ULTRASOUND-ASSISTED EXTRACTION OF OLIVE OIL: A PRELIMINARY ECONOMIC ANALYSIS

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Abstract

The objective of this work was to perform a preliminary economic analysis of the ultrasound-assisted extraction process of olive oil and compare it with the manufacturing costs of the conventional extraction process. The DWSIM software was used for economic modeling considering data found in the literature; the five cost parameters were considered. The results showed a cost of USD 126.50/kg of olive oil in the proposed process. Although expensive, about 54,350 bottles more of oil could be produced due to the higher yield that can be obtained. In parallel, about USD 11,350,000.00 could be earned in one year of operation. In this sense, more research must be done to demonstrate the economic viability of this type of industry, to improve the operations and the costs of manufacturing until the process becomes profitable.

Keywords: olives, separation, food industry, cost analysis, process scale-up.

1. Introduction

The olive tree (*Olea europaea L.*) produces olives, which are used to produce olive oil, a product widely consumed worldwide, particularly in the Mediterranean countries (NUNES et al., 2016). Of great importance for agribusiness, Brazil is among the ten countries with the highest consumption of olive oil and is the world's second-largest importer, and the production has been promoted mainly in the southern region of the country, with about 500 hectares of cultivated area (EMBRAPA, 2015). Globally, the cultivation of the olives covers about 10 million hectares of land, and the volume of olive oil production between the years 2018-2019 reached 2.5 million tons. According to the International Olive Oil Council, the 2020/21 crop year is expected to reach 3,119,400 tons of production worldwide (IOC, 2021).

Besides, olive oil is also well known for its nutritional and bioactive properties, which play a key role in human health (BRUSCATTO et al., 2017). The main compounds involved in its nutritional effect are monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), and saturated fatty acids (SFA), mainly in the form of esters with glycerol (triacylglycerols), which represent more than 98 % of its total content. They are responsible for containing protective effects against cardiovascular diseases (BALLUS et al., 2014). Likewise, phenolic compounds, as secondary metabolites, are of interest, however, with antioxidant, anti-inflammatory, and antimicrobial properties (CAVALHEIRO et al., 2015).

In terms of the oil extraction process, the techniques are exclusively through mechanical and physical operations. Conventionally, the process begins with olives cleaning and washing, followed by crushing, the stage of which favors the cell rupture of the pulp to allow the oil to escape from the vacuoles and form larger droplets. Thus, the olive paste obtained goes through the malaxation stage, which consists of the mass mixture for a given time and temperature to form a continuous liquid phase, yielding oil, which can be separated into the other two phases (liquid and waste) by centrifugation (BAKHOUCHE et al., 2014).

However, malaxation is considered to be the main bottleneck in the extraction process, because the machine operates in batch and works between continuous devices, causing losses in efficiency due to the waiting time and, therefore, decreased yield (AMIRANTE et al., 2017).

Currently, many oil extraction techniques have been explored not only for research purposes but at an industrial level. Supercritical fluid extraction (SFE) and microwave-assisted extraction (MAE) are applied to obtain vegetable oils (PICOT-ALLAIN et al., 2021). However, the use of ultrasound-assisted extraction (UAE) is recognized for being economically viable (CHEMAT et al., 2011).

The UAE is an emerging technology with potential for application in the food industry. It can offer numerous advantages in the olive oil processing field when compared to traditional methods, among which stand out the mechanical and thermal effects useful to guarantee oil productivity, less processing time, better flavor, texture, aroma characteristics, and color (TAMBORRINO et al., 2021; KUMAR et al., 2021). Stankiewicz & Moulijn (2000) report that these characteristics also define process intensification, whose approach includes initiatives that improve the use of raw materials to increase production capacity within a given volume of equipment, without affecting the quality of the final product. At the same time, the UAE is a key technique concerning the sustainable concept of green technology, because the process is cleaner, with low production of residues and toxic compounds and, consequently, less environmental impact (CHATEL, 2018).

