Design, fabrication and evaluation of horizontal rotary separator of olive oil (Three-Phase Decanter)

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Abstract: Olive is one of the strategic products in Iran, and due to the significant cultivation area of this product, oil companies should be equipped with suitable processing equipment. Unfortunately, despite the high capacity of olive in Iran, oil companies are equipped with imported machines. In this study, the construction and evaluation of the Three-counter device of Iran has been developed. The machine has three oil, water and olive pulp outputs. In order to evaluate the machine, the amount of moisture content and fat extracted from the machine was checked at 2500 and 3500 rpm and 30% and 45% water content. Also, four different samples Manzallina, Fishemi, Kalamata and Oily were used in this experiment. The main components of the machine include an electric motors chassis, machine axis, spiral conveyor and compartment. The evaluation of the device showed that the highest and lowest moisture and fat were obtained at 2500 and 3500 rpm, respectively, with a moisture content of 45% and 30%, respectively. The highest moisture content of the device was for the Manzanilla sample with 54.2% and the lowest for the Fishemi sample with 30.12%. Also, the highest and lowest amount of fat output of pulp that measured, was for oily samples (11.2%) and Kalamata (5.4%), respectively.

Keywords: Olive, oil, water, pulp, moisture, fat

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1 Introduction

Olive is one of the oldest plants on earth, and about 1200 varieties have been identified (Borràs et al., 2015). Olive because of the significant amount of oil and unsaturated fatty acids is human attention (Herrera-Cáceres et al., 2017). Also, an average of five kilograms of olive fruit can be extracted from about 1 liter of oil (Trapani et al., 2017). Olive plant cultivates as a strategic product in countries that have favorable weather (EI-Soaly, 2008). Because of the chemical properties, it is not possible to store olive fruit in storage for a long time, so it should be transported as soon as possible to the oil extraction plant for oil extraction (Tamborrino et al., 2015). The method of extracting oil from olive fruit has evolved over time and, to a degree, is different from other oily seeds (Leone et al., 2015). Olive oil is the only oil that can be used after extraction and does not require secondary processes (Kiritsakis et al., 2017). Despite the high level of olive cultivation in Iran, no major research has been carried out on olive oiling problems, and there is no reliable report regarding the optimization of the oiling process in the country.

Olive processing machines in Iran are made from Italy, Spain and Germany (RAPANLI, PIRALYSIS, Omega and Olivia from Italy, Spanula from Spain and West Falio from Germany) with a capacity of between 100 and 3000 kilograms of grain Olives vary in hours. The different stages of the process of extracting olive oil by centrifugation (rotary press) are described in the

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following diagram (Figure 1). This diagram is a general process from the olive oil processing line by the rotary press, which is usually used for high capacities in olive oil factories and large workshops.

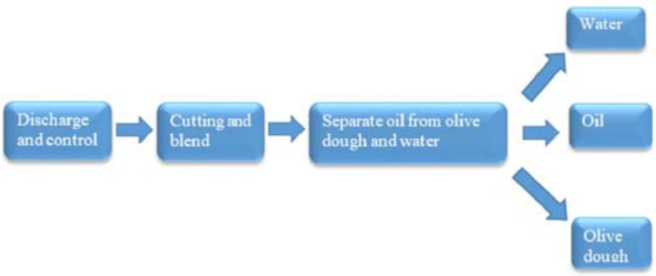


Figure 1 Process diagram of olive oil extraction by centrifugation

The researchers also performed research on the production of olive extraction machine as well as mechanical properties of olive oil in order to optimize the extraction devices.

Ghamary et al. (2010) have performed a research about mechanical properties of two kinds of olive, yellow and oily. For every olive three dimensions including width, diameter and volume were measured and base on that, physical properties like geometric diameter and sphericity were determined. They reported appropriate angle to cutting both kind of olive is 27.7 degree and average hardship for olive flesh is 2.392N and for olive core is 265.8 N. Kılıçkan and Güner (2008), under pressure loading had obtain the physical and mechanical properties of olive that at speeds of 2 mm s^{-1}, minimum of rupture force for flesh of olive was 57.38 N and for olive core was 320 N. Also, maximum of rupture force at speeds of 6 for olive flesh was 0.33 and for olive core was 18.34. In addition, they claimed that raise of push button speed causes increase power and rupture force.

