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Pilot-Plant-Scale Extraction of Antioxidant Compounds from Lavender: Experimental Data and Methodology for an Economic Assessment

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Abstract: The techno-economic feasibility of lavender essential oil supercritical CO_2 extraction was studied. The process was scaled up to a pilot plant, and the extraction yield, composition, and antioxidant potential of the extracts were evaluated at 60 °C and 180 bar or 250 bar, achieving a maximum yield of 6.9% and a percentage inhibition of the extracts of more than 80%. These results drove the development of a business plan for three scenarios corresponding to different extraction volumes (20, 50, and 100 L) and annual production. The SWOT matrix showed that this is a promising business idea. The COM was calculated and an investment analysis was performed. The profitability of this process was demonstrated by means of a financial analysis for 8 years, considering a selling price of 1.38 EUR/g for the extract from the 20 L plant and 0.9 EUR/g for industrial-scale plants, supported by the price curve. The sensitivity analysis showed that the price of the equipment was the factor that could most influence the robustness of the project and the business strategy, and the financial ratios evaluation resulted in a ROE value above 57% in all cases, indicating the economic attractiveness of the process.

Keywords: lavender essential oil; economic evaluation; supercritical fluid extraction (SFE); price curve; financial analysis; antioxidant potential

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1. Introduction

The continuously growing demand for natural products in sectors such as food and pharmaceuticals has led to the search for natural sources rich in bioactive substances with beneficial properties for human health to synthesise drugs and develop nutraceuticals [1–3].

One of the main commercial products derived from nature is essential oils [4,5]. Traditionally, one of the most commonly used essential oils is lavender. It stands out for having compounds with a high antioxidant and anti-inflammatory capacity such as linalool [6,7]. Conventionally, this substance predominates in cosmetic applications such as soaps and perfumes. However, in recent years, the therapeutic potential of this molecule has been tested in different ways with successful results, such as an alternative to traditional topical drugs [8]. The above properties would make it an effective substance for the treatment of skin diseases such as atopic dermatitis.

In addition, these bioactive, antioxidant, and anti-inflammatory substances play an important role in the progression of reactive oxygen species and antioxidative function, which helps to reduce the development of some types of cancer and mitochondrial dysfunction [9–11].

Regarding the method of obtaining bioactive substances, one of the most used techniques for the extraction of essential oils is distillation, specifically the type based on steam extraction. It is a simple and cost-effective technique. Nevertheless, this method has lower yields than others. Another traditional alternative is extraction with organic solvents, which is carried out at ambient pressure but has several drawbacks: the need for solvent recovery, the energy-intensive operation, and the thermal degradation and loss of valuable compounds in the purification step [12]. In recent years, new technologies have been implemented to reduce the environmental impact, such as microwave and supercritical fluid extraction (SFE), the latter being a sustainable alternative that provides extracts with high purity. Microwave-assisted extraction is a technique that combines microwave extraction and traditional solvent extraction. Although it reduces the use of solvents and offers high extraction yields, it does not avoid the use of solvents and involves significant thermal degradation of the extracts [13].

SFE overcomes the limitations of traditional methods, as it is more efficient and reduces the environmental impact by avoiding the use of organic solvents. CO_2 is usually employed as the solvent in supercritical conditions due to its non-flammable, non-toxic, and non-corrosive nature [14]. Moreover, the use of SFE has proven to be effective for obtaining bioactive compounds and mixtures such as essential oils from natural matrixes [15] and, in particular, lavender essential oil and derived compounds [16–18].

By contrast, the main disadvantage of employing this technique is that, due to the high-pressure technology required, the operating costs and the investment needed for the equipment is higher than that of other conventional processes [19], although at present the development of industrial-scale units enables us to lower equipment costs associated with SFE processes [20–22]. However, its relatively energy-intensive needs make it an economically demanding process, and usually it is restricted to the use of supercritical CO_2 extraction for high-value applications [23,24].

Some studies have proposed the extraction of lavender essential oil with CO_2 under supercritical conditions. Reverchon et al. compared this process with hydrodistillation [16]. Different modelling and working conditions have also been analysed [17] as well as water extraction techniques [25]. Moreover, some research has focused on the antioxidant property and composition of lavender extracts obtained by supercritical fluids [18].

To properly analyse the economic feasibility of an SFE process, its special characteristics should be considered. An easy approach traditionally used to predict the economic viability of this type of process is to determine the cost of manufacturing (COM) of extracts [26]. Many authors have used this method to develop techno-economic studies of supercritical extraction processes for different raw materials [21,27,28].

However, this estimation is not sufficient to make a comprehensive economic assessment. Supercritical extracts are characterised by their exclusivity, higher quality, and customised design, thus not simple substitutes of conventional extracts. Hence, the higher-quality market niche in which these products could be placed has to be strategically determined. Therefore, other economic characteristics such as profitability over the time horizon, their flexibility to price changes, and their convenience for particular strategies have to be assessed before their introduction on the market [24]. Consequently, a complete study of the economic viability of this type of process must be based on a business plan.

The aim of this study was to demonstrate the technical and economic feasibility of extracting lavender essential oil with supercritical CO_2. Based on a preliminary study at laboratory scale, the extractions offering the highest yield were carried out in a pilot plant. The extraction yield, composition, and antioxidant potential of the supercritical extracts were evaluated, data on which the economic study was based. This study involved evaluating three different annual productions, 20 L, 50 L, and 100 L. After carrying out a strengths, weaknesses, opportunities, and threats (SWOT) matrix to capture the ideas in which the interest of the project lies, the business plan was started. First, the necessary investment was calculated, formed by the cost of the equipment and facilities as well as the necessary capital and the COM. After that, the financial analysis was developed, consisting of an analysis of the income statement, the sales curve price, and financial ratios such as the return on equity (ROE), which are crucial in considering the economic value of this project. Economic profitability is not enough to ensure economic success, and for that reason a sensitivity test was performed in order to validate the robustness of the idea by considering aspects that could affect the return on investment such as global or local events, changes in the interest rate, and underestimation of items [29]. This last piece of information is highly valuable to determine the market strategy of the company.