The application of ultrasound as an auxiliary device to olive oil processing machinery could provide better performance regarding the time and temperature of malaxation in addition to transforming a batch process into a continuous one. Some recent studies show that the use of UAE increases the separation and, consequently, higher oil yields can be obtained (JULIANO et al., 2017). Nevertheless, its implementation on a larger scale would involve new investments and costs related to the ultrasonic apparatus. Also, little research has demonstrated the manufacturing costs and scaling up procedures for the UAE (VIEIRA et al., 2013).

Considering that the current market requires processes and products with competitive costs, the industrial sector must invest in technological innovations and tools that evaluate the process economy, making it possible to identify the future viability and profitability for the producing companies (FAO, 2017).

In this sense, the objective of this study was to perform a preliminary economic analysis of the UAE process of olive oil and compare it with the manufacturing costs of the conventional extraction process emphasizing the malaxation step.

2. Material and methods

2.1. Process description

In this study, the database was obtained from existing values in the literature (JULIANO et al., 2017; BEJAOUI et al., 2018). The conditions used were: 500 kg of olives, constant rate of 200 kg/h of olive paste flow, temperature of 27ºC, time of 30 min, ultrasound power 900 W, frequency 900 Hz, and the water content, and water content 30% added to the paste.

The unit operations of the process were based on a pilot processing plant operating 24h/day, 330 days/year, during 3 daily shifts, where the discounted 35 days will be allocated to other operations, such as maintenance and repairs of the facility.

The core of the process is an ultrasound coupled to the malaxation step for better efficiency in oil extraction. Besides, defoliation, cleaning, washing, crushing, centrifuging, and tank storage processes were considered. The process flow diagram (PFD) with the respective operations is shown in Figure 1.

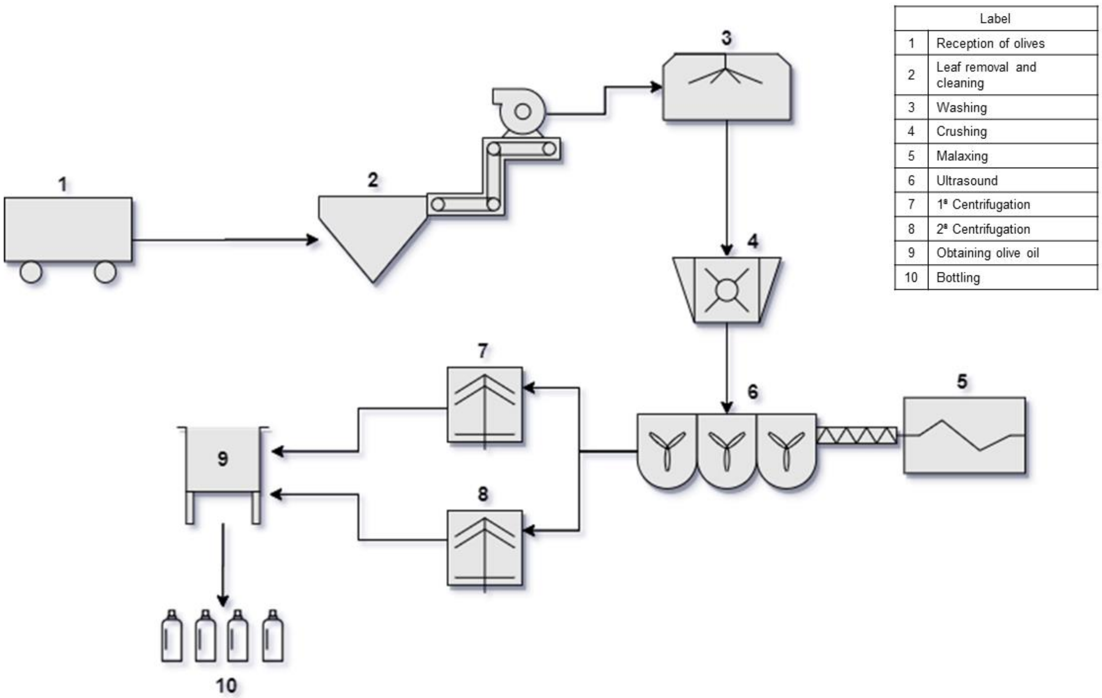

Figure 1. Process flow diagram of olive oil production.