Moghadasi (1998) performed research on oil extraction from oilseeds and developed a machine of snail type. This machine includes a press that is used to compress dry oily seeds. Also, the use of these presses for olive seeds is possible if the olive grain moisture content is reduced naturally or artificially by less than 10%, which in each case causes a significant reduction in the quality and quantity of olive oil (Moghadasi, 1998). Fletcher et al. (1965) fulfilled an investigation about the speed of force on the mechanical properties of fruits. The diameter of Planning used was 35/6 mm, which was compressed a full sample of fruit. The results showed that the biological critical point was seen at low and medium loading rates (Fletcher et al., 1965). Caponio et al. (2002) examined the effect of temperature variations in the hammer shredder during the preparation of the olive pulp before the oil was extracted during an experimental experiment using polar compounds and HPSEC analysis. In this test, a three-temperature, 12, 16 and 20 degrees centigrade of olive oil was applied by a hammer shredder on a laboratory scale. The results showed that the chopper unit had a negative effect on the quality of the extracted oil. The oil obtained at a high temperature by the chopper unit was more sensitive to oxidation than the oil that was prepared at the lower temperature of the crushers (Caponio et al., 2002).

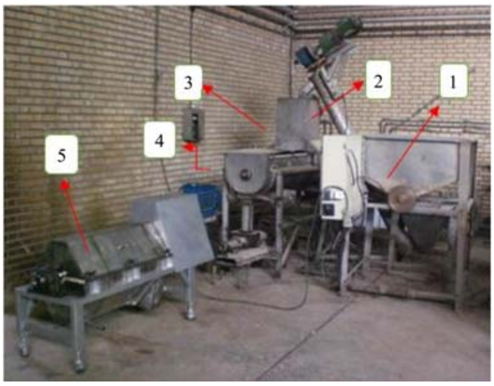
Servili et al. (2003) showed that the effective conditions for mixing olives, such as the temperature and time of exposure of the olive pulp in contact with air, steam and the phenolic composition of pure olive oil, will result in the resulting olive oil. The optimum heat and time of exposure of the dough to the air were determined by modeling the reaction surface. For 30 minutes, contact with air, 22 degrees Celsius, and in airless mode, obtained 26 degrees Celsius temperature for the Frantio and Moralo species. Kubasek et al. (2006) carried out research on how heat dissipated in pressurized oil was affected and claimed that heat release necessarily depends not only on direct contact but also on the free conductivity of heat energy, and the viscosity of foods affected by these factors (Kubasek et al., 2006).

According to the plan for the development of olive cultivation in Iran, it is necessary to investigate and study the growth of the cultivated area in order to determine the best conditions for the extraction of olive oil, in order to preserve the properties of this oil, it is worthwhile comparing to the construction of the extraction line of olive oil in Inside the country. The purpose of this research is to make the machine tool in semi-industrial dimensions and complete the technical knowledge of making the processing line and extraction of olive oil in the country and native to this industry.

2 Material and Method

2.1 Device layout

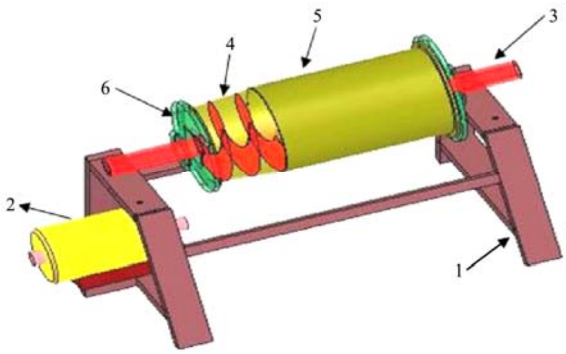
After collecting and installing the complete parts on the chassis, it was transferred to the centrifugal machine to transfer it alongside the pre-made processing line, to establish a connection between the mono pump and the three-counter (centrifuge) to inject the olive pulp inside the mixer. (Figure 2).