2. Materials and Methods

2.1. Materials

Dried lavender flowers (Peñarrubia del Alto Guadiana S. L., Albacete, Spain) and CO_2 of 99.8% purity (Carburos Metálicos, Barcelona, Spain) were required for the extraction. For the chromatographic analysis, lavender essential oil and Sigma-Aldrich Spain sponsors were needed, as well as diethyl ether for analysis (Scharlab, Barcelona, Spain). For the antioxidant potential assay, ethanol absolute HPLC grade (Scharlab, Barcelona, Spain), 1,1-diphenyl-2-picrylhydrazyl (DPPH) (Alfa-Aesar, Thermo Fisher, Ward Hill, MA, USA), and L-(+) ascorbic acid (Scharlab, Barcelona, Spain) were used.

2.2. SFE Process

The supercritical CO_2 extraction tests were carried out in semi-continuous mode, according to the diagram in Figure 1. The main part is the extraction vessel, whose nominal volume was 20 L. In the process, the raw material was fed through the upper part by means of a basket, and CO_2, after subcooling, was pumped and thermally conditioned to reach the working conditions of pressure and temperature. Once the pressure in the extractor was reached, the opening of the outlet was initiated and the fluid passed to the two separators, where the process conditions were modified to cause the precipitation of those substances that may have been recovered together with the CO_2 and to allow the solvent to recirculate.

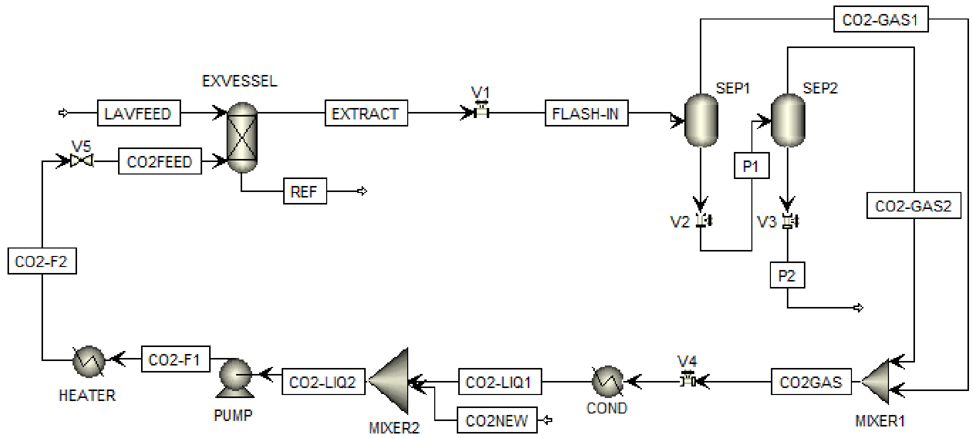

Figure 1. Supercritical extraction process flow diagram and equipment.

To develop the economic feasibility study, a solvent cycle was proposed in order to make the process more efficient. The pressure of the supercritical CO_2 was decreased after extraction until reaching 50 bar for separation of the extract, and then, in a condenser, it had to be cooled until obtaining liquid phase and conditioned in order to feed it back to the extraction vessel. The solvent cycle was fed by the two gaseous streams of the separators, and consisted of a mixer, a condenser, another mixer in which a fresh stream of CO_2 entered (assuming losses of 10% of solvent in the process [30,31]), a pump, and a heater that conditioned the CO_2 for entering the extraction vessel.

The working pressures and temperature were 180 and 250 bar and 60 °C, respectively. These conditions were selected based on previous experiments at lab scale that showed they offered the highest extraction yields. The extractions lasted 90 min with a CO_2 flow rate of 60 kg/h. Equation (1) was used to quantify the extraction yield.

$$(\%)\ Extraction\ Yield = \frac{weight\ of\ collected\ extract}{weight\ of\ fed\ lavender} \times 100 \quad (1)$$

2.3. Extracts Characterisation

Gas chromatography coupled to mass spectrometry (GC-MS) was used to evaluate the composition of the lavender extracts. The equipment used was a Varian Saturn 2000 GC-MS equipped with a HP-5 capillary column (30 m, 0.25 mm i.d., 0.25 µm film thickness). The method of analysis applied is summarised below [32]. The column temperature was set to 60 °C for 5 min. Then, it was increased to 160 °C at a rate of 4 °C/min. Finally, it was raised to 240 °C at 15 °C/min. The injector temperature was 250 °C and the detector temperature was 280 °C. An electron ionisation system with an energy of 70 eV was used. The diluted samples were analysed with 1:100 diethylether and 1 µL of the diluted samples was injected in splitless mode. The carrier gas was helium at a flow rate of 1 mL/min.

The 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay was used to estimate the antioxidant capacity of the extracts [33]. DPPH• is a stable nitrogen-centred free radical which is conventionally used to determine the free radical scavenging activities of antioxidants present in plant extracts or synthetic compounds. The reduction capability of DPPH• radical is determined by the decrease in absorbance at 517 nm induced by the antioxidant.

The procedure described in L. T. Danh et al. [18] was used. Briefly, 40 µL of extracted essential oil was mixed with 0.4 mL of 0.5 mM DPPH• solution in ethanol and the final volume was adjusted to 1.5 mL with ethanol. The control solution was prepared with 0.4 mL of the ethanolic DPPH solution with 1.1 mL ethanol. In addition, a sample of the standard antioxidant, ascorbic acid, was prepared to compare the antioxidant potential of the supercritical extracts. The absorbance of the solutions was measured at 517 nm, with three replicates, after 30 min of stirring in darkness to allow a complete reaction.

To quantify the antioxidant potential of the supercritical extracts, the inhibition percentage (I%), which corresponds to the radical scavenging activity of the extracts, was calculated with Equation (2), where A_0 corresponds to the absorbance of the control sample and A_s to that of the extracted oil samples.

$$(\%)\ Inhibition = \frac{A_0 - A_s}{A_0} \times 100 \quad (2)$$

2.4. Economic Evaluation

For the economic evaluation of the supercritical CO_2 extraction of lavender essential oil, the annual production was used as a design basis. The study was conducted for three process scales concerning the volume of the extractor: 20 L (scenario 1), which corresponds to pilot plant scale, and 50 L (scenario 2) and 100 L (scenario 3), which are more like industrial production. In addition, the production data were calculated taking into account the maximum yield obtained in a laboratory-scale extraction, which is reported in another study [34].

Economic evaluations based on the business plan strategy follow a methodology in which the process is first evaluated by a SWOT analysis (Figure 2). This method takes the information from an environmental analysis and separates it into internal (strengths and weaknesses) and external issues (opportunities and threats) to obtain the SWOT matrix.

