MISR JOURNAL OF AGRICULTURAL ENGINEERING ISSN-Print: 1687-384X
https://mjae.journals.ekb.eg/ ISSN-Online: 2636-3062
Misr J. Ag. Eng., 39 (2): 221 – 232 **DOI:** 10.21608/mjae.2022.121502.1065

THE EFFECT OF EXPELLER PRESS OPERATIONAL PARAMETERS ON OLIVE POMACE OIL EXTRACTION

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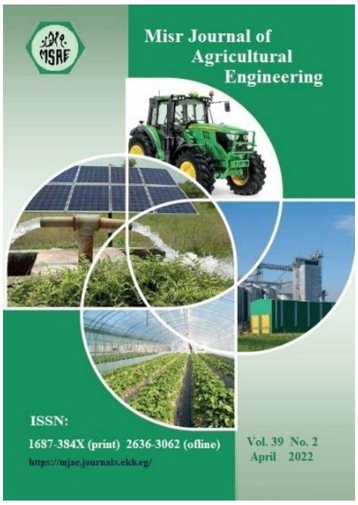

Keywords:
Expeller; Olive pomace; Extraction; Oil quality; Cost.

ABSTRACT

An investigation was carried out on the effect of expeller press operational parameters such as screw speeds (20, 30, 40 and 50 rpm) and nozzle diameter (8,10 and 12 mm) on olive pomace oil extraction in order to determine the optimum operating conditions of oil expeller for maximum yield. The obtained results showed that, the oil yield and extraction efficiency had a negative relationship with the nozzle diameter and screw speed. However, a positive relationship was detected with the throughput capacity. The increase in screw speed was observed to increase the oil extraction rate and cake output but decrease the extraction loss. However, the increase in nozzle diameter increased the extraction loss and cake output but decreased the extraction rate. The extraction time was decreased by increasing the screw speed and nozzle diameter. Analysis of results showed that, the highest pomace oil yield was obtained at screw speed of 20 rpm and nozzle diameter of 8 mm with operational cost of 27.57 LE/h. No effect of the operating parameters on oil quality was observed. The result of this study revealed the possibility of extracting oil from the dried pomace by using the screw-type oil expeller.

1. INTRODUCTION

The production of olive oil is a booming industry in the Mediterranean countries. The annual average production of olive oil was around 3.1 million tons in the 2020/2021crop year. Meanwhile the annual average production in Egypt was around 40.000 tons **(International olive council (IOC), 2020**). Olive pomace is the solid residue obtained from the olive oil production process. This residue retains a significant amount of remaining oil of about approximately 10–12% after virgin olive oil extraction, called crude olive pomace oil, which then needs to be extracted from those residues **(Akgun and Doymaz, 2005)**. Currently, the growing interest in olive pomace oil is attributed to its economic benefits. It is cheaper than olive oil and contains a variety of minor bioactive components. It includes all of the functional compounds found in virgin olive oil in addition to other biologically active components **(De la Puerta et al., 2009)**. This crude oil can be used for soap industry or be refined then the refined olive-pomace oil can be blended with virgin olive oil, obtaining olive pomace oil for human consumption.

Mechanical pressing and chemical solvent extraction are the most commonly used procedures in commercial oil extraction **(Atabani et al., 2013).** Each of these methods has its own benefits and limitations. For instance, Mechanical pressing is used to extract oil on hydraulic presses which results in very high pure oil. This method is not completely efficient as it leaves a large quantity of oil still in the paste which needs to be processed by different method **(Banat et al., 2013).** Chemical solvent extraction is another well-established procedure for oil removing from the solid by-product after extraction process. This method is more efficient in terms of oil recovery **(Shivani et al., 2011)**. However, despite the advantage of solvent extraction method, concerns with safety, environment and health have nowadays led to search for alternative options. The screw press method (expeller) is the next improvement in extracting oil. Oil expeller is a device that produces pressure by automatically or manually rotating the feed to expeller screw **(Khan et al., 2016).** Continuous pressing by means of expellers is a widely applied process for the oil extraction. It replaces the historical method for the batch wise extraction of oil by mechanical or hydraulic pressing **(Tekale et al., 2017)**. **Aung et al. (2019)** reported the screw press oil expellers to be more efficient than all other methods of oil extraction.