2.2. Economic analysis

The simulation of the process was performed using the open interface software DWSIM v6.4.6, a chemical process steady state simulator, which was previously described in Peshev & Livingston (2013) and Kristianto & Zhu (2017), contributing to the projection of other engineering processes.

To estimate the manufacturing cost (MC) of ultrasound-assisted extraction (UAE) of olive oil, this study considered the methodology proposed by Turton et al. (2009). The calculation of MC depends on five main costs for the installation of all equipment (Eq. 1): fixed investment capital (FIC), cost of operational labor (COL), cost of utilities (CUT), cost of waste treatment (CWT), and cost of raw materials (CRM). All of these parameters are expressed as unit cost of production (USD/kg), obtained from the relationship between the MC (USD/year) and the production rate (kg/year).

$$MC = 0.304 \times FIC + 2.73 \times COL + 1.23 \times (CUT + CWT + CRM) \qquad \text{(Eq. 1)}$$

Figure 2 shows the scope of the methodology used for the economic analysis.

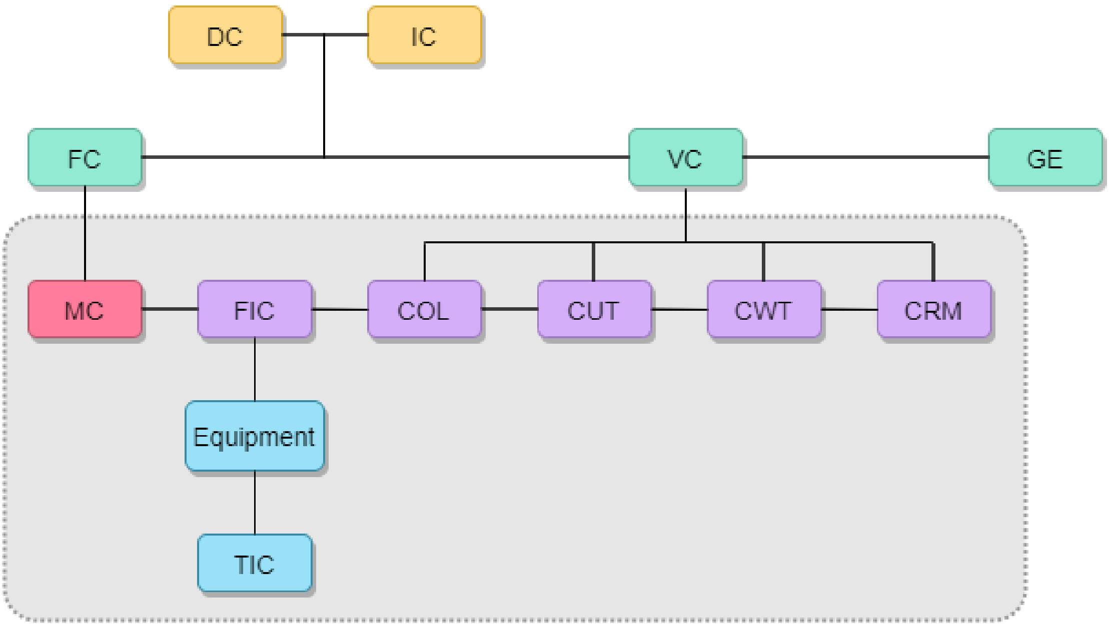

Figure 2. Representation of the cost methodology. DC: direct costs; IC: indirect costs; FC: fixed costs; VC: variable costs; GE: general expenses; MC: manufacturing costs; FIC: fixed investment capital; COL: cost of operational labor; CUT: cost of utilities; CWT: cost of waste treatment; CRM: cost of raw materials; TIC: total investment capital.