1. Tank unit and washer olive 2. Olive lifter unit 3. Crusher unit 4. Mixer unit 5. Three counter (centrifuge) unit

Figure 2 Rotary pump (centrifuge) and olive oil processing line

Based on the actions taken, the first step was to review and prepare technical and executive plans for the Three-counter based on the dimensions and capacity selected in the project (Figure 3). Since the machine is used to separate the various phases of the olive pulp, it should be used to make the steel used in making the food industry equipment (Figure 4).



1. Chassis 2. Electromotor 3. Axle of machine 4. spiral conveyor 5. Encasement 6. Flange retaining of encasement on axle

Figure 3 Horizontal rotary separator pump

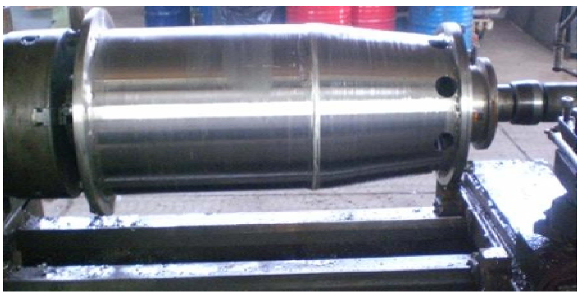


Figure 4 A view of the machined shell

2.2 External rotary pump shell

Due to the fact that the centrifuge has a high rotational speed, this shell should be as smooth as possible to avoid vibration during operation and with the least variation in weight it can be balanced. After construction of the cone, the cylindrical shells in the steel market with the dimensions of the cone were not compatible; therefore, the cylindrical section of the encasement was ordered and made using the rolling process. Then it was machined, welded and drilled (Figure 5).

Figure 5 View of the conical shell before and after the machining operation

2.3 Main shaft and spiral conveyor

The main shaft is not only the base of the machine but also the inlet (injecting) of the olive pulp into the encasement, as well as the oil outlet from the chamber to the outside of the device. Before making the helical blades and installing them on the main shaft, the shaft was initially designed to make the crust (Figure 6). By installing the crust on the shaft, the shaft helical blades were prepared and, by preparing the crust and helical crowns, welded and mounted on the main shaft.

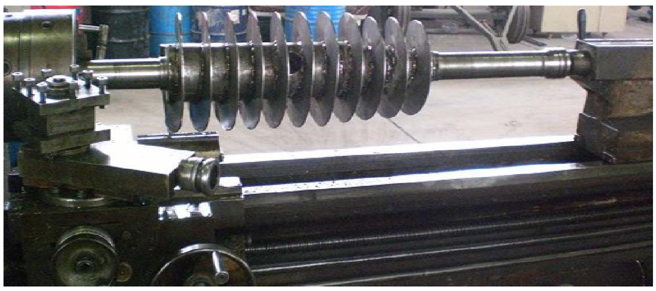


Figure 6 A view of the position of the shaft and the helix

2.4 Calculate the diameter of the axis of the Three-Counter

The total volume has been calculated based on the determined dimensions of the units of the processing line. Computing of the device are mentioned in equations (1)-(16). It should be noted that all calculations were based on the processing line of the device and if the series of factors such as the volume change, the calculations must change.