Through the analysis of the matrix, it is possible to know without very strict calculations whether a project is interesting or whether any changes leading to improvements must be made before an economic investment is considered. If a positive conclusion is drawn from the matrix analysis, the business plan should be continued with the analysis of the total capital investment of the plant [35].

Once the necessary investment has been determined, the annual costs and revenues are calculated and then the profit and loss account. In addition, before moving on to the assessment of financial ratios, the COM will be calculated. As mentioned previously, this is a simple method for calculating the cost per kg of extract that provides useful information for classifying production costs. This information is required in the search for investors (Figure 2).

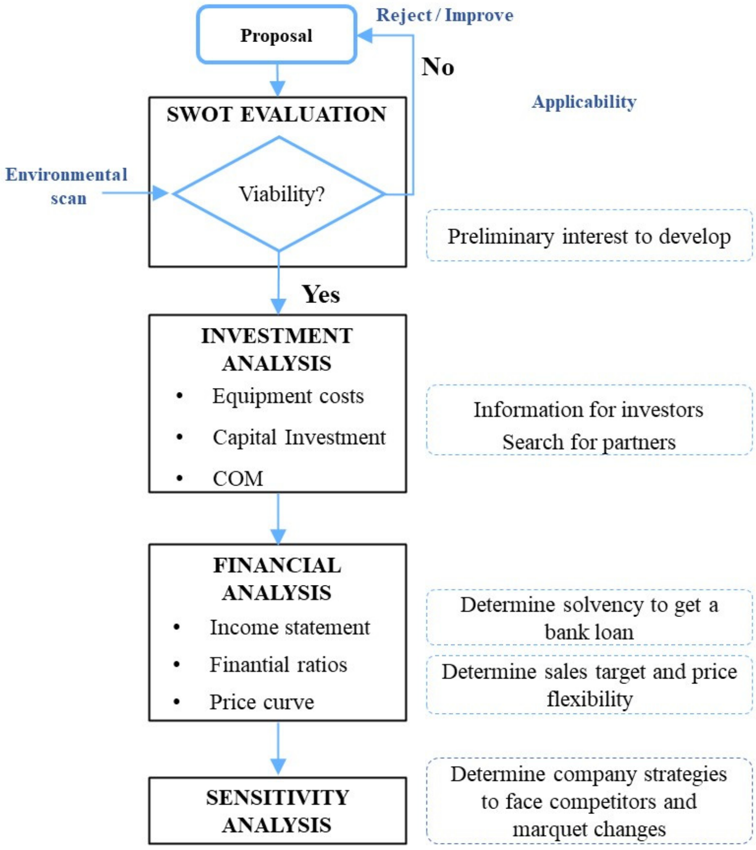

Figure 2. Flow diagram of the economic analysis based on the business plan strategy.

The financial analysis defines, for a given income statement associated with sales, a set of financial ratios used for the determination of solvency in applying for a bank loan, such as the ROE, return on investment (ROI), and earnings before interest, taxes, depreciation, and amortisation (EBITDA). Financial analysis also provides the price curve, required for the sales department to define the price flexibility and sales needs in the context of competitors. Finally, a sensitivity analysis is performed to check the influence of possible variations in factors such as equipment costs, salaries, raw materials, electricity, and interest rates on the profitability of the project to better define the robustness of the business idea in market situations not considered to be affected by global or local changes. This information would be used by the chief executive office to define the company strategies.

2.5. Data Reproducibility Analysis

Extraction experiments were carried out under two different conditions, 180 bar and 60 °C and 250 bar and 60 °C, both for a duration of 90 min and a solvent flow rate of 60 kg/h. The extraction experiments were performed in triplicate and the extraction yield value obtained was averaged. The difference in the value obtained was less than 1% in all cases.

As for the characterisation of the extracts, GC-MS analysis and a DPPH assay was performed for two different extract samples from each experiment. Concentration and absorbance were measured in triplicate to check reproducibility.

3. Results and Discussion

The technical viability of the SFE of lavender essential oil at pilot plant scale will first be discussed based on the lavender essential oil extraction yield obtained for the two different working pressures. In addition, the composition and antioxidant potential of the obtained extracts were analysed, which are considered key factors that encourage the idea of designing a commercially attractive product. From these results, the business plan can be started, and this is discussed in the corresponding section.

3.1. Lavender Essential Oil Supercritical CO_2 Extraction

For an operating pressure of 180 bar, an extraction yield of 6.2% was obtained, while for 250 bar it was 6.9%. Although this is not a very significant increase, it follows the usual trend in supercritical CO_2 extraction processes: the higher the pressure, the higher the CO_2 density and therefore the higher the solubility of the interesting compounds in the supercritical solvent [36].

Table 1 shows the mass% data for the main compounds identified in the extracts. As studies on the composition of lavender (L. Angustifolia) essential oil indicate [37], the two major components are linalool and linalyl acetate. The extracts obtained in this work concur with these results, and it can be seen that the mass percentage of linalool is approximately 32% and linalyl acetate 43%. These are interesting results from the point of view of the commercial application of these supercritical extracts, as the mass percentage of these two main compounds in the extracts is higher than in the commercial essential oil (Sigma-Aldrich) that was also analysed and which showed a mass percentage of linalool and linalyl acetate of 28 and 31%, respectively. As can be seen, the pressure increase had no clear influence on the composition. Eucalyptol, camphor, endoborneol, terpinen-4-ol, α-terpineol, nerol acetate, caryophyllene, and β-Famesene were also identified as minor compounds present in the supercritical extracts.

Table 1. Composition of supercritical extracts.

% wt	**60 °C**	
	180 Bar	**250 Bar**
Eucalyptol	3.48	4.11
Linalool	32.07	32.20
Camphor	4.24	4.58
Endoborneol	4.07	3.91
Terpinen-4-ol	3.60	3.58
α-terpineol	1.49	1.43
Linalyl acetate	43.03	43.01
Nerol acetate	2.44	2.34
Caryophyllene	2.95	2.58
β-Famesene	2.64	2.25

Regarding the study of the antioxidant capacity, by means of the DPPH method, it was observed that the two extracts showed an inhibition percentage higher than 80%, values very close to the inhibition percentage of ascorbic acid, a substance considered as an antioxidant standard. It can be stated, therefore, that the lavender essential oil obtained by supercritical technology has a high antioxidant potential. Figure 3 shows the results of the DPPH assay for each of the samples analysed.

