

Article

The Design of an Intensified Process and Production Plant for Cosmetic Emulsions Using Amazonian Oils

Laura Scalvenzi ^{1,*} , Estela Guardado Yordi ¹ , Edgar Wilfrido Santamaría Caño ¹ , Ibeth Nina Avilez Tolagasi ¹ , Matteo Radice ¹ , Reinier Abreu-Naranjo ² , Lianne León Guardado ³, Luis Ramón Bravo Sánchez ¹  and Amaury Pérez Martínez ^{1,*} 

¹ Facultad de Ciencias de la Tierra, Universidad Estatal Amazónica, Puyo 160150, Ecuador; e.guardadoy@uea.edu.ec (E.G.Y.); ueaedgarsantamaria95@outlook.com (E.W.S.C.); ibethnina2599@gmail.com (I.N.A.T.); mradice@uea.edu.ec (M.R.); lbravo@uea.edu.ec (L.R.B.S.)

² Facultad de Ciencias de la Vida, Universidad Estatal Amazónica, Puyo 160150, Ecuador; rabreu@uea.edu.ec

³ Independent Researcher, Miami, FL 33012, USA; liannegleon@gmail.com

* Correspondence: lscalvenzi@uea.edu.ec (L.S.); amperez@uea.edu.ec (A.P.M.)

Abstract: The cosmetic industry in the Ecuadorian Amazon region faces the challenge of competitively integrating locally sourced plant-based raw materials into efficient and sustainable production processes. This study proposes the design of a pilot plant for the production of a cosmetic emulsion (CE), using oils extracted from Morete (*Mauritia flexuosa*) and Ungurahua (*Oenocarpus bataua*), with a focus on process intensification to reduce both capital investment and resource consumption. Process design methodologies and computational simulation (SuperPro Designer V10) were applied, along with Systematic Layout Planning (SLP) principles to optimize spatial configuration. The intensified scheme enabled the integration of extraction lines, reducing the number of major equipment units from 12 to 9 and lowering the investment from USD 1,016,000 to USD 719,000. Energy and environmental indicators showed consumption levels of 5.86 kWh and 48.4 kg of water per kg of cream, which are lower than those reported for other natural cosmetics plants. The intensified design achieved a Net Present Value (NPV) of USD 577,000 and a payback period of 3.93 years. Furthermore, solid by-products were valorized through circular economy principles. This approach offers a feasible, viable, and sustainable solution for the utilization of these Amazonian oils in the cosmetic industry.

Keywords: technological process; vegetable oils; SuperPro Designer V10; SketchUp web 2022; enhanced technology



Academic Editors: Roberta Campardelli and Paolo Trucillo

Received: 14 May 2025

Revised: 9 June 2025

Accepted: 12 June 2025

Published: 17 June 2025

Citation: Scalvenzi, L.; Guardado Yordi, E.; Santamaría Caño, E.W.; Avilez Tolagasi, I.N.; Radice, M.; Abreu-Naranjo, R.; León Guardado, L.; Bravo Sánchez, L.R.; Pérez Martínez, A. The Design of an Intensified Process and Production Plant for Cosmetic Emulsions Using Amazonian Oils. *Processes* **2025**, *13*, 1923. <https://doi.org/10.3390/pr13061923>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

In recent years, the emulsions industry has been in a constant state of flux, and by the year 2020, this market was valued at USD 341.1 billion. It is expected to reach USD 560.5 billion by 2030, with a compound annual growth rate of 5.1%, between 2021 and 2030 [1].

The emulsions industry in Ecuador represents 1.6% of the GDP, producing 1100 million dollars a year and growing annually by 10%, which has led to the generation of many job opportunities [2]. The industry is placing greater emphasis on individuals aged 12 to 25, because this age group constitutes the primary consumer base for emulsion products such as cosmetic emulsion [3].

