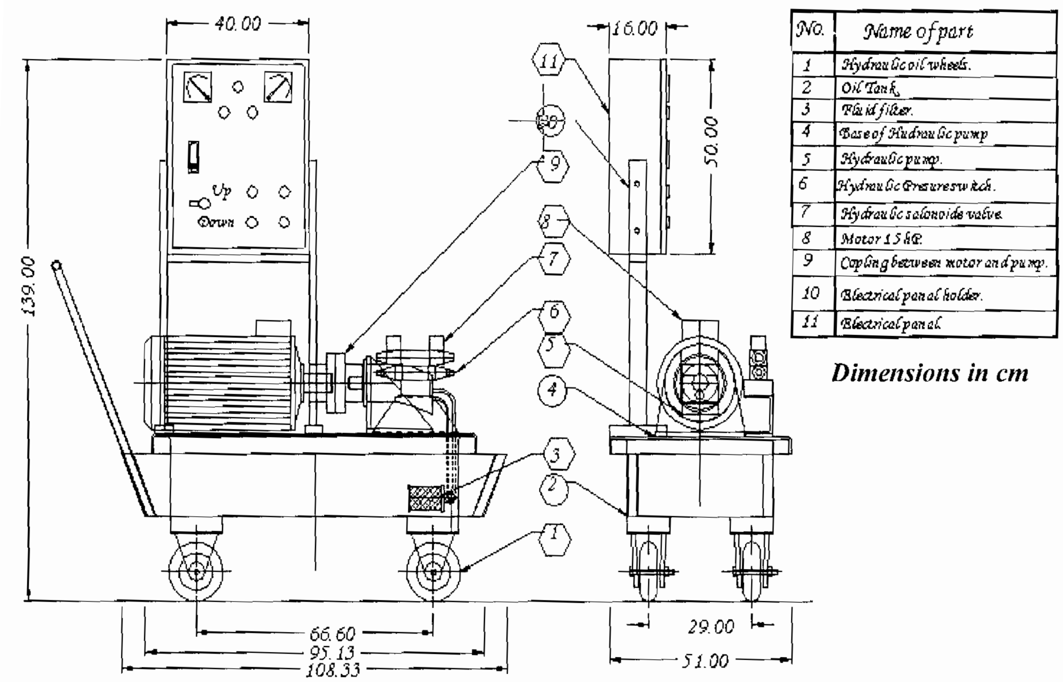


Fig. 8. Schematic diagram for the hydraulic pump and the automatic power control system.

Testing Procedure and Measurements:

Testing procedure for the washing, crushing, mixing and the hydraulic press units of the developed machine was carried out for the studied varieties of olives. The experimental work was divided into two main groups:

1st group of tests were carried out at four different levels of pressing pressure (70, 75, 80, 85 bars) to asses the proper pressure for operating the machine.

2nd group of tests were devoted to asses the performance of the machine at the selected proper pressure.

The procedure of each extracting run may be summarized as follow:

1- A sample of 200 kg of pre-cleaned olive fruits was poured into the feeding box of the washing machine, then starting the operation of both washing and crushing units.
2- The crushed paste was allowed to mix thoroughly in the mixing unit for 60 minutes.
3- Operation times for the washing and crushing units were recorded using a digital stop watch.
4- The obtained mixed paste was then dispersed in thin layers on the mat trays (made of plastic fibers) at a rate of 2.5-3 kg/mat.

5- The mats with olive paste were vertically loaded on the pressing tray of the hydraulic unit in one column of 75 trays/one press.

6- The mat trays with olive paste were separated every five mats by a 3 mm thick stainless steel tray for obtaining a uniform application of the pressing load.

7- After adjusting the vertical alignment of the mats to avoid any movement when the system is subjected to hydraulic press, the hydraulic unit was operated at the required level of pressure for 60 minutes pressing time. The extracted oil was received in a stainless steel tank, and then the liquid phase was separated from the solids.

8- The remaining percentage of oil on the residual cake was determined after removing the moisture content as reported by (Matouk, *et al.*, 2006).

9- The extracting efficiency of the pressing unit (η_{pu}) was calculated as follow:

$$\eta_{pu} = \frac{Q_f - Q_r}{Q_f} x100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

Where:

Q_f = percentage of oil in the used olive fruits, %

Q_r = percentage of remaining oil in the produced cake, %

10- Working capacity, energy consumption, and of the machine units were measured and calculated at the selected proper pressure using the following relationships:

a- The actual capacity of the washing and crushing units ($Wcc_{act.}$):

$$Wcc_{act.} = \frac{60\ Ws}{t_1} \ldots\ldots\ldots\ \ldots\ldots\ldots\ \ldots..(18\ )$$

Where:

W_s = weight of the producing paste, kg

t_1 = time of washing and crushing the sample, min.

b- The actual capacity of the extracting unit (Euc_{act}):

$$Euc_{act.} = \frac{Q\ x\ n\ x\ N}{t} \ldots\ldots\ldots\ \ldots\ldots\ldots\ \ldots..(19)$$

Where:

Q = weight of the olive paste in one mat tray, kg.

n = number of mat trays fully with olive paste.