Weight of pomace and water (15/100) per cubic meter of olive seed:

$$650\ \text{kg}\times(15/100)+650\ \text{kg} = 747\ \text{kg} \quad (1)$$

The weight of the dough and water in the Three-counter:

$$0.028\times747\text{N}\times9.81 = 205.18\ \text{N} \quad (2)$$

The torque obtained in the Three-counter:

$$205.18\text{N}\times(300/2)\ \text{m} = 30777.8\ \text{N.m} \quad (3)$$

40% torque was added in terms of dynamic loads:

$$30777.8+8.8\text{N.m}\times(40/100) = 30780.82\ \text{N.m} \quad (4)$$

Responding forces at the two backrest of decanter (Figure 7):

$$F_1= F_2 = 205.18/2 = 102.6\ \text{N} \quad (5)$$

Force per unit length of Three-counter:

$$205.18/700 = 0.29\ \text{N mm}^{-1} \quad (6)$$

The weight of the Three-counter is about 80 kilograms (800 N), which can be distributed in the backrests, so:

$$F_A = F_B = 102.6 + (800/2) = 502.6\ \text{N} \quad (7)$$

Therefor:

$$M_{\max} = 502.6\times(700/2) - 0.29\ (700/2)\times(700/4) = 158147.5\ \text{N mm} \quad (8)$$

M: Maximum bending torque.

40% of maximum flexural torque is added due to dynamic forces, thus:

$$158147.5 + 5.5\times(4/100) = 221406.5\ \text{N mm} \quad (9)$$

Ultimately:

$$\frac{1}{2}\pi C^3 = \frac{\sqrt{(43088/95\times3)^2+(221406/5\times3)^2}}{\frac{276}{2}} \Rightarrow 29.23\ \text{mm} \quad (10)$$

C: Radius of decanter shaft.

Horizontal rotary separator pump (Tree-counter) has rotational speed of 3000 rpm. The distance between the encasement (external shell) and the helical (internal part) relative to each other causes the linear movement of the material inside the tertiary canter. Hence:

$$T = F\times r = 197.8\times(0.28/2) = 27.7\ \text{N m} \quad (11)$$

T= the torque required to start the spiral movement (N m); F= Force applied at the beginning of the spiral movement (N); r= Spiral radius (m).

Therefore:

$$P_1= T\times\omega = 27.7\times(2\times3.14\times3000/60) = 8697.8\ \text{W} \quad (12)$$

P_1: Power of rotation (W); ω: Angular velocity (Radian per second).

Also:

$$V = \frac{np}{60\times1000} = 100\times70/60000 = 0.12\ \text{m s}^{-1} \quad (13)$$

V: The speed of the material inside the three-counter (m s^{-1}); n: Spiral speed (round per minute); p: The spiral step (mm).

$$P_2 = F\times V = 197.8\times0.12 = 23.7\ \text{W} \quad (14)$$

That P_2: Power to move materials (W).

$$P_3 = \frac{F\times L}{t} = 402.5\times9.81\times0.70/3600 = 0.76\ \text{W} \quad (15)$$

That P_3: Power consumption for material transfer over the Three- counter (W); F: Force applied at the beginning of the spiral movement (N); L: Length of route (m); t: Time (s).

$$\text{Ultimately: } P_{(total)} = P_1+P_2+P_3 = 8722.27\ \text{W} \quad (16)$$

2.5 Device chassis

After the preparation of the shaft, the encasement, the poles, and the covers of the encasement were compared to their assembly, then the horizontals were installed. After the construction of the chassis, the centrifuge device and its power system were manufactured and controlled by installing it on the chassis (Figure 7). It should be noted that after installing the parts on the chassis, controlling the distance between the cylinder and its protective and rotating the rotating parts in order to control the fluidity of their rotation, the rotating parts were reopened on the chassis and used to balance them. For this purpose, the spiral and the encasement was united in a single turn, and in the second stage, it was balanced by installing a spiral inside the encasement.

In the final stage, the balance was shifted to the power shaft, along with the belt and coupler.