Regarding the influence of pressure on the percentage of inhibition obtained, a small increase in its value can be observed (Figure 3) with increasing working pressure. This can be attributed to the increase in the concentration of the compounds of the essential oil to which the antioxidant characteristics are attributed.

The technological feasibility of lavender essential oil extraction with CO_2 under supercritical conditions can now be considered. High-purity extracts can be obtained without the need to apply high temperatures and by avoiding the use of organic solvents. Moreover, the antioxidant potential allows considering these natural extracts for the development of pharmaceuticals and cosmetics, which requires an economic feasibility study.

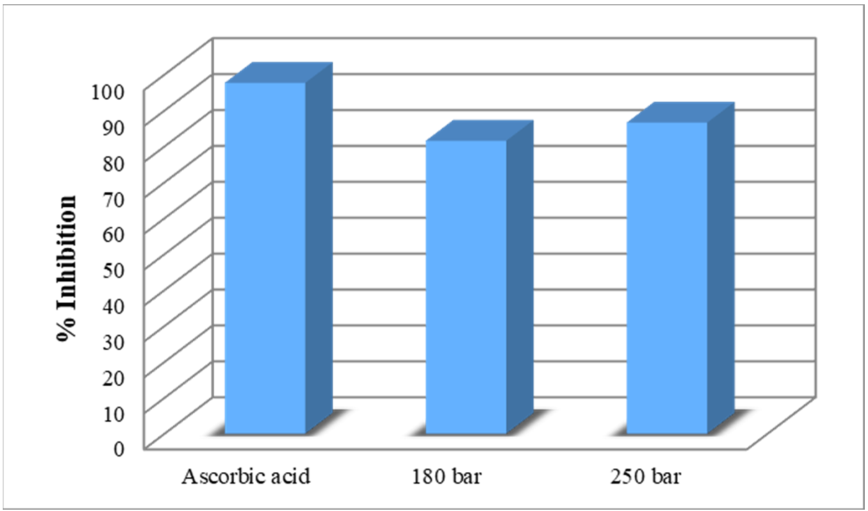

Figure 3. % Inhibition of ascorbic acid and lavender essential oil supercritical extracts.

3.2. SWOT Analysis

Table 2 shows the SWOT matrix obtained for the process of extracting lavender essential oil with supercritical CO_2. It should be noted that the SWOT matrix is a tool that depends on the current situation and future market trends [38].

Table 2. SWOT matrix for the supercritical extraction of lavender essential oil.

Strengths	Weaknesses
S1. Great availability of high-quality lavender in the area. S2. Large knowledge of the extraction process using supercritical technology and characterisation of the extracts obtained. S3. Cost advantages of patented know-how. S4. Obtention of a product with high added value and beneficial properties for health.	W1. High-cost structures. W2. Need for safety mechanisms due to high working pressures. W3. Limited financial resources. W4. Lack of access to distribution channels.
Opportunities	**Threats**
O1. Economic and social promotion of the surrounding area. O2. Use of the extracts in new and growing pharmaceutical and nutraceutical products. O3. Use of green solvents that promote compliance with health and food standards. O4. Unsatisfied customer needs.	T1. Minimum control in the final distribution. T2. High dependence on market developments. T3. Customers' ability to differentiate the new product from the traditional one. T4. Strong competitors. T5. Emergence of substitute products.

To design a SWOT matrix, internal factors of strengths and weaknesses and external factors of opportunities and threats must be taken into account.

The strengths of this business plan are the competitive advantages of the project, such as the wide availability of lavender at a good price in the area of Castilla-La Mancha, where the research was carried out, and the extensive experience of the research group with supercritical extraction. The most important advantage is the possibility of developing a novel product of high purity. Weaknesses that could compromise the viability of the project include the high investment costs of the facilities, working at high pressures, and the limited economic resources, as well as the challenge of finding a distribution channel.

On the other hand, the study of external factors has shown that this project is highly dependent on market developments and that there are many products whose properties can be considered similar to those obtained by this high-pressure process. Therefore, the main threat lies in competition. However, the use of green solvents that comply with the imposed standards, the economic and social promotion of the area, and the unmet need of customers are opportunities that make this process suitable to enter the growing market of natural products dedicated to human health care. Furthermore, it could provide an economic and social boost to the region. In summary, after the analysis of all the factors in the SWOT matrix, it is considered that the extraction of lavender essential oil with supercritical CO_2 can be a good business idea and should not be ruled out a priori.

3.3. Investment Analysis

To calculate the investment in supercritical equipment required at various sizes, information is usually available for one of the sizes and the power law (Equation (3)) is used to scale the costs of equipment with different capacities [39,40], where C_1 is the cost of equipment with capacity Q_1, C_2 is the cost of equipment with capacity Q_2, and M is a constant that refers to the type of equipment and is available in the literature [41].

$$C_1 = C_2 \times \left(\frac{Q_1}{Q_2}\right)^M \quad (3)$$

The costs associated with the three production plants proposed in this study have been estimated on the basis of the costs relating to the volume of a 1 L extractor as in the research of other authors [42]. Table 3 lists the data used to estimate the cost of the three proposed scenarios as well as the total cost for each scenario.

Table 3. Base cost for the equipment of the supercritical unit.

Item	M [a]	Unit Base Cost (EUR) [b,c]	Quantity (un.)	Total Cost Scenario 1 (EUR)	Total Cost Scenario 2 (EUR)	Total Cost Scenario 3 (EUR)
Jacketed extraction vessel	0.82	4361.00	1	50,866.36	107,830.47	190,364.55
CO_2 electrical pump	0.55	10,399.65	1	54,023.81	89,423.62	130,923.84
Cooler	0.59	1210.40	1	7088.21	12,170.86	18,320.15
Heater	0.59	382.70	1	2241.13	3848.14	5792.40
Separation vessel	0.49	979.00	2	8498.01	13,313.98	18,698.75
Manometer	0.00	62.30	3	186.90	186.90	186.90
Blocking valve	0.60	53.40	4	1288.90	2233.49	3385.33
Backpressure valve	0.60	1157.00	1	6981.54	12,098.05	18,337.21
Safety valve	0.60	80.10	1	483.34	837.56	1269.50
Flowmeter	0.60	249.20	4	6014.87	10,422.94	15,798.22
Temperature controller	0.60	160.20	5	4833.38	8375.57	12,694.99
Piping, connectors, mixers	0.40	587.40		1946.91	2808.81	3706.24
Structural material	0.40	267.00		884.96	1276.73	1684.66
Total cost of SFE plant				145,338.31	264,827.10	421,162.75

[a] M constant [41], [b] based on an operating plant with extraction and separation vessels of 1 L, [c] direct quotation for reference year of 2018.