Cosmetic emulsion (EC) refers to homogeneous, semi-solid preparations intended for skin application consisting of opaque emulsion systems [4]. The consistency and properties

of these creams vary depending on the type of emulsion and the raw materials used. These raw materials are primarily vegetable oils—substances produced by the metabolism of certain plants [5]. Therefore, it is necessary to use plant oils as raw materials. These oils not only serve sensorial and functional roles in the formulation, but they may also exhibit desirable depigmenting activity in certain cosmetic products [6]. They can also enhance oxidative stability, the bioavailability of bioactive compounds, and skin compatibility, which is key in the design of differentiated and sustainable products. In cosmetic production, the use of plant oils and the analysis of their triacylglycerol composition are essential to formulate sustainable products. These oils not only reduce the environmental footprint, but also act as (i) natural emollients, which improve skin flexibility and resilience, (ii) strengthen the skin barrier through their hydrophobic nature, and (iii) provide antioxidant benefits that enhance the overall quality of the cosmetic product [7].

When applied to the skin, the water available in the cream evaporates and creates a cooling sensation, while the oil creates a protective barrier. Creams with a higher amount of oil, or oily phase, are ideal for dry, sensitive skin or skin prone to atopic dermatitis, as they provide superior hydration and nourishment [8].

ECs are used for skin care, moisturizing and slowing down the aging process [9]. Many consumers prefer to use products containing plant-based components, which has led to research into alternatives that meet these requirements. Plant oils are also used to make soaps, medicines, foodstuffs, and other products [10]. There are a variety of plant oils; however, the most traditional are olive, avocado, and coconut oil [11]. In the Amazonian forest, promising oils have been extracted from fruits such as Morete (*Mauritia flexuosa*) and Ungurahua (*Oenocarpus bataua*). Amazonian oils are distinguished by their high content of essential fatty acids (such as oleic and linoleic acids), phytosterols, and antioxidant compounds, making them high-value functional raw materials for cosmetic formulations with both ecological appeal and sensorial benefits [12].

Studies have shown that ECs, formulated with these oils, exhibited properties such as skin softening, as well as enhancing skin radiance and firmness. Other fruits, including Sacha Inchi (*Plukenetia volubilis*), Chontaduro (*Bactris gasipaes*), and Ginger (*Zingiber officinale*), showed similar properties but few studies are available [13]. Proaño et al. [14] developed an exfoliating cream using passion fruit oil and its seeds as an alternative raw material, addressing the significant waste generated by passion fruit seeds. Similarly, Rivera et al. [15] formulated an exfoliating cream based on Morete peels, highlighting its potential as a valuable contribution to the development of new emulsion-based formulations by Proaño et al. [14].

The utilization of plant by-products in cosmetics opens the door to circular economy strategies, which can be incorporated into the plant design to minimize waste, reduce raw material costs, and add value to local agro-industrial processes [16–19].

A study reports that the production of Morete and Ungurahua-based cream involves two distinct phases, each with a specific technological process tailored to meet defined criteria. These phases incorporate key unit operations—heating, mixing, agitation, homogenization, and cooling—which must be precisely controlled to ensure the final product's physical stability, sensory quality, and functional performance [20].

Technological advancements in emulsion production have progressed significantly, and a variety of equipment and processing techniques are now available for manufacturing diverse cosmetic emulsion formulations [21]. Process design methodologies, such as the one proposed by Cerda Mejía et al. [22] for hydroalcoholic gel production, have been successfully applied to the development of products analogous to emulsion-based creams.

In this case, simulation and computational modeling tools—such as process flow diagrams, Aspen Plus-type simulators, and energy consumption estimation—were applied

to facilitate the scaling of processes from the laboratory to the pilot plant level, incorporating criteria of sustainability and operational efficiency.