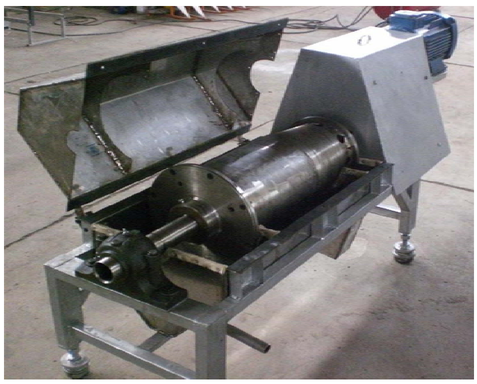


Figure 7 Components and complete parts of a rotary horizontal separator pump (Three-counter) of olive oil

2.6 Preparation and mechanical properties of samples

In order to mechanize the processing of olive products, the physical and mechanical properties of olive should be analyzed. In general, the physical and mechanical properties of agricultural products as a basis for the design and construction of machinery and equipment for the transfer, grading and processing of agricultural products have always been considered. In general, the design of agricultural machinery, regardless of these parameters, is incomplete and Leads to poor results. In this research, the physical, mechanical and aerodynamic properties of four varieties of olive oil of Manzallina, Fishemi, Kalamata and Oily were studied. Samples were collected from the research station of Rudbar Ministry of Jihad-e-Agriculture, located in Gilan province. Four trees of each cultivar were randomly selected and about one kilogram of olive fruit was harvested from different areas of each tree.

In order to measure, evaluate and determine the dynamic behavior of olive samples, the Santam SMT-20 test material and Load Cell 500N in a single axial compressive test was used. The purpose of the single-axial pressure test is to draw force-deformation curves of olive between two plates at 8 mm min^{-1} (Vursavuş, & Özgüven, 2004). The device consists of three main parts: fixed jaw, moving jaw, and screen. Performing the test with 20 samples of each type, which were randomly selected was done. In each experiment, according to the force-deformation diagram, the breakpoint was determined and rupture force of the samples was read. Also, the energy consumed for breaking the olive sample was obtained by calculating the surface under the force-deformation curve, and by dividing the amount of fracture energy into the sample volume, the amount of specific deformation was calculated.

3 Evaluation of device

3.1 Evaluation of mechanical properties

The rupture force was measured for all olive samples. With reference to Figure 8, it can be concluded that there was a direct relation between the thickness of the olive and the rupture force. The highest rupture force was observed in Manzallina sample with a thickness of 18.1 mm and force of 181.36 N and the lowest in the oily sample with a thickness of 14.42 mm and force of 70.55 N.

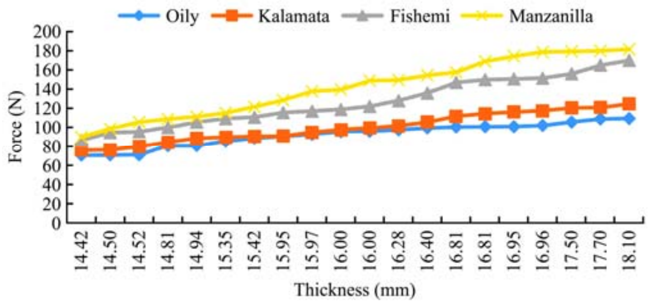


Figure 8 Changes of rupture force in olive cultivars

Also, rupture energy was obtained by calculating the level below the graph. In regard the relationship between the rupture energy and the rupture force, with increasing the diameter of the failure energy, also increased. According to Figure 9, the Manzanilla, Fishemi, Kalamata and oily varieties had the most and the least rupture energy.