In order to be able to determine the investment required for the establishment of a supercritical CO_2 extraction plant for lavender essential oil, the scale of the plant has to be taken into account, in particular the volume of the extraction vessel, which is closely linked to the production. For scenario 1, the price of the electric pump exceeds that of the extraction vessel. In contrast, in scenarios 2 and 3, it is the cost of the container that is the largest, accounting for approximately 40% and 45% of the total plant cost, respectively. These results are consistent with studies on extraction plants published by other authors [42,43].

3.4. Cost of Manufacturing (COM)

To determine the COM in processes using supercritical fluids, the methodology described by Turton et al. [44] (Equation (4)) is commonly used, where the *COM* is a function of five main costs: fixed capital of investment (*FCI*), cost of operational labour (*COL*), cost of utilities (*CUT*), cost of waste treatment (*CWT*), and cost of raw material (*CRM*). Table 4 indicates the parameters used for this estimation. Updated prices to 2021 were used to calculate the costs of different items.

$$COM = 0.304 \times FCI + 2.73 \times COL + 1.23 \times (CUT + CWT + CRM) \quad (4)$$

Table 4. Parameters for estimating the COMs of extracts.

Economic Parameter	20 L Scale	50 L Scale	100 L Scale	Units
Fixed Capital Investment (FCI)				
Tangible fixed assets	384,419.84	700,467.69	1,113,975.46	EUR
Depreciation rate	10	10	10	%
Maintenance and others rate	6	6	6	%
Cost of Raw Material (CRM)				
Lavender	11.50	11.50	11.50	EUR/kg
Commercial CO_2	5.33	5.33	5.33	EUR/kg
Cost of Operational Labour (COL)				
Worker	3	3	3	Worker/year
Wages	90,000.00	90,000.00	90,000.00	EUR/year
Cost of Utilities (CUT)				
Electricity	0.27	0.27	0.27	EUR/kW.h
Water	0.33	0.33	0.33	EUR/m^3
Cooling fluid	1.83	1.83	1.83	EUR/L

The COM has been estimated for the lavender essential oil extraction process in the three proposed dimensions. The cost of raw material (CRM) includes the amount of lavender flowers and CO_2 needed for one year of operation, and the cost of operational labour (COL) refers to the salary of the workers. The number of workers will vary depending on the production. In the utilities part (CUT), the costs for electricity, water, and coolant are included. In addition, the cost of waste treatment (CWT) must be excluded. This is because the refined and exhausted lavender from the extraction, which is the only solid waste, can be used for various purposes, such as biomass or sold to companies for fertiliser or animal feed.

The fixed capital investment cost (FCI) consists not only of the cost of the equipment but both the installation costs of the extraction plant and the investment necessary for the operation of the plant, and it was calculated using the "Percentage Method" [45]. Moreover, an annual rate of 10% for depreciation and 6% for maintenance and other costs has to be taken into account [21].

In order to analyse the COM values obtained for each of the proposed scenarios, it is also useful to evaluate the productivity for each case. This value corresponds to the annual production of lavender essential oil in each scenario and was calculated on the basis of the maximum extraction yield obtained in the experimental work [34]. The results for the COM estimation are shown in Table 5.

Table 5. Specific costs, productivity, and COM.

	20 L Scale	50 L Scale	100 L Scale
Productivity (kg extract/year)	322.96	807.39	1614.78
FCI (EUR/kg extract)	1380.77	1089.56	866.01
CRM (EUR/kg extract)	168.30	168.30	168.30
COL (EUR/kg extract)	241.52	96.61	48.30
CUT (EUR/kg extract)	210.94	211.51	210.49
COM (EUR/kg extract)	1512.43	1035.98	840.26
COM (EUR/g extract)	1.51	1.04	0.84

As shown in Table 5, an increase in the volume of the extraction vessel leads to a decrease in COM, thus justifying the economic viability of large-scale projects, particularly concerning supercritical processes [46]. The specific costs related to raw materials, utilities, CRM, and CUT are virtually independent of scale. Conversely, with increasing production capacity, fixed equipment costs and operating costs with operators, FCI, and COL decrease.

The distribution of the specific costs in the value of the COM is represented in Figure 4, which shows the distribution of each of the factors involved in the total cost for each volume of the 20 L, 50 L, and 100 L extraction plants. It has to be taken into account that the 20 L volume could be considered as pilot plant size, so it cannot be compared in terms of investment and production to the 50 L and 100 L plants.

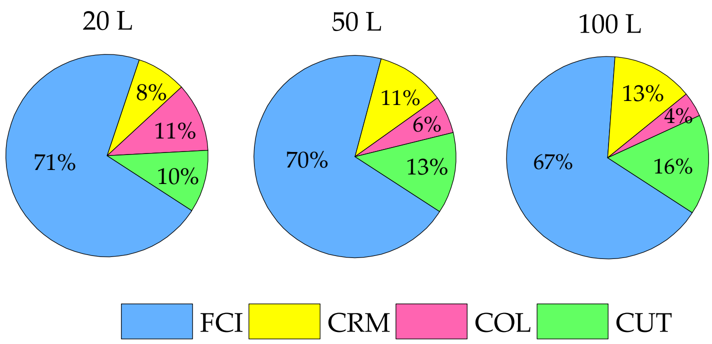

Figure 4. Distribution of specific costs according to the different plant sizes.

The distribution of relative costs (Figure 4) shows that it is the relative cost of capital (FCI) that represents the highest percentage, between 71 and 67%, being higher in the plant pilot scale.

In the case of operators (COL), the percentage in the case of the 20 L extractor is 11% while in the larger scales it decreases. In addition, it should be noted that for the 20 L plant the COL has the highest economic importance after the investment, which can be attributed to the fact that in this case the number of workers is the same as in the other two scenarios.

The decreasing impact of COL and FCI allows the percentage of CUT and CRM to increase with the increase in scale, although their specific cost is constant (Table 5). The percentage of CRM input increases from 8% to 13% from 20 L to 100 L, and the value of CUT varies from 10% to 16%. This fact confirms the theories of other authors about the trend of COM in scale-up analyses [47,48].