To calculate the FCI, equipment prices were considered as a function of the initial investment cost. Therefore, the FCI represents the required capital for the installation of the equipment with all the auxiliaries necessary for the complete process operation. This parameter is calculated according to the appropriate correction factors and multiplied by the corresponding factor according to the nature of each item described (PETER & TIMMERHAUS, 2003).

Except for ultrasound, the information on the main equipment that makes up the olive oil processing plant was obtained from a local company, considering the production capacity and the materials (carbon steel and stainless steel). The data for the UAE apparatus were considered from Bejaoui et al. (2018) and extrapolated from a laboratory scale to an industrial scale, as described in the following subsection.

The annual depreciation rate was considered to be 10%. The direct COL, rates, charges, and the number of workers were estimated according to Turton et al. (2009). The required CUT was based on a survey of the price charged for electricity by a local electricity company (USD 0.112 kWh). The CWT was disregarded, as the processing of the olives produces an important residue that can be reused as an input in other processes or marketed as a by-product (NUNES et al., 2016). Finally, the CRM is related to the cost of all incoming raw materials as well as their loss during the process and was calculated from the direct quotation with the supplier of a local company for acquisition in the current year.

2.3. Scale-up

Generally, the purchasing cost of equipment with different capacities is available in the literature. However, the cost for other equipment with different sizes and capacities must be estimated. The scale-up procedure to determine the purchasing cost the ultrasound was calculated using Eq. 2, considering criterion adopted by Zabot et al. (2015):

$$C_E = C_B \left(\frac{Q_B}{Q_E}\right)^M \qquad (2)$$

Where CE is the cost of the equipment with QE capacity; CB is the known base cost for equipment with QB capacity; and M is the constant depending on the type of equipment, since the cost of a specific item is a function of its size, materials used for construction and projection. The M value was collected in the literature (TURTON et al., 2009; ANDERSON, 2009). This scale-up criterion, which has been used by other authors (ROSA & MEIRELES, 2005; AGUIAR et al., 2012; ZABOT et al., 2017; VARDANEGA et al., 2017), assumes that the process will have the same performance the laboratory scale if the same conditions are used (time, temperature, yield).

3. Results and discussion

3.1. Manufacturing cost of olive oil

The economic analysis of an industrial process is focused on technologies designed to be viable within a certain time. Thus, before a plant is in operation, a budget needs to be analyzed for the purchase and installation of the required equipment and machinery (MAROULIS & SARAVACOS, 2007). Table 1 summarizes the costs of the equipment used during the extraction, including the number of units and the type.

Table 1. Costs of major equipment that make up the plant.

Item	Base unit cost (USD)	Number of units	Total base cost (USD)
1. Leaf remover	5,595.00	1	5,595.00
2. Washer	16,700.00	1	16,700.00
3. Crushing	132,000.00	1	132,000.00
4. Malaxation container	12,170.00	1	12,170.00
5. Intermediate tank	14,320.00	1	14,320.00
6. Ultrasound	240,000.00	1	240,000.00
7. Centrifuge	39,900.00	2	79,800.00
8. Filter	8,880.00	1	8,880.00
9. Pump	2,440.00	2	4,880.00
10. Storage tank	14,320.00	1	14,320.00
Total cost (USD)			528,665.00

Based on the results obtained, the equipment with the highest added value was an ultrasound, followed by the crushing machine and the two centrifuges, with values of USD 240,000.00, USD 132,000.00, and USD 79,800.00, respectively. The cost of the main equipment totaled USD 528,665.00, which represents the value of the FCI at the plant.