Many works have been done on pomace oil extraction, but literature has shown that little or no work has been done in terms of mechanical process of pomace oil extraction. The objective of this work is to evaluate the effect of mechanical extraction method using screw press on the oil yield, cake output, extraction rate, extraction loss, extraction time, throughput capacity and extraction efficiency in order to determine the optimum operating conditions for maximum yield.

2. MATERIALS AND METHODS

Selection, preparation and pre-treatment of test materials

For this research, the olive pomace samples were obtained from a local olive oil mill located in North Sinai governate, Egypt for the performance evaluation of the constructed machine. The sample was dried at 125 ˚C for approximately 35 minutes using accelerated rotary dryer. This process disrupts the cell membranes thus allowing leakage out of oil. The olive pomace contains of 15.57 meq /kg oil peroxide value, 1.97 mg KOH/g acid value, 0.989 % free fatty acid, 11.3 ± 0.06 % (d.b.) and 17 % (d.b.) moisture content.

Oil expeller design

The expeller machine used in this study was developed and constructed to extract the olive pomace oil. It consists of the main base, the feeding unit, the expelling unit, the discharge unit and the transmission system as shown in **Figure (1).** The main base of the expeller machine constructed from an iron bars with dimensions of (700 × 400× 25 mm). It carries the expelling unit, the feeding unit, the main electric motor and the machine control panel. The feeding unit consists of a hopper with conical shape made from iron sheet metal, 2 mm thickness. It has upper diameter of 250 mm, bottom diameter of 100 mm and 238 mm high. The expelling unit consists of a screw shaft rotating inside a perforated barrel with diameter of 80 mm outer casing to permit the passage of oil only and helps to create pressure inside the barrel. The screw is divided into feeding, milling and discharge sections. An electrical resistance-heating ring was attached around the press head to ensure that, the screw press work at the required level of temperature. A discharge unit with different nozzle diameter was installed at the end of the expelling unit from which the residual (cake) is discharged. An electric motor with power of 2.2 kW and 1420 rpm rotating speed is transmitted its motion to the screw shaft through a gearbox for reduction of its rotational speed. The rotational speed was controlled by a frequency inverter (Model No: SV022iG5A-4). A direction switch was used to inverse the direction of motor motion and a temperature thermostat was used for temperature control.