N = number of extracting trays (entire trays).

T = total time of the extracting process.

c- Electric energy consumption (kW.hr):

$$E=\frac{t.\sqrt{3}.I_I.V_L.\cos\varphi}{60x1000} \quad ....(20)$$

Where:

E = electric energy consumption (kW.hr),

t = time taken for the operation (min),

I_L = line current strength, ampere,

V_L = potential difference, voltage,

cos Φ = power factor of motor obtained from the capacitor monitor

RESULTS AND DISCUSSION

Extraction efficiency of the hydraulic press unit:

a- Effect of pressing pressure:

Figures (9) and (10) illustrate the extraction efficiency of the hydraulic press unit as a function of pressing p.essure for the selected oil and dual purpose olive cultivars.

As shown in the figures, with increasing the pressing pressure from 75 to 85 bars, the extraction efficiency increased from (83.03 to 86.43%), (78.27 to 81.20%) and (85.32 to 88.16) for the oil producing varieties Picual, Manzanillo and Watiken respectively. While, it was increased from (86.02 to 88.82%) (79.52 to 82.36%), (85.55 to 88.25%) and (85.82 to 88.18%) for the dual purpose varieties Coratina, Arabqueen, Kronaki and Maraki respectively.

The observed variation in oil extraction efficiency for different studied varieties may be attributed to the nature of variety, percentage of olive paste particles at the range of (2.25 - 4 mm) and the initial percentage of oil in each variety.

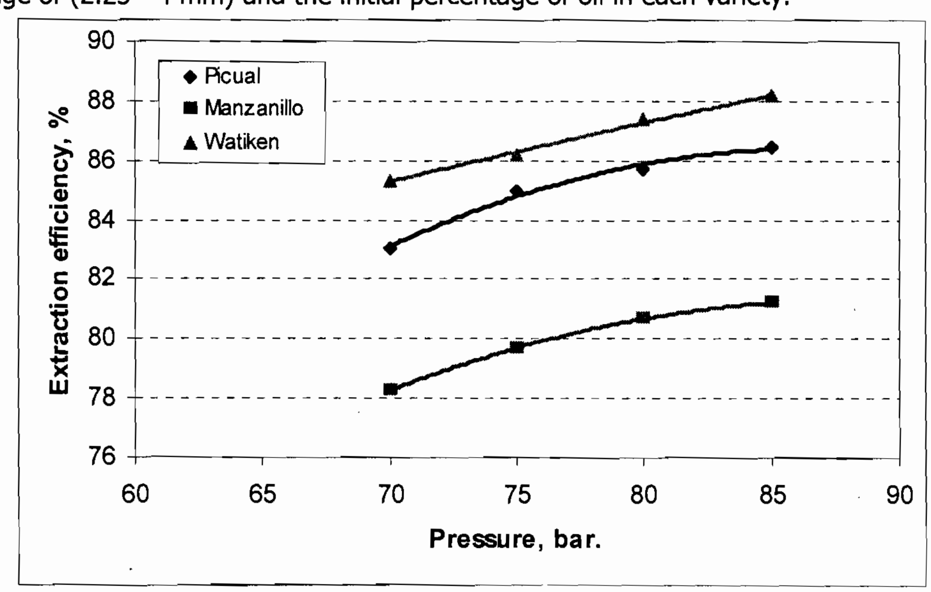


Fig. 9. Effect of pressing pressure on the extraction efficiency of the dual purpose olive varieties.