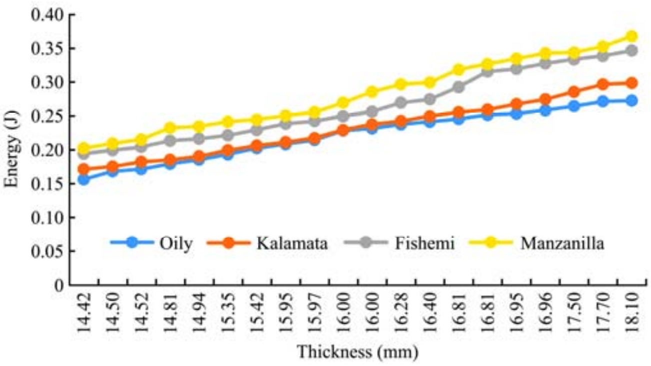


Figure 9 Changes of rupture energy in olive cultivars

The mean rupture force, rupture energy and toughness were shown in Table 1. Fishemi and oily varieties showed the highest and lowest toughness with the values of 0.081 and 0.045 J mm^{-3} respectively. Also, according to Table 1, the results of the comparison of the mean energy, force, and toughness in different varieties were different. Lavasani et al. (2007) studied the Mari and Oily variety and obtained maximum force, maximum energy and toughness at a significant 1% level. They obtained the highest amount of rupture force, fracture energy and toughness for oily sample respectively, 60.91 N, 152.181 J and 0.053 J mm^{-3} at the time of six days after harvest, and the lowest amount of rupture force, fracture energy and toughness for Mari sample was reported.

Table 1 Mean and comparison of the average effect of sample on mechanical properties of olive species

Sample	Rupture energy (J)	Rupture force (N)	Toughness (J mm^{-3})
Manzanilla	0.280 ^{A}	141.315^{A}	0.067^{A}
Kalamata	0.231^{C}	99.900^{B}	0.050^{B}
Fishemi	0.263^{B}	126.294^{C}	0.081^{C}
Oily	0.221^{B}	92.264^{A}	0.045^{C}

Note: In each column, averages with common alphabets do not have a significant difference.

3.2 Evaluation the effects of variables

After the fabrication and setting up the Three-counter machine, according to its intended capacity (about 350 kg h^{-1} input materials), the amount of olive was provided (about 750 kg) and fed the processing line towards crushing. By preparing olive dough, it was injected into the rotary pump according to the treatments (two different rounds of the rotary pump and two percent water content). Then the amount of fat and moisture of output were measured.

For better mixture the operator of device should add some water. It is be noted that content of water depend on volume of device. Also, the moisture content of olive sample play important role in performance of device. Analysis of variance was performed to evaluate the effects of speed, water content and moisture content of olive (Table 2). Duncan's Multiple Range Test was used to performance of factors. According to the analysis table for variance, the speed and content of water at 1% level and olive sample index were significant at 5% level. Also, AB effect was significant at 1% level while effects AC and BC at no level were insignificant.

Table 2 Analysis of variance of moisture

Source	Sum of Squares	df	Mean Square	F-value	p-value
A-Rpm	3073.38	1	3073.38	958.13	<0.0001
B-Water content	145.98	1	145.98	45.51	<0.0001
C-Olive	33.56	3	11.19	3.49	0.0193
AB	724.79	1	724.79	225.95	<0.0001
AC	23.05	3	7.68	2.39	0.0741
BC	20.54	3	6.85	2.13	0.1021
Residual	266.24	83	3.21		

Analysis of variance for evaluation of velocity and water parameters has a significant effect on the moisture content of output materials of device. As a result, the final shape of the model for Manzanilla, Kalamata, Fishemi and oily varieties are presented in Equations (17) to (20), respectively.

$$\text{Manzanilla model} = -0.972917 + 0.0166104\times\text{Rpm} + 2.1015\times\text{Water content}+-0.000732722\times\text{Rpm}\times\text{Water content} \quad (17)$$

$$\text{Kalamata model} = 0.477083 + 0.0169354\times\text{Rpm} + 2.04206\times\text{Water content}+-0.000732722\times\text{Rpm}\times\text{Water content} \quad (18)$$

$$\text{Fishemi model} = 10.3854+0.0144788\times\text{Rpm}+1.93383\times\text{Water content}+-0.000732722\times\text{Rpm}\times\text{Water content} \quad (19)$$

$$\text{oily model} = 0.06875+0.0166188\times\text{Rpm}+2.05761\times\text{Water content}+-0.000732722\times\text{Rpm}\times\text{Water content} \quad (20)$$