Besides, Table 2 shows all the economic parameters necessary to obtain the manufacturing costs of EAU of the olive oil, including the installation costs of main equipment, fees, and charges.

Table 2. Economic parameters to estimate the manufacturing cost of olive oil.

Parameter	Item/category	Value*	Unity	Cost
FCI	Main equipment's	1	USD	528,665.00
	Depreciation	10		
	Purchase rate	0.15		
COL	Base rate	6.00	USD/h, 3 shifts	156,816.00
	Number of workers	3		
CRM	Olives fruits[a]	0.63	USD/kg	942,480.00
	Water	0.05	USD/m^3	
CUT	Electricity consumption	0.112	USD/kWh	19,160.00

COM	Selling price	USD/kg	126.50

[a]Data provided by the local company.

*Correction factor.

Considering that the plant has a useful life of 10 years, the fixed annual capital required to keep the installation in operation was estimated at USD 7,893.40. The FCI represented a cost close to 45% of the total cost for the facility implementation. From the preliminary economic evaluation of the proposed process, it was observed that CRM was the most influential parameter in this study concerning other costs (FCI, COL, and CUT), totaling USD 942,480.00. Although this value is extremely high, it is directly related to the production capacity and energy expenditure of the ultrasonic machinery, which had an estimated value of 641,500 kWh per year. Additionally, the result of COM was USD 1,519,994.00 per year. The product sale price in this process was USD 126.50/kg of olive oil.

Comparatively, in other studies, the CRM for obtaining vegetable oils using alternative extraction technologies was also predominantly high (SANTOS et al., 2012, VEGGI et al., 2014). In the work carried out by Zabot et al. (2018), using the SFE, the estimated sale value of the extracted oil was USD 337.00/kg, almost 3.5 times higher than that obtained in this study.

3.2. Applicability of the process

The UAE process, as evidenced, presents some technical-economic bottlenecks for implementation on an industrial scale due to the high COM. According to the current quote from the Olive Oil Market, the selling price ranges from USD 8.00-26.00/kg (OLIVE OIL MARKET, 2021). However, the process described in this study is approximately USD 100/kg higher than the oil obtained in conventional malaxation.

However, considering that the malaxation time for both processes is the same (30 min), it is worth mentioning that the yield for UAE is higher. The average yield obtained in exclusively mechanical operations of malaxation is around 20%. On the other hand, Juliano et al. (2017), showed that the yield for ultrasound-assisted malaxation increased by approximately 5%. Although this percentage is not so high, when the values are scaled at an industrial level, the difference is notorious.

By way of exemplification, considering that a medium-sized production industry requires 250 tons of olives to operate monthly (3,000 tons per year), approximately 543,500 bottles of 500 ml of olive oil can be obtained. Regarding the proposed process with the UAE, approximately 267 tons/month of olives would be necessary, which is equivalent to an average of 597,850 bottles/month, that is, in 1 month of process, about 54,350 more bottles could be produced. Therefore, if the selling price is USD 126.50/kg of olive oil, approximately USD 11,350,000.00/year will be obtained.

It is worth mentioning that the analysis took into account a process that currently does not operate on a large scale, justifying its considerable manufacturing cost. This value corroborates with other economic analyzes found in the literature. Therefore, to ensure the commercial viability of the process, it is crucial to clearly determine the process parameters, including, for example, the possibility of increasing extraction efficiency and, thus, shortening the total time, which would lead to increased productivity.

4. Conclusion

Although the preliminary economic analysis of the UAE process presented in this study is expensive, considerable profits are expected in the medium term. These results provide valuable information about a given process and/or product, even in the case of emerging technologies. Thus, decision-making on operating conditions and initial investment costs can be weighted based on studies that confirm the technical potential of a specific process. In this regard, more research on the economic viability parameters must be performed, to obtain more information on which points should be focused to improve the manufacturing costs of the process and product until it becomes profitable on an industrial scale.

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