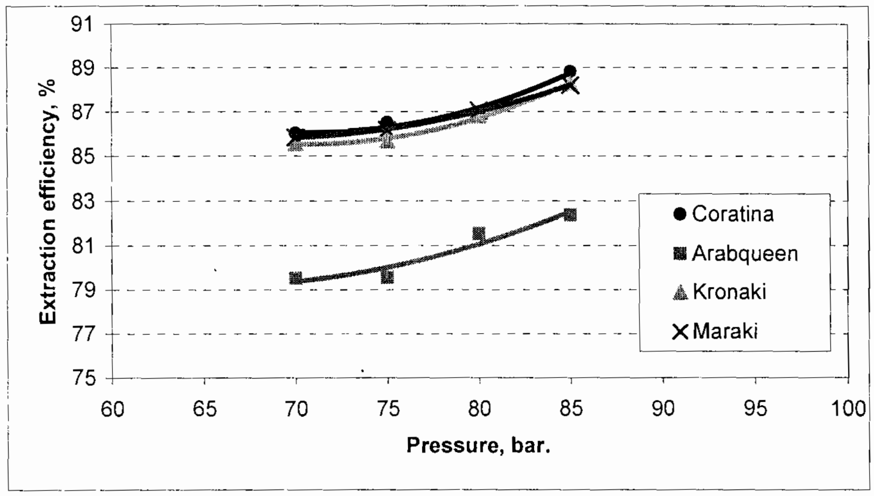


Fig. 10. Effect of pressing pressure on the extraction efficiency of the oil producing olive varieties.

In general, one may conclude that the pressing pressure of 85 bars showed the heights extracting efficiency for all the studied varieties.

Effect of variety:

To study the effect of olive variety on the extraction efficiency of the hydraulic press unit. The pressure and pressing time of the hydraulic press unit were kept at 85 bars and 60 minutes, respectively.

As shown in fig.(11), the recorded extraction efficiency were 94.85, 86.02, 83.00, and 98.33% for pure olive oil varieties kronaki, coratina, arab-queen, and maraki, respectively. In other words Maraki variety recorded the highest efficiency while the arab-queen recorded the lowest.

Extraction efficiencies were 91.84, 84.48, and 83.40 % for for the pure dual varieties (picual, manzanillo, and watiken), respectively.

The effect of mixing olive varieties on the extraction efficiency also shown in Fig. (11). The recorded extraction efficiencies were 87.96, 88.55, and 91.81% for the mixtures of (Picual + manzanillo + watiken), (koronaki + maraki), and (picual + maraki), respectively. This means that, mixing of different varieties may affect the extraction efficiency of the hydraulic press unit.