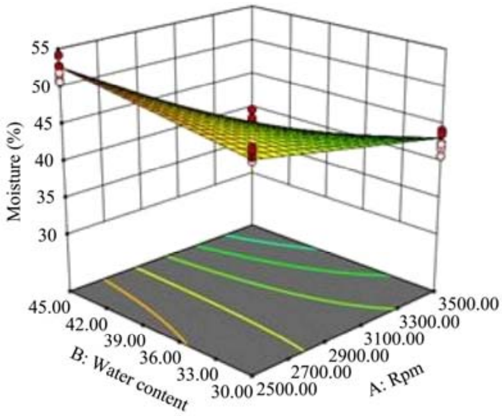
The Figure 10 shows the effect of the variables studied on the moisture content of the device output using different olives samples. The amount of moisture content of olive pulp output is one of the criteria for the device's performance detection. In other words, if the moisture content of the olive oil output is lower, it indicates that the separation of the machine is better. According to the Figure 10 the maximum moisture content was 2500 rpm and the initial water content was 45%. It should be noted that this process was true for all tested samples.

According to the Figure 11 it can be concluded that the amount of fat had direct proportion with speed of the device and inversely proportion with the ratio of water content. As can be seen in Figure 11, the maximum fat content of the Oily sample was 11.2%, at 2500 rpm and 45% moisture content. Also, the lowest fat was obtained from the Kalamata 5.4% fat that was extracted at a rate of 3500 rpm and a moisture content of 30%.

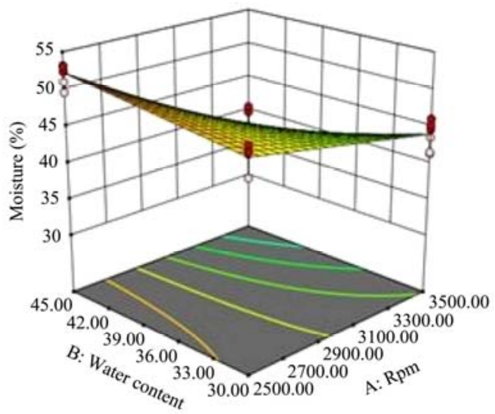
The standard oil content in the pulp was 5%-11%. Since the amount of oil present in the various varieties of olive oil were 30%-54%, by comparing the percentage of remaining fat in the depreciated waste from the three-counter of the table. The amount of performance of the machine made, compared to the machines that were available inside the country (Table 3).

Table 3 The results of three samples of output dough from active oil companies in Iran

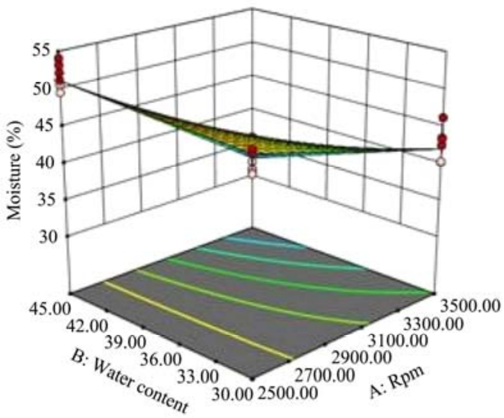
Moisture (%)	Fat (%)	Capacity (ton h^{-1})	Producer company	User company
41.12	5.26	3	PIERALISI	White river
41.7	5.38	1	PIERALISI	Gold olive
40.2	4.84	2.5	PIERALISI	Green land