3.5. Financial Analysis

3.5.1. Selling Price Assessment

The sale prices have been set on the basis of current market research as well as promoting the idea that these are exclusive products which have been obtained through environmentally sustainable technology and in a selective way [24]. Furthermore, the business strategy is in line with the idea of entering an exclusive niche, with high added value, which represents an alternative for health care [49].

In this study, to establish the selling price to be used for the financial study, the prices of the main sellers of lavender essential oil on the market were evaluated. Table 6 shows the four references considered. These are lavender essential oils with similar characteristics to the essential oil studied in this project and are intended for cosmetic and nutraceutical applications.

Table 6. Sales prices of the most popular essential oils on the market.

	Price (EUR/g)
Lavender Essential Oil 1 [a]	0.50
Lavender Essential Oil 2 [b]	0.80
Lavender Essential Oil 3 [c]	1.99
Lavender Essential Oil 4 [d]	4.98

[a] Mundo Dos Oleos [50], [b] Pranarom [51], [c] Apivita [52], [d] Alqvimia [53].

As shown in Table 6, lavender essential oil prices vary greatly depending on the brand. This is because of the different markets targeted and the scale of production. The highest prices correspond to brands that promote their exclusivity and for functions more related to cosmetics. Conversely, lower prices are attributed to brands that produce on a larger scale and prefer to expand their market on demand for any application.

In the case of the essential oil in this study, despite being a product with exclusive properties and an application related to the pharmaceutical or nutraceutical market, an average value will be taken to make initial economic estimates.

In addition to the prices of the most recognised essential oils on the market, in order to establish the selling price of lavender essential oil to be obtained in supercritical extraction plants, the investment and operating costs associated with the production of lavender essential oil have to be considered.

Considering the above information, the selling price for the following calculations will be set at 1.38 EUR/g for the extract from the pilot plant (20 L) and 0.9 EUR/g for the 50 and 100 L industrial-scale plants. Reasonably, production at pilot-plant scale results in higher costs, so the selling price would have to be higher to ensure the viability of the business. Moreover, an attempt has been made to establish a selling price that is in line with the prices of other manufacturers.

3.5.2. Income Statement

The income statement is an essential part of an economic evaluation; it shows the income for a given period and also the related costs and expenses such as depreciation, amortisation of assets, and taxes. In this sense, the income statement shows the development of a company's assets and liabilities, i.e., it indicates whether investors are earning or losing money over the set time horizon.

For the preparation of the profit and loss account for each of the scenarios to produce lavender essential oil, a linear amortisation of 8 years (duration of the project) was established, and a leverage of 70% was considered, with an 8-year loan at 5% interest, and the remaining 30% obtained from own resources. VAT of 21% [54] and an average tax rate of 21.1% [55] were taken into account. Inflation of 6.5% [56] was also considered to analyse the evolution over the time horizon of the project [57]. The profit and loss account report is shown in Table 7.

In year 0, no cash flow or net profit is calculated, as no income is generated. This year is considered the start-up year in which the investment is fully realised. For the rest of the years, the gross margin is obtained by subtracting the variable costs, referring to raw materials and utilities, from the total sales, if all the essential oil obtained is sold.

EBITDA is determined by also considering fixed costs such as salaries, supplies, advertising, repairs and maintenance, and transport services or insurance. In addition, the earnings before interest and taxes (EBIT) and the earnings before taxes (EBT) were calculated, showing that both increase for each exercise.

Table 7. Income statement over the time horizon of the project for 3 scenarios.

Scenario	Financial Year	1	2	3	4	5	6	7	8
1	Gross Profit	323,200	344,208	366,581	390,409	415,786	442,812	471,594	502,248
	EBITDA [a]	214,200	235,208	257,581	281,409	306,786	333,812	362,594	393,248
	EBIT [b]	165,784	186,792	209,165	232,993	258,370	285,396	314,179	344,832
	EBT [c]	148,871	171,650	195,883	221,664	249,091	278,270	309,313	342,340
	Net Income	117,459	135,432	154,552	174,893	196,533	219,555	244,048	270,106
	NPV [d]	161,044	183,682	202,962	223,308	244,948	267,971	292,464	318,522
2	Gross Profit	419,997	447,297	476,371	507,336	540,312	575,433	612,836	652,670
	EBITDA [a]	310,997	338,297	367,371	398,336	431,312	466,433	503,836	543,670
	EBIT [b]	222,777	250,077	279,151	310,115	343,092	378,212	415,615	455,450
	EBT [c]	191,987	222,512	254,971	289,490	326,200	365,239	406,758	191,987
	Net Income	151,478	175,562	201,172	228,408	257,372	288,174	320,932	355,770
	NPV [d]	232,717	263,545	289,385	316,628	345,592	376,394	409,152	443,991
3	Gross Profit	841,643	896,349	954,612	1,016,662	1,082,745	1,153,123	1,228,076	1,307,901
	EBITDA [a]	732,643	787,349	845,612	907,662	973,745	1,044,123	1,119,076	1,198,901
	EBIT [b]	592,343	647,050	705,312	767,362	833,445	903,823	978,776	1,058,601
	EBT [c]	543,398	603,230	666,875	734,576	806,592	883,201	964,696	1,051,389
	Net Income	428,741	475,949	526,164	579,580	636,401	696,845	761,145	829,546
	NPV [d]	552,467	615,695	666,446	719,880	776,701	837,145	901,445	969,846

[a] EBITDA: earnings before interest, taxes, depreciation, and amortisation, [b] EBIT: earnings before interest and taxes, [c] EBT: earnings before taxes, [d] NPV: net present value at 3% interest.

To conclude the income statement, the net income was determined by deducting the value of the income tax provision from the EBT. Positive results were obtained for all scenarios, increasing this value every year and with an increase in scale, which can be taken as an indicator that this is a viable process that can be scaled up and a promising business plan.

On the other hand, we also applied other methods to judge the viability of the investment, such as the calculation of net present value (NPV) [58]. This method takes into account the timing of cash flows, and therefore uses the discounting or discounting procedure in order to homogenise the amounts of money received at different points in time [35]. These results again indicate that this is a healthy investment. The maximum value of NPV reached was EUR 969,846 in year 8 of scenario 3, which indicates that it is the most profitable scenario and the most attractive investment to scale the extraction process of lavender essential oil with supercritical CO_2.