Beltrán Chacón & Aguayo Carvajal [23] mention that it should be taken into account that the investment for the start-up of an agro-industrial plant is significant, as the acquisition of equipment represents one of the biggest expenses within a company. For this reason, a well-planned and designed plant should favor the efficient use of the resources within it, thus contributing to environmental sustainability. The process should also be optimized to minimize complexity and waste while enhancing overall efficiency. Additionally, the consideration of worker safety and ergonomics is essential to mitigate potential future costs related to compensation, regulatory fines, or other liabilities.

To reduce investment and acquisition costs, process intensification can be considered. According to [24], process intensification represents one of the most promising areas for industrial development. This approach involves modifying conventional processes or developing novel technologies to lower energy consumption, enhance yields, and improve product quality. Specifically, it aims to increase efficiency and production benefits, improve processing quality and safety, minimize the size of both primary and auxiliary equipment, and reduce waste and energy demands through the adoption of more sustainable technologies [25].

Research on the oil properties of Morete and Ungurahua has been carried out at laboratory level (basic research), and cosmetic emulsions have been produced in small quantities [20]. However, in the Amazonian context, the problem is that there is no technological process or plant designed to obtain EC from Morete and Ungurahua oils at a pilot or industrial level. This reveals a technological gap that currently limits industrial-scale production, due to the absence of well-defined parameters such as plant capacity, emulsion yield, energy consumption, material compatibility, and standardized operating conditions. In response, this study aims to design a pilot plant for the production of a cosmetic emulsion formulated with Amazonian plant oils, by applying process simulation tools and principles of process intensification to develop an efficient, scalable, and environmentally sustainable manufacturing system.

2. Materials and Methods

The design of an industrial plant for the production of EC was carried out following the methodology proposed by Dimian [26], which comprises four stages. These stages include the definition of requirements, conceptual design, and basic design, which collectively form the core of the process design. Additionally, detailed engineering was incorporated to develop the plant layout, ensuring a well-structured facility capable of producing high-quality cosmetic emulsion with efficiency and sustainability [26]. The complete procedures for fruit selection, oil extraction, emulsion formulation, final product measurement, and material balance calculations were described in detail in Guardado et al. [20].

2.1. Proposal for the Design of the Technological Process

The design of the technological process of an EC was carried out using the methodology proposed by Pérez-Martínez et al. [27]. This phase includes product identification, technology selection, and definition of the technological scheme. Production capacity, macro-location, and mass and energy balances are assessed. Raw material availability, environmental compatibility, and equipment design and costs are evaluated. Process control is implemented, followed by investment and production cost analysis to identify optimized, viable alternatives. Finally, the integration of emerging technologies is considered.

The process intensification strategies employed included equipment integration as proposed by Stankiewicz and Moulijn [28], utility integration based on the approach

in [29,30], and by-product valorization within a circular economy framework as suggested by Frosch and Gallopoulos [31]. These techniques were selected to achieve the following intensification objectives: (a) reducing the number of equipment units by leveraging similarities in the extraction processes of Morete and Ungurahua oils; (b) minimizing energy and material consumption through steam reuse; and (c) decreasing environmental impact by implementing a valorization strategy for the generated waste.

2.2. Plant Distribution Strategy for the Production of Emulsion Creams

As a complement to the process design, the simulation methodology proposed by Dimian et al. [32] was applied, comprising four stages: data analysis, input, simulation execution, and result evaluation. Initially, relevant data is collected and analyzed, then entered the simulator to configure process parameters. The simulation was executed to model system behavior under various conditions. Finally, the results were assessed to optimize process design and operation [32].

To simulate the design of an EC manufacturing plant, the SuperPro Designer V10.0 (Intelligen, Freehold, NJ, USA) simulator was used. The simulation considered a 7% discount rate and a 20-year analysis horizon for the calculation of dynamic economic indicators. Additionally, the breakdown of operating costs implemented in SuperPro Designer V10 was considered.

Plant layout was developed using Richard Muther's Systematic Layout Planning (SLP) methodology (1968). This approach supports efficient design by systematically considering material flow, accessibility, safety, and optimal space utilization in the cosmetic emulsion manufacturing plant [33,34].