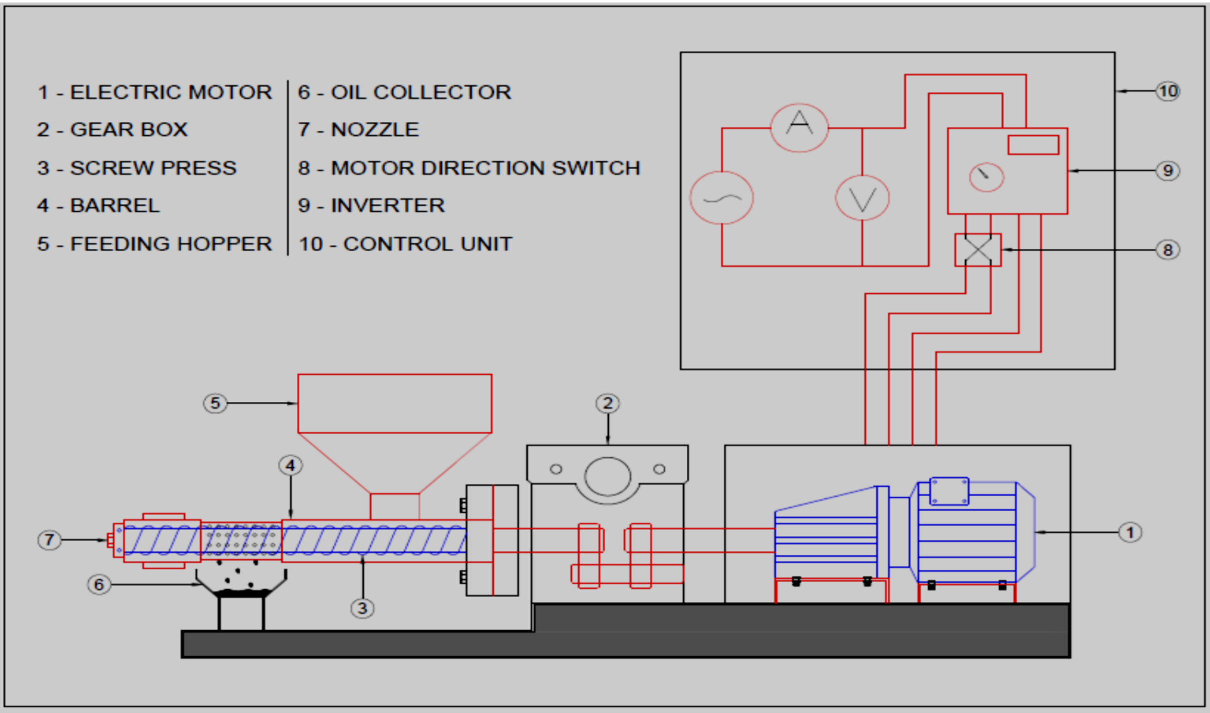

Figure (1): Schematic diagram of the expeller machine.

Experimental Procedure

The oil extraction was performed using a laboratory scale mechanical oil expeller. The experiments were conducted with four screw speeds of 20, 30, 40 and 50 rpm, three nozzle diameters of 8, 10 and 12mm, extraction temperatures of 80 ˚C. This level of heating temperature was used in order to minimize the undesirable fatty acids in the extracted oil.

Upon achieving steady operation, Firstly the olive pomace was fed to the machine through the hopper. Then the pomace come in contact with the cylindrical cage (barrel) and the screw shaft. The barrel is a stationary part while the screw shaft is a rotating part. When the pomace comes between these two parts, the milling process takes place and the pomace propelled by the rotating screw in a direction parallel to the axis. The friction and pressure produced by the screw on the barrel causes the mass to heat up. This action gradually increased the required pressure to releases the oil which flows out of the press through the slots provided on the periphery of the barrel and is collected beneath the expeller chamber, while the press cake continues to move in the direction of the shaft, towards the discharge nozzles are provided. At the end of each operation, the extracted oil was kept away from light, placed in a dark container (wrapped with aluminum foil) and stored to allow foreign materials to settle down. After 48 hours, the oil was filtered using a pre-weighed filter paper to remove the sediment in the crude oil and obtain the actual oil weight.

Quality Evaluation of the Dried Olive Pomace

Determination of olive pomace moisture content

The moisture content of pomace samples was determined by drying the samples of pomace in electric oven at 105 ˚C for 4 h until reaching a constant weight as mentioned by **(Doymaz et al., 2004**).

Determination of the extracted oil acid value

The acid value was determined according to the method 696.17 described by **A.O.A.C (2000).**

Determination of the free fatty acids (FFA%) of olive pomace oil

The FFA % of oil samples were calculated as oleic acid to determine the level of oil and fat degradation using the corresponding acid value of each sample according to the **A.O.A.C. (1991)** as follows:

$$FFA\% = \frac{A.\text{V}}{1.99} \quad \text{......} (1)$$

Where:

A.V: Acid value

Determination of olive pomace oil content

Chemical extraction of olive pomace oil from dried olive pomace was carried out using hexane. 250 ml of solvent and 10-gram olive cake sample was used in each experiment to maintain a solvent-to-solid ratio of 25:1. The total extraction process was completed within 5 hours. The extracted phase was then distilled to separate the oil from the solvent. The percentage of oil content was calculated.

Cost analysis of the oil expeller machine:

The operational cost was estimated using the following equation:

$$CO = \frac{E_C}{C_p} \quad \text{......} (2)$$

Where :

Co : Operation cost, (L.E./Kg).

E_C : Expeller hourly cost, (L.E./h).

C_p : Expeller capacity, (kg/h).

The extruder cost analysis was performed and taking into account the conventional method of estimating both fixed and variable cost.