3.5.3. Financial Ratios

The financial ratios are used to further investigate the profitability of the project in addition to the realisation of the income statement. This information is mandatory to obtain a bank loan. Table 8 shows the main financial ratios studied together with their generally considered healthy values. The investment will be attractive to investors if the result of these ratios for each financial year is above their healthy value [29]. These ratios are calculated for the three proposed scenarios and their results are shown in Table 9.

These results are grouped into categories. First, those related to profitability were calculated: ROE, ROI, and EBITDA to sales. These values indicate how assets are used to cover costs and achieve maximum profitability. It is shown that all these parameters increase as the time horizon progresses and become higher the larger the scale. Of note, the ROE value obtained reaches a high value, indicating the advantages of investing capital in this business instead of a bank deposit. The maximum value for this ratio is acquired in year 8 of each of the scenarios and has a value of 76.74, 71.65, and 77.65 for scenario 1, scenario 2, and scenario 3, respectively.

Table 8. Summary of the main financial ratios of economic analyses.

Financial Ratio	Equation	Definition	Healthy Value
Return on equity (ROE)	$ROE = \frac{\text{Net Income}}{\text{Shareholder's Equity}}$	Profit generated with the money that shareholders have invested	>13%
Return on investment (ROI)	$ROI = \frac{\text{Net Income}}{\text{Total capital}}$	To compare the efficiency of a number of different investments	>15%
EBITDA to sales	$\text{EBITDA to Sales} = \frac{\text{EBITDA}}{\text{Revenue}}$	Company's operational profitability by comparing its revenue with earnings	>10%
Solvency	$\text{Solvency} = \frac{\text{After Tax Net Profit} + \text{Depreciation}}{\text{Long Term} + \text{Short Term Liabilities}}$	Company's ability to meet long-term obligations	>0.2
Acid test	$\text{Acid test} = \frac{\text{Cash Accounts Receivable} + \text{Short Term Invests.}}{\text{Current Liabilities}}$	Enough short-term assets to cover its immediate liabilities	>1
Debt to capital	$\text{Debt to capital} = \frac{\text{Total Debts}}{\text{Shareholder's Equity} + \text{Debt}}$	Ability to absorb asset reductions without jeopardising the interest of creditors	Low
Manoeuvre fund	$\text{Manoeuvre fund} = \text{Current assets} - \text{Current Liabilities}$	Company's efficiency and its short-term financial health	High
Break-even point Margin of safety	$\text{Margin of safety} = \frac{\text{Sales}}{\text{Break even Point}}$	The point at which a business begins to make profits	>1.1

Table 9. Main financial ratios for 3 scenarios.

Scenario	Financial Year	1	2	3	4	5	6	7	8
1	ROI (%)	41.26	43.45	45.50	47.40	49.19	50.86	52.42	53.89
	ROE (%)	63.21	65.57	67.76	69.81	71.73	73.51	75.18	76.74
	EBITDA to sales (%)	48.06	49.55	50.96	52.27	53.51	54.67	55.76	56.78
	Solvency	3.57	4.11	4.70	5.34	6.01	6.71	7.43	8.17
	Acid test	1.04	2.07	3.10	4.12	5.14	6.14	7.13	8.10
	Debt-to-capital ratio (%)	34.68	34.77	34.85	34.92	34.99	35.04	35.09	35.13
	Manoeuvre fund	5384	160,010	336,384	535,920	760,127	1,010,609	1,289,077	1,597,351
	Break-even point	174,328	172,557	170,697	168,745	166,694	164,541	162,281	159,907
	Margin of safety	2.56	2.75	2.96	3.19	3.44	3.71	4.01	4.33
2	ROI (%)	35.95	38.02	39.98	41.84	43.61	45.28	46.86	48.37
	ROE (%)	57.70	60.02	62.22	64.31	66.30	68.18	69.96	71.65
	EBITDA to sales (%)	42.80	43.71	44.57	45.38	46.14	46.85	47.52	48.15
	Solvency	4.05	4.35	4.72	5.15	5.64	6.17	6.74	7.33
	Acid test	0.90	1.80	2.72	3.63	4.54	5.45	6.36	7.25
	Debt-to-capital ratio (%)	32.96	33.18	33.38	33.57	33.75	33.91	34.06	34.19
	Manoeuvre fund	−20,521.54	175,523.59	399,792.51	654,122.70	940,471.22	1,260,922.50	1,617,696.61	2,013,158.10
	Break-even point	228,009.48	224,785.16	221,399.62	217,844.81	214,112.26	210,193.08	206,077.94	201,757.05
	Margin of safety	3.19	3.44	3.72	4.03	4.37	4.74	5.15	5.60

Table 9. *Cont.*

Scenario	Financial Year	1	2	3	4	5	6	7	8
3	ROI (%)	47.36	48.85	50.28	51.64	52.94	54.18	55.35	56.48
	ROE (%)	67.08	68.82	70.47	72.05	73.56	74.99	76.35	77.65
	EBITDA to sales (%)	50.41	50.87	51.30	51.70	52.08	52.44	52.77	53.09
	Solvency	3.86	4.66	5.47	6.29	7.12	7.96	8.79	9.63
	Acid test	1.32	2.59	3.84	5.05	6.23	7.37	8.48	9.56
	Debt-to-capital ratio (%)	32.18	32.39	32.58	32.76	32.93	33.08	33.23	33.36
	Manoeuvre fund	127,159	684,196	1,297,872	1,971,874	2,710,126	3,516,811	4,396,383	5,353,584
	Break-even point	298,244	293,118	287,737	282,086	276,152	269,922	263,380	256,512
	Margin of safety	4.87	5.28	5.73	6.22	6.77	7.38	8.05	8.80

Moreover, the ratios for cash flow and solvency were then calculated as well as those related to debts such as the debt-to-capital ratio. As for the manoeuvre fund, as shown in Table 9, it has a negative value in year 1 of scenario 2. The change in scale may imply a reduction in the amount of liquid cash held by the company in the first year. Fortunately, this value becomes positive from the second year onwards. In general, this value acquires a positive value in all cases and is greater as the scale increases, which means that in scenario 3 the company could face short-term debts in a much more efficient way and without losing liquid assets.

Other ratios, such as the break-even point, were also calculated. Its value decreases over the years for all cases, indicating that the company's situation improves over the years and it has to sell less to cover costs. In addition, it is worth noting that the value of the safety margin is always above the healthy value, which affirms the robustness of the investment.