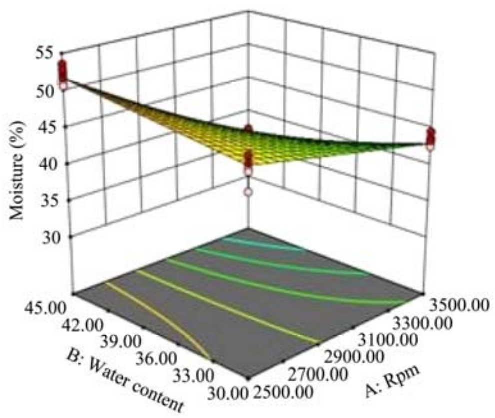
(a) Manzanilla



(b)Kalamata

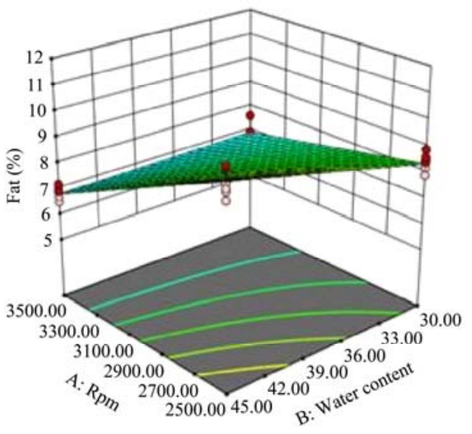


(c) Fishemi

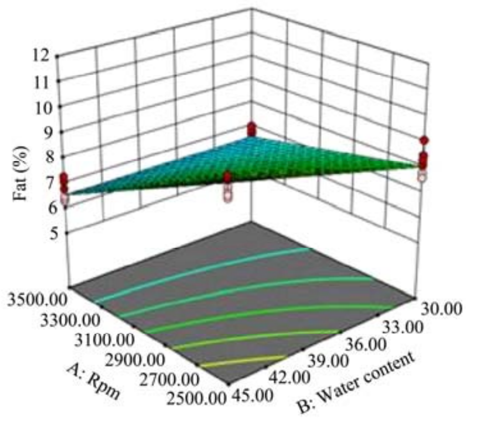


(d) Oily

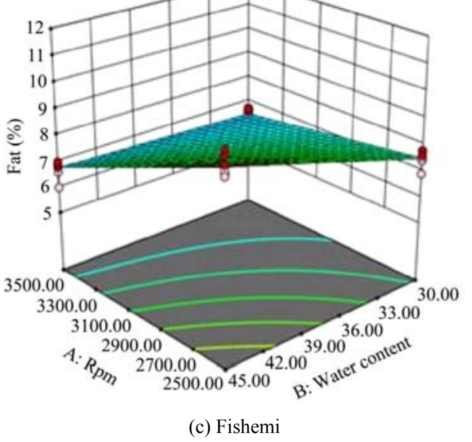
Figure 10 Results of the surface method of response of velocity and water content variables on the moisture content of waste pulp



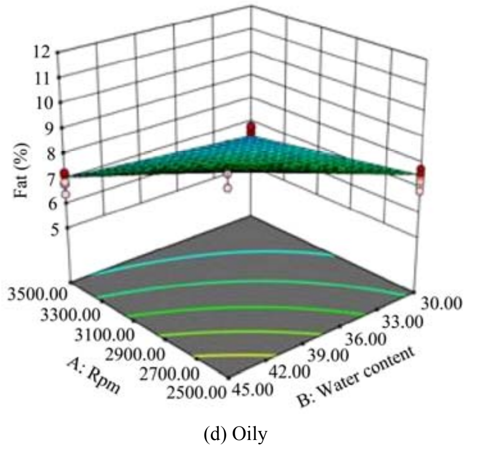
(a) Manzanilla



(b) Kalamata



(c) Fishemi



(d) Oily

Figure 11 Results of the surface method of response of velocity and water content variables on the fat content of waste pulp

4 Conclusion

Due to the results of the evaluation of the Three-Counter, it is seen that increasing the amount of water added to the olive pulp will release more of the oil from the olive dough. Also, increasing the cylinder's circumference leads to a decrease in the moisture and fat content of the olive pomace, which will increase the oil extracted from the olive dough. It should be noted that the quality of olive oil depends on the conditions for processing olive dough in units before the centrifuge machine, such as time and time of harvesting, temperature of the mixer unit and the time of the mixer unit. By comparing the percentage of residual fat in the waste pulp from the rotary pump and the devices located in the oil companies, it is seen that the amount of residual fat in the waste pellet is made within the limits of the permitted value. The amount of fat and less moisture produced by the processing lines of the lubrication companies are due to the application of the highest mechanical and thermal conditions in the lubrication stages. Also, failure to observe the appropriate mechanical and thermal conditions in different stages of oil extraction leads to a sharp decrease in the useful properties of the medicinal oil.

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