A. Fixed costs (FC):

1- Depreciation cost

Deprecation was expressed by the following equation, **(Shepley et al., 1984):**

$$Depreciation = \frac{Unit\ price\ (LE) - Salvage\ value}{Useful\ life\ (hr)} \quad \text{......} (3)$$

Salvage value has been assumed as 0.1 of the unit price.

2- Interest cost

Interest cost was expressed by the following equation, **(Shepley et al., 1984):**

$$Interest = \frac{Unit\ price\ (LE) + Salvage\ value}{2} \times \frac{Interest\ rate}{Yearly\ operation\ (hr)} \text{ ....(4)}$$

3- Taxes and insurance cost

Taxes and insurance costs were assumed as 2 % of the purchase price of the expeller.

B. Variable cost (VC):

1- Labor cost

Is defined as payment for operator who load and operate the machine (LE/h)

2- Electricity cost

The cost of electricity was determined using the following equation:

E = Elec. consumption (kWh) × Elec. cost (LE/kWh) ....(5)

3- Repair and maintenance cost

Repair and maintenance costs are calculated based on the accumulated using the equipment and are set to be equal to the accumulated repair and maintenance divided by the lest price of the equipment. The repair and maintenance costs were determined as follows:

Repair and maintenance costs = (90%) depreciation

C- Total costs (TC)

The total costs, (LE/h) are the summation of the total fixed costs (LE/h) and the variable costs (LE/h) as follow:

Total costs (LE/h) = Fixed costs (LE/h) + Variable costs (LE/h) ....(6)

Expeller performance evaluation

The machine performance parameters were determined by using the following equations:

1 - Determination of extraction yield, O_{yield} (%)

Oil yield is defined as the ratio of filtered oil expressed to the weight of pomace simple fed into the hopper **(Aremu and Ogunlade, 2017).**

$$O_{yield} = \frac{M_{oil}}{M_{ps}} \times 100\ \% \text{ ....(7)}$$

Where :

M_{oil} : Mass of oil expelled, g

M_{ps} : Mass of pomace sample, g

2- Determination of cake output, C_{output} (%)

Cake is squeezed out during the oil expulsion. It is defined as the ratio of residual cake after extraction operation to the weight of pomace sample fed into the hopper **(Amretha Krishnan et al., 2017).**

$$C_{output} = \frac{M_c}{M_{ps}} \times 100\ \% \text{ ....(8)}$$

Where:

M_c : Mass of residual cake after extraction, g

3- Determination of oil extraction rate, E_r (kg/s)

Extraction rate is the volume or weight of oil that the machine is capable of expelling per unit time **(Olaniyan and Oje, 2011).**

$$E_r = \frac{M_{oil}}{T} \quad \text{......} \quad (9)$$

Where :

T : Pressing duration, s

4- Determination of extraction loss, E_{loss} (%)

Extraction loss was calculated as the difference between the weight of the sample before extraction and the sum total of the weights of oil expressed and residual cake after extraction divided by the weight of the sample before extraction **(Olaniyan and Oje, 2007).**

$$E_{loss} = \frac{[M_{ps} - (M_{oil} + M_c)]}{M_{ps}} \times 100 \ \% \quad \text{......} \quad (10)$$

5- Determination of throughput capacity, C_p (kg/s)

The capacity of the machine was calculated as the weight of pomace sample fed into the hopper divided by the consumed time for the process **(Olaoye et al., 2020).**

$$C_p = \frac{M_{ps}}{T} \quad \text{......} \quad (11)$$

6-Determination of extraction efficiency, η_{oil} (%)

The extraction efficiency of the machine was evaluated by expressing the oil extracted as a percentage of the total oil content of the pomace samples **(Aremu and Ogunlade, 2017).**

$$\eta_{oil} = \frac{M_{oil}}{\mathrm{X}M_{ps}} \times 100 \ \% \quad \text{......} \quad (12)$$

Where:

X = The oil content in kg per 100kg of olive pomace.

3. RESULTS AND DISCUSSION

Effect of different studied parameters on oil yield:

The percentage of extracted pomace oil using the expeller machine under different screw speeds and nozzle diameters are shown in **Figure (2)** The highest percentage of oil yield 7.89% was obtained at the combination of nozzle diameter of 8 mm, and screw speed of 20 rpm. While, the lowest oil yield of 4.05% was obtained at combination of nozzle diameter of 12 mm and screw speed of 50 rpm.