This method minimizes material handling costs, reduces production time, and improves workflow by strategically organizing the workstation, departments, equipment, and other elements within a facility; the nature of this distribution can vary depending on the type of industry, production processes, workflow needs, and other factors [35]. Computerized software, specifically SketchUp Web 2022, was used to visualize and optimize the distribution and sizing of areas and equipment.

3. Results

3.1. Proposal for the Design of the Technological Process

3.1.1. Product in Demand

The production of EC requires the extraction of oils from Morete and Ungurahua fruits. Once obtained, the fatty phase (oils and cocoa butter) and the aqueous phase (purified water) were prepared. The emulsifier was then added and mixed, followed by the incorporation of the aqueous into the fatty phase. Finally, a preservative is added, and the mixture stored.

3.1.2. Technology Selection

Figure 1a,b illustrate the processes to produce EC using Morete and Ungurahua fruit oils characterized by unit operations. Two technologies with similar characteristics are used in the traditional method (Figure 1a), while the intensified technology (Figure 1b) evaluates the economic feasibility of a single extraction line for both oils. In the proposed process, both oils are extracted using a single technology; when Morete oil is not being extracted, the line is cleaned and prepared for Ungurahua oil extraction, and vice versa. The first step involves selection and washing, where fruits with bruises or poor conditions are discarded based on ripeness, ensuring cleanliness. The fruits are then softened at 100 °C for 1 h, facilitating pulping and allowing for easier oil extraction.