3.5.4. Price Curve

Additionally, to assess how the sales strategy could evolve in function to obtain the same profit, a price curve was made for scenario 3 (Figure 5), which corresponds to industrial-scale production.

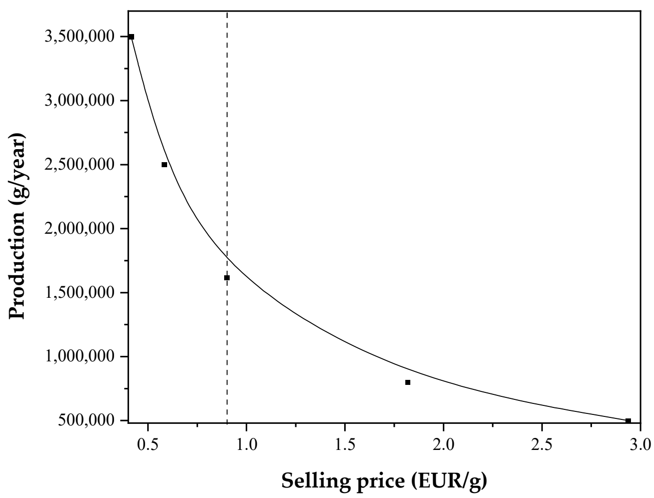

Figure 5. Price curve (scenario 3).

The price curve gives information about sales department objectives (increase production and hence sales) when prices must be decreased in order to fight competitors. From Figure 5, it can be observed that reducing prices lower that 0.9 EUR/g (selling price set for scenario 3) means that sales must be increased exponentially to reach a similar profitability, so this situation should be avoided as its dangerous for the company.

3.6. Sensitivity Analysis

In order to analyse the robustness of the business idea, a sensitivity study was carried out. This study analyses changes in factors not considered previously due to external or internal circumstances, providing information about commercial strategies and alternatives to face them. This study consisted of assessing the ROE profitability based on a 10% overestimation of equipment prices, wages, raw materials, electricity, and interest on money for scenario 3, assuming an average value of ROE. Table 10 shows the average ROE results for the 8-year time horizon. In addition, these results are plotted in Figure 6.

Table 10. Sensitivity analysis for scenario 3.

	ROE (%)	Variation (%)
Initial situation	72.62	-
+10% Raw material	71.89	−1
+10% Wages	72.48	−0.19
+10% Interest	72.62	0
+10% Electricity	72.62	0
+10% Equipment	71.71	−1.25

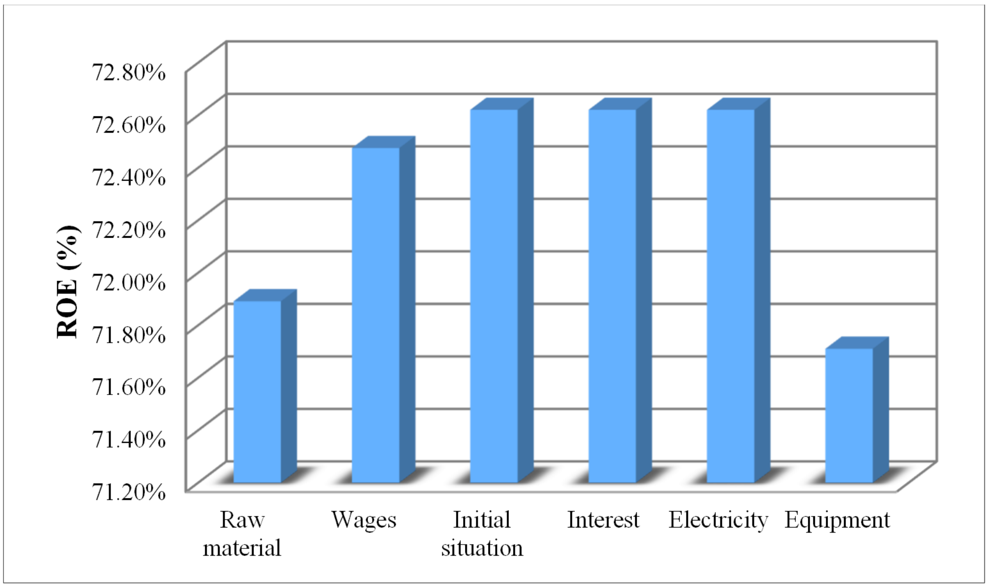

Figure 6. Sensitivity analysis for scenario 3 with the 10% overestimation in the price of raw materials, wages, interest, and equipment.

From the results shown in Table 10 and Figure 6, it can be assumed that the interest rate and wages has less influence on the profitability of the project. Furthermore, the increase in the price of electricity would hardly imply any change in the profitability of the process [59]. On the other hand, the increase in the price of equipment and raw materials, particularly the latter with a decrease of more than 1% compared to the initial situation, do have a significant influence on the ROE value.

Therefore, it can be concluded that the two factors that will determine the commercial strategy of the lavender essential oil extraction business with supercritical CO_2 over the time horizon are the price of raw materials and equipment. These results are in line with those reported by the COM determination. In this sense, it should be considered that these will be the parameters to which the profitability of this project is most sensitive to any possible variation in them.

4. Conclusions

The technical feasibility of supercritical CO_2 extraction of lavender essential oil was tested at pilot plant scale, with an extraction temperature of 60 °C and working pressures of 180 and 250 bar. The extracts obtained had linalool and linalyl acetate as their main compounds and showed an inhibition percentage higher than 80%, which shows that this extract could be promising in the current market. After these experiments, the economic viability of this supercritical process was studied by means of an 8-year business plan for three scenarios that included production from pilot plant scale to industrial scale. The SWOT matrix showed that it is a promising business idea, and by means of the price curve and the study of the market niche it was possible to establish the ideal prices for the success of the project: 1.38 EUR/g for the extract from the pilot plant (20 L) and 0.9 EUR/g for the 50 and 100 L industrial-scale plants. The profit and loss account was drawn up, and by calculating the financial ratios a detailed study of the profitability could be performed, paying special attention to the ROE value, which always acquired a value above 57%, indicating that it is an interesting project from an economic point of view. In addition, to determine the robustness of the idea and find out the cost items that most influence the commercial strategy to be followed, a sensitivity analysis was carried out, from which it could be seen that the cost of the equipment is the item that most influences the ROE value. The business plan provided results that postulate the production of lavender essential oil and other natural extracts by means of supercritical technology as an attractive technology for investment and one capable of satisfying the needs of a growing market niche.

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