Also, the percentage of oil yield was decreased with the increase of nozzle diameter. This might be due to the effect of nozzle diameter on the pressure level of the expeller outlet. The pressure increased with decreasing the nozzle diameter in which smaller diameter of nozzles might add pressure to the material which thus promote heat to be produced as a result of collision between the shaft screws and the material and also between the material particles themselves which causes more destruction of cells and thereby more oil yield. Meanwhile, the percentage of oil yield was decreased as the screw speed getting increased. This might be due to the higher speed of screw would reduce residence time of pomace and thus give less chance for oil to flow from the pomace particles.

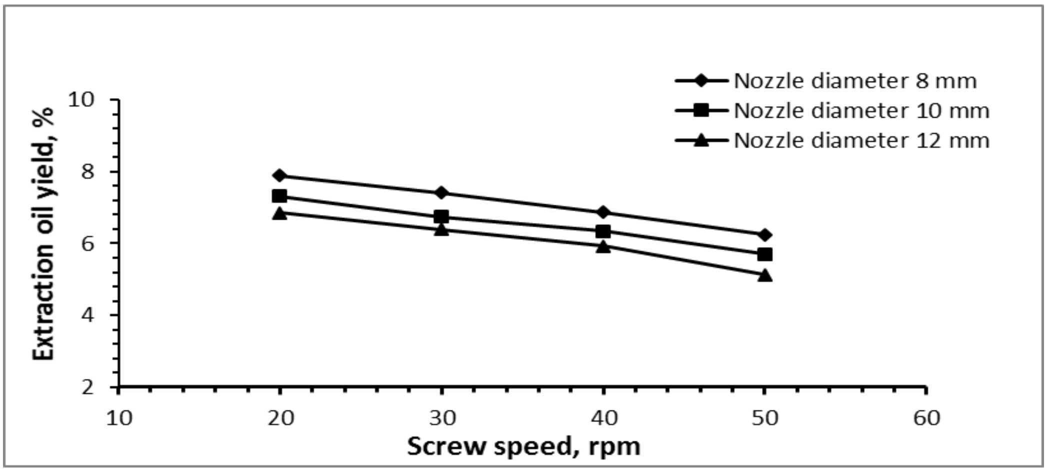

Figure (2): Effect of different screw speeds and nozzle diameter on yield of oil extraction.

Effect of different studied parameters on cake output percentage:

The effects of screw speed and nozzle diameter on the percentage of cake output after pomace oil extraction using the expeller machine are shown in **Table (1)**. The highest percentage of cake output (88.46%) was obtained at the combination of nozzle diameter of 12 mm and screw speed of 50 rpm. While the lowest percentage of cake output (80.81%) was obtained at nozzle diameter of 8 mm and screw speed of 20 rpm.

Table (1): Effect of expeller press parameters on mean cake output (%).

Nozzle diameter (mm)	Screw speed (rpm)			
	20	**30**	**40**	**50**
8	80.81	82.86	84.95	87.97
10	81.11	82.97	85.13	88.20
12	81.20	83.11	85.33	88.46

Furthermore, the percentage of cake output was increased with the increase of screw speed and nozzle diameter in which the cake output percentage increased from 80.81 to 87.97%, from 81.11 to 88.20 and from 81.20 to 88.46 % by increasing the screw speed from 20 to 50 rpm at nozzle diameter of 8, 10, 12 mm, respectively.

Effect of different studied parameters on time of oil extraction:

Table (2) illustrates the effect of different operating parameters of oil expeller machine on oil extraction time. As shown in the Table, the oil extraction time ranged from 391 to 651 seconds depending upon screw speed and nozzle diameter. The extraction time was decreased by increasing the screw speed and nozzle diameter. This might be due to increasing the screw speed and nozzle diameter reduced the residence time of the material inside the barrel, hence the time for the oil to drain from the pressed olive pomace also decreased.

Table (2): Effect of expeller press parameters on oil extraction time (Sec).