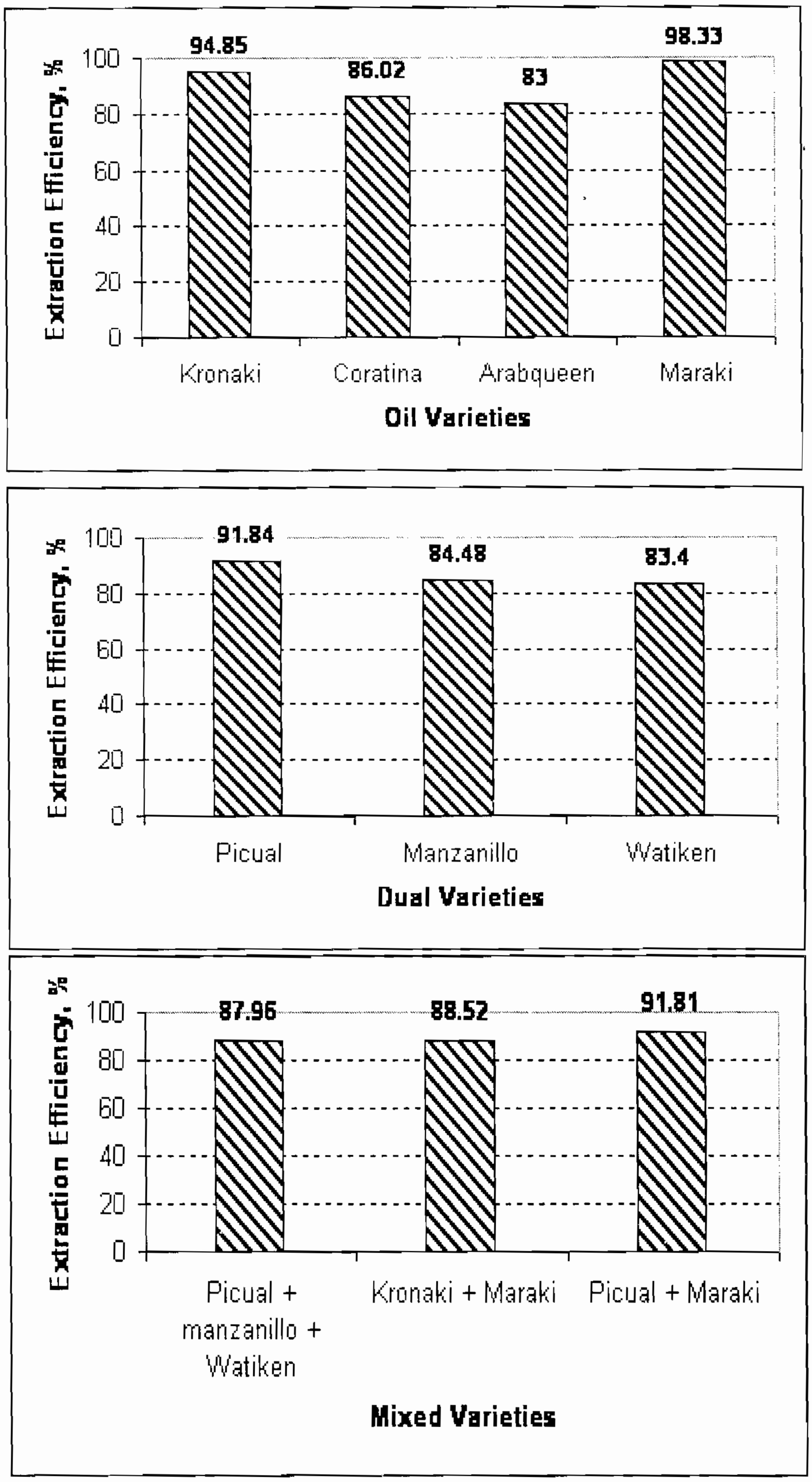


Fig. 11. Effect of variety mixing on the extraction efficiency of the hydraulic press unit.

Working Capacity and Energy Consumption of the Machine Units:

Working capacity and energy consumption for the machine units were determined at fixed pressing pressure of 85 bars and resting time of 60 minutes.

The obtained results (Fig. 12), showed that Watiken variety recorded the highest working capacity of 199.017 kg/h while Arab-queen variety recorded the lowest value of 185.225 kg/h. On the other hand, the mixed varieties recorded very close values of working capacity with an average of 197.7 kg/h. The observed variations in machine capacity may be due to the difference in physical and mechanical properties of the studied varieties. In general, the average machine capacity approached about 197.1 kg/h. which was very close to the target capacity of the designed machine (200 kg/h.)

The figure also shows that, energy consumption for the washing crushing, and mixing units varied from 19.462 to 20.714 kW.h/ton for the oil producing varieties, while it was ranged from 17.702 to 20.565 kW.h/ton for the pure dual varieties. Fig. (12) also showed that energy consumption for the mixed varieties were 18.143, 20.210, and 20.313 kW.h/ton for the mixtures varieties (Picual + Maraki), (Kronaki + Maraki), and (Picual + Manzanillo + Watiken), respectively.

It can be seen that the pure variety Watiken recorded the lowest energy consumption of 17.702 kW.h/ton, while Arab-queen variety recorded the highest value of 20.714 kW.h/ton. In general the overall average of energy consumption for the washing, crushing, and mixing unit was 19.65 kW h/ton.

It should be mentioned also that, the energy requirement for the pressing unit ranged from 41.047 to 43.947 kW h/ton. for pure oil olive varieties, from 40.901 to 41.593 kW h/ton. For the dual purpose variety, and from 41.126 to 41.218 kW h/ton. For the mixed varieties with overall average of 41.53 kW h/ton.