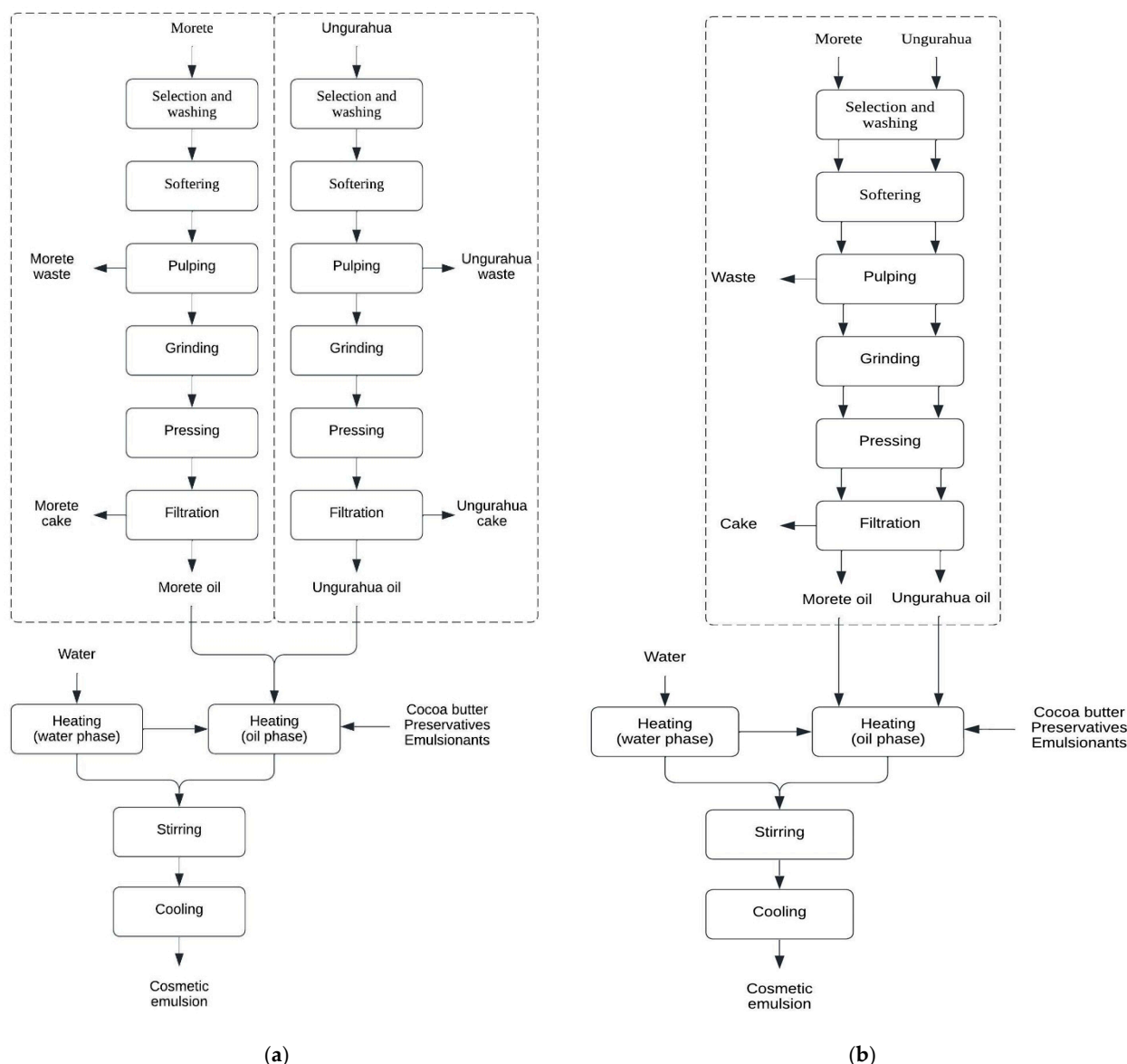


Figure 1. A block diagram illustrating the process of obtaining Morete and Ungurahua oil and emulsion with (a) traditional technology [20]; (b) intensified.

All of the processes mentioned above fit the Gantt chart, as summarized in Figure 2a,b.

3.1.3. The Technological Scheme

Figure 3a,b present the process flow diagrams for traditional and intensified technologies. It can be observed that the vegetable oil production line is streamlined, with a single technology employed, leading to a more efficient work organization as shown in the Gantt chart in Figure 2. In the intensified technology (Figure 3b), after softening and progression through each unit operation, the equipment can be cleaned and reused for the alternate extraction process once the first extraction is completed.

3.1.4. Production Capacity Estimation

To estimate the production capacity of cosmetic emulsion from Morete and Ungurahua, 2.5 kg of Morete and 10.5 kg of Ungurahua were used to produce a total of 18.98 kg of cosmetic emulsion, with 13 kg coming from the main ingredients, and the production ratio was calculated by dividing the amount of cream produced by the total ingredients, resulting in a production rate of 1.46 kg of cream per kilogram of ingredients.