Nozzle diameter (mm)	Screw speed (rpm)			
	20	**30**	**40**	**50**
8	651	558	491	434
10	624	530	469	409
12	599	514	457	391

Effect of different studied parameters on extraction rate of oil:

While evaluating the effects of machine parameters on oil extraction rate, results of performance tests showed a variation of oil extraction rate from olive pomace at different screw speeds and nozzles diameters were plotted, as shown in **Figure (3).**

The **Figure** shows that, the maximum oil extraction rate of 0.000288 kg/s for olive pomace was obtained at 50 rpm screw speed and nozzle diameter of 8 mm. While, the minimum oil extraction rate of 0.000228 kg/s was obtained at screw speed of 20 rpm and nozzle diameter of 12 mm, respectively. Also, it can be observed that, the oil extraction rate increased with the increase of screw speed. This might be due to increasing the screw rotational speed tended to decrease the extraction time and thus increase the extraction rate. Meanwhile it was decreased with the increase of nozzle diameter. This may be due to the fact when the nozzle diameter increased, the oil productivity decreased as a result of less pressure on the pomace samples.

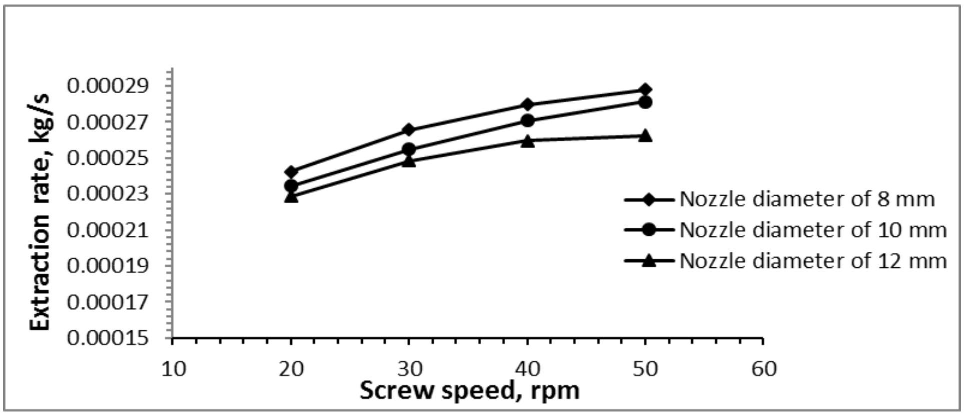

Figure (3): Effect of different screw speeds and nozzle diameter on oil extraction rate.

Effect of different studied parameters on the extraction losses:

Table (3) shows the effect of different levels of the machine screw speed and nozzle diameter on the extraction losses during the extraction process. The results show that, the highest extraction loss of 11.95 % was obtained at the condition of 12 mm nozzle diameter and 20 rpm screw speed. While, the lowest extraction loss of 5.78% was obtained for the condition of 8 mm nozzle diameter and 50 rpm machine screw speed.

Table (3): Effect of expeller press parameters on mean extraction losses (%).

Nozzle diameter (mm)	Screw speed (rpm)			
	20	**30**	**40**	**50**
8	11.30	9.73	8.18	5.78
10	11.57	10.28	8.52	6.09
12	11.95	10.50	8.74	6.41

In general, it can be noted that, for the studied range of experimental treatments, the extraction loss increased with the increase of nozzle diameter, but it was decreased with increasing the machine screw speed. **Bako et al. (2018)** observed similar trends when considering the effect of machine speed on the extraction loss.

Effect of different studied parameters on throughput capacity of the machine:

The Representative throughput capacity rate values versus different levels of screw speed and nozzle diameters is provided in **Table (4).** The obtained results show that, the highest machine throughput capacity (18.4 kg/h) was obtained at a nozzle diameter of 12mm and machine screw speed of 50 rpm. While, the lowest throughput capacity of 11.05 kg/h was obtained at nozzle diameter of 8 mm and screw speed of 20 rpm.

Table (4): Effect of expeller press parameters on mean throughput capacity (kg /h).