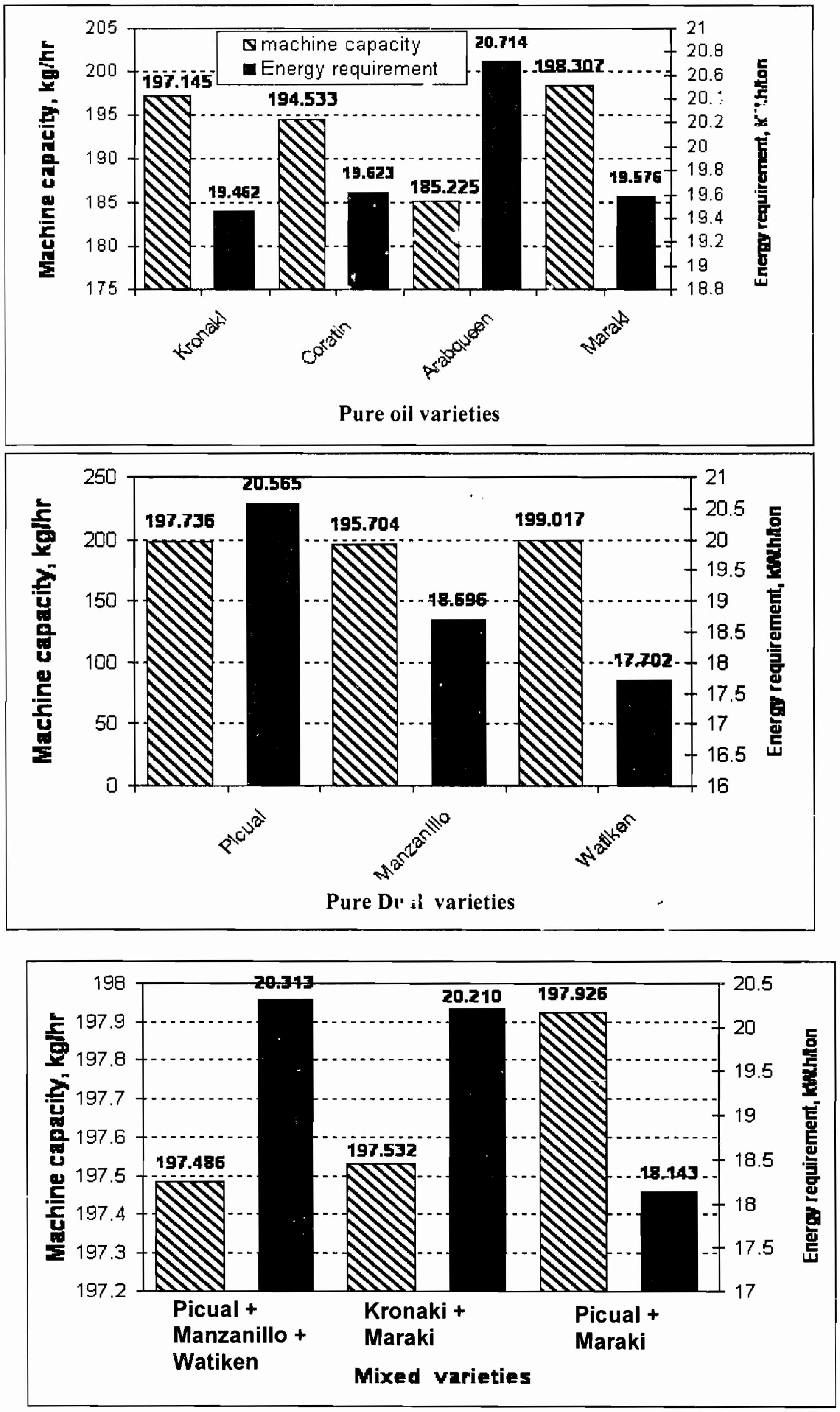


Fig. 12. Machine capacity and energy consumption for the washing and crushing units using pure and mixed olive varieties.

CONCLUSION

1. The average working capacity of the machine components was about 197.1 kg/h for the pure and the mixed studied varieties.
2. The average energy requirement was 19.65 kW h/ton for the washing, crushing, and mixing unit, while it was 41.53 kW.h/ton for the hydraulic press unit.
3. The extraction efficiency of the hydraulic press unit was varied from 83.00 to 98.33% for the pure varieties and from 87.96 to 91.81% for the mixed varieties.
4. The developed machine was proved to work satisfactorily considering working capacity, efficiency and energy consumption.

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تطوير وتقييم آله إستخلاص زيت الزيتون

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أجريت تلك الدراسة لتطوير وتقييم آله لإستخلاص زيت الزيتون تشتمل على وحدة للغسيل، وحدة للجرش والخلط ووحدة للإستخلاص بنظام الكبس الهيدروليكي. وتم تقييم الوحدات المختلفة للآله على أساس معدل الأداء، الطاقه المستهلكه، والكفاءه الكليه لعملية الإستخلاص وذلك في حالتي الأصناف المنفرده والأصناف المختلطة.

أظهرت النتائج أن متوسط معدل الأداء للوحدات المختلفة بالآلة وصلت إلى حوالي ١٩٧,١ كجم/ساعه .

وكانت الطاقة المستهلكه لوحدتي الغسيل والجرش والتقليب ١٩,٦٥ كيلووات.ساعه/طن بينما كانت ٤١,٥٣ كيلووات.ساعه/طن لوحدة الإستخلاص الهيدروليكي.

من ناحية أخرى تراوحت كفاءة الإستخلاص لوحدة الكبس الهيدروليكي بين ٨٣,٠٠ – ٩٨,٣٣% في حالة الأصناف المنفردة بينما تراوحت تلك النسب بين ٨٧,٩٦ – ٩١,٨١% في حالة الأصناف المختلطه مما يعني تأثر كفاءة الإستخلاص بعملية الخلط .

وبصفه عامه أظهرت نتيجه التقييم للوحدات المختلفة للآلة أن معدل الأداء، الطاقة المستهلكة والكفاءة الكلية قد أعطت نتائج مرضيه لتصنيع الآله محليا.