Nozzle diameter (mm)	Screw speed (rpm)			
	20	**30**	**40**	**50**
8	11.06	12.90	14.66	16.59
10	11.54	13.58	15.35	17.73
12	12.02	14.01	15.76	18.41

Also, the machine throughput capacity increased as the screw speed increased. This might be due to the increase in olive pomace flow rate through the screw feeding entrance lead to increase the oil extraction rate. While, the increase in the machine throughput capapcity by increasing the nozzle diameter could be due to the decrease of nozzle pressure effect on the pomace flow outlet.

Effect of different studied parameters on efficiency of the expeller machine:

Figure (4) shows the effect of screw rotational speeds and nozzle diameters on the oil extraction efficiency. The results show that, the maximum oil extraction efficiency of 69.82 % was obtained at screw speed of 20 rpm and nozzle diameter of 8 mm. While the minimum efficiency of 45.40 % was obtained at, screw speed of 50 rpm and nozzle diameter of 12 mm.

Also, it could be noticed that, the outlet nozzles diameter was the most important designation parameter that controls the other variables of oil expression process as well as the output material characteristics. Decreasing the nozzles diameter, increases the extraction time and increasing oil yield. The narrow nozzles may reduce the flow of the material inside the expression cage that may increase the duration of extraction which led to higher extraction efficiency.

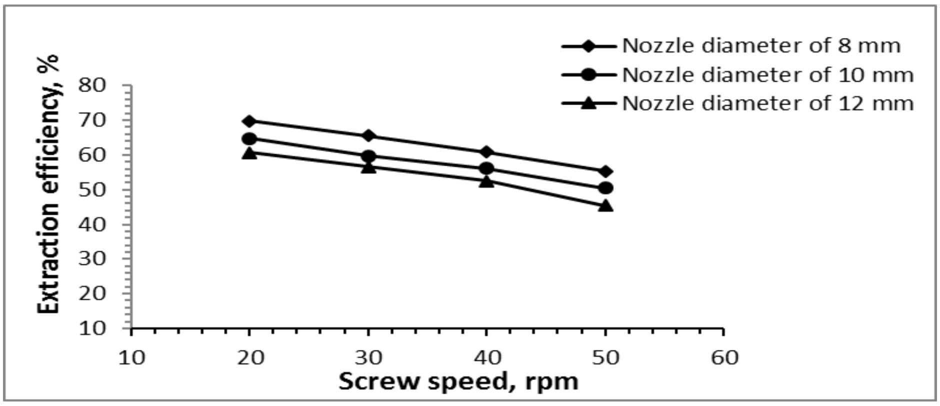

Figure (4): Effect of expeller press parameters on mean extraction efficiency (%).

On the other hand, the results show a reduction in oil extraction efficiency by increasing screw rotational speed. This behavior may be due to increasing the rotational speed reduced the extraction duration and thus give less chance for the oil to flow from the solid material as previously mentioned.

Quality evaluation for the crude olive pomace oil:

The acid and free fatty acid values consider the most important indicators for pomace oil quality which affected by many factors. **Table (5)** illustrates the effect of the studied operating parameters of the tested expeller machine on the extracted pomace oil quality (acid value and free fatty acid).

Table (5): The effect of studied operating conditions on the extracted pomace oil quality.

Pomace oil quality	Nozzle diameter (mm)	Screw speed (rpm)			
		20	30	40	50
Acid value	8	1.98	1.97	1.99	1.95
	10	1.97	2.08	1.96	1.97
	12	1.99	1.98	1.96	1.96
Free fatty acid	8	0.99	0.99	1.00	0.98
	10	0.99	1.05	0.98	0.99
	12	1.00	0.99	0.98	0.98

The results show that, the acid value and the free fatty acid (FFA) of the extracted pomace oil ranged from 1.95 to 2.08 mg KOH/g oil and from 0.98 to 1.05 %, respectively under different studied parameters. Furthermore, the contents of free fatty acids and acid value are not affected by the studied parameters of pomace oil extraction process.

Cost analysis of the oil expeller machine:

The industrial cost one of the important targets for any market, it is difficult to produce high quality with low cost, but this study aimed to extract the crude pomace oil with the optimum industrial cost, by determine values of the operating parameters affected the performance of the machine and the quality of the product. The cost analysis for the machine was estimated under the optimum operational conditions in this study which selected to be screw speed of 20 rpm and nozzle diameter of 8 mm. The calculation showed that, the oil expeller machine hourly cost found to be 27.57 LE/h. Consequently, the operational cost for the machine found to be 249 LE/ton with ability of extract 8 kg/ton of crude pomace oil approximately. The average cost for marketing the olive pomace oil is 45 LE/ kg. Hence a cost reduction of 30.83% was obtained when using the proposed domestic unit.

4. CONCLUSION

The functional parameters evaluated in the study included nozzle diameter of 8, 10 and 12 mm and screw speeds of 20, 30, 40 and 50 rpm. The results obtained showed that, the nozzle diameter and screw speed showed negative relationship with the oil yield and the extraction efficiency. However, a positive relationship was detected with the throughput capacity. The oil extraction rate was found to increase with increase in screw speed. While, increase in screw speeds from 20 to 50 rpm was observed to decrease oil extraction yield and extraction efficiency. The best extraction condition was 20 rpm screw speed and 8 mm nozzle diameter which gave oil yield of 7.89% and extraction efficiency of 69.82%. The results of this study are useful in optimising the design of presses for oil extraction.

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تأثير عوامل تشغيل ماكينة استخلاص الزيت بواسطة البريمة على استخلاص زيت تفل الزيتون

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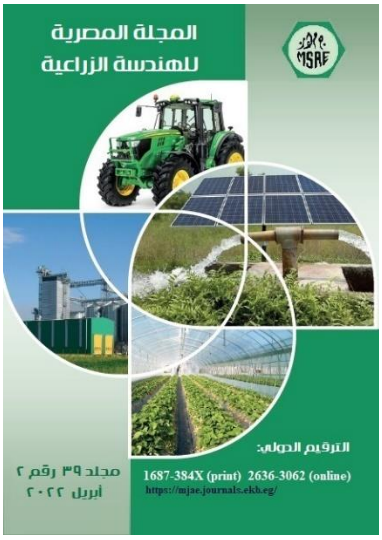

الكلمات المفتاحية:

طارد الزيت؛ تفل الزيتون؛ الاستخلاص؛ جودة الزيت؛ التكلفة.

الملخص العربي

تم اجراء تجربة لدراسة تأثير اداء ماكينة استخلاص الزيت باستخدام البريمة على عملية استخلاص زيت تفل الزيتون حيث شملت عوامل الدراسة : قطر فوهة الخروج (٨، ١٠ و١٢ مم) وسرعة البريمة (٢٠، ٣٠، ٤٠ و٥٠ لفة/دقيقة) وذلك للحصول على ظروف تشغيل مثالية للماكينة من اجل الحصول على اعلى كمية للزيت المستخلص. اوضحت النتائج التي تم الحصول عليها وجود علاقة عكسية بين قطر فوهة الخروج وسرعة البريمة مع كمية الزيت المستخلص وكفاءة الاستخلاص بينما كانت العلاقة طردية مع سعة الانتاجية للماكينة. لوحظ زيادة كلا من معدل استخلاص الزيت ونسبة المنتج الخارج من عملية الاستخلاص وانخفاض نسبة فاقد الاستخلاص عند زيادة سرعة البريمة بينما ادت الزيادة في قطر الفوهة الى زيادة فاقد استخلاص الزيت ونسبة المنتج الخارج وانخفاض معدل استخلاص الزيت. كما انخفض وقت الاستخلاص بزيادة سرعة البريمة وقطر الفوهة. أظهرت النتائج ايضا ان اعلى كمية من زيت تفل الزيتون كانت عند استخدام سرعة بريمة ٢٠ لفة / دقيقة وقطر فوهه ٨ مم والتي عندها كانت التكاليف اللازمة للتشغيل ٢٧,٥٧ جنية/ ساعة. لم تؤثر معاملات التشغيل المختلفة على جودة الزيت. كما اوضحت النتائج امكانية استخراج زيت تفل الزيتون الخام من تفل الزيتون المجفف باستخدام ماكينة استخلاص الزيت ذات البريمة بكفاءة عالية.