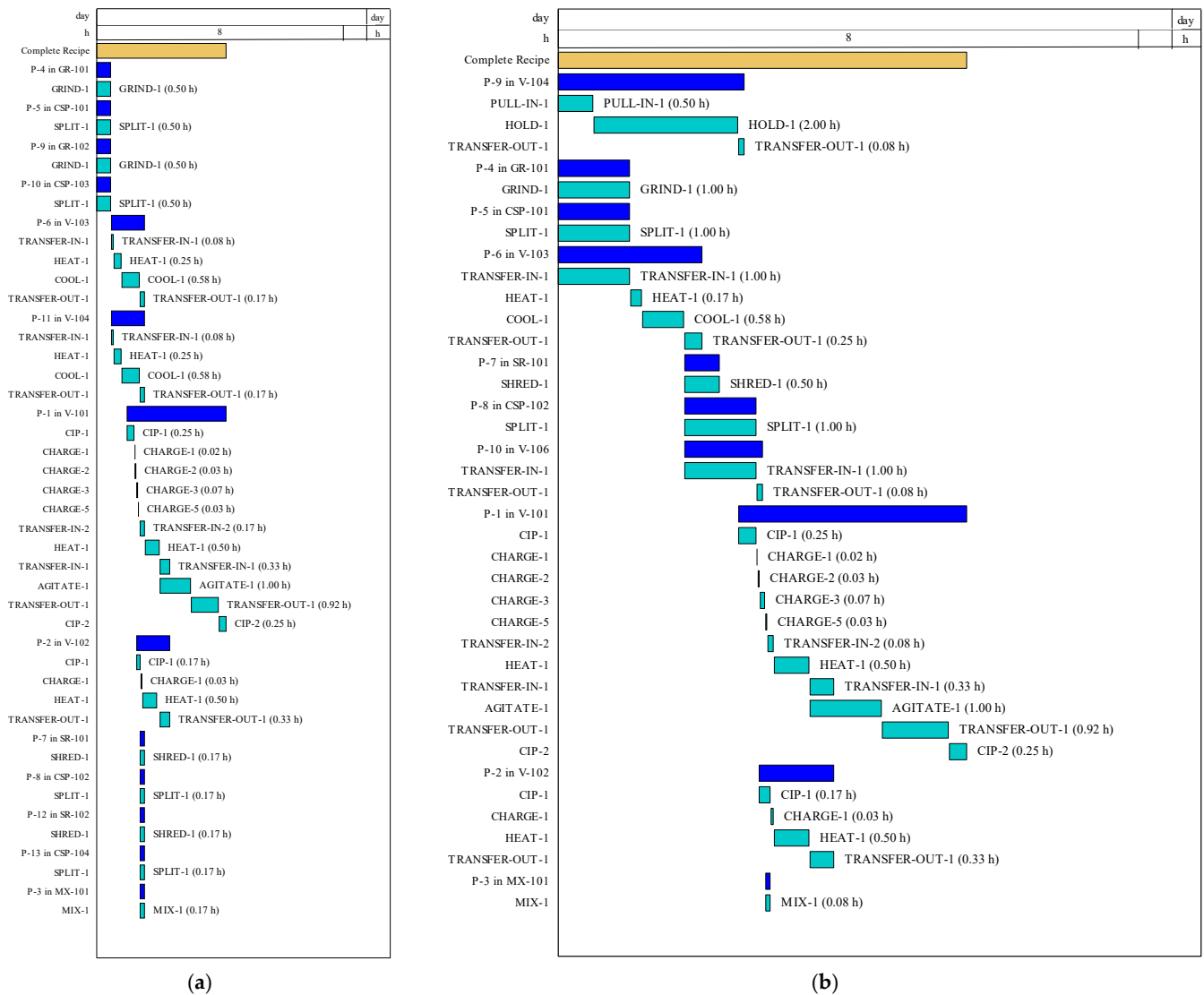


Figure 2. Gantt chart (a); traditional [20]; (b) intensified. The key stages are represented, including grinding (GRIND), separation (SPLIT), heating (HEAT), agitation (AGITATE), material transfer (TRANSFER-IN and TRANSFER-OUT), and cleaning (CIP), allowing for the visualization of the duration and sequence of each operation within the process.

3.1.5. Location

Due to the availability of the raw material, the processing plant for the extraction and production of EC will be located in the province of Napo, Tena Canton, in the Muyuna parish, as shown in Figure 4.

3.1.6. Mass and Energy Balances, and Environmental Compatibility

Table 1 details the environmental indicators associated with the annual production of 4717.48 kg, representing 260 batches of cosmetic creams for both traditional and intensified technologies.

Furthermore, in terms of energy consumption, traditional plants of the same size reported an expenditure varying between 8 and 10 kWh/kg of cream and an estimated carbon footprint of 3.5–4.0 kg CO₂e/kg product [36]. However, the intensified scheme reduced energy consumption to 5.86 kWh/kg and limits emissions to around 2.3–3.0 kg CO₂e/kg, thanks to the shared use of steam for heating and the aqueous phase, as well as the opti-

mization of equipment distribution. These results demonstrate a 25–30% improvement in energy efficiency and emission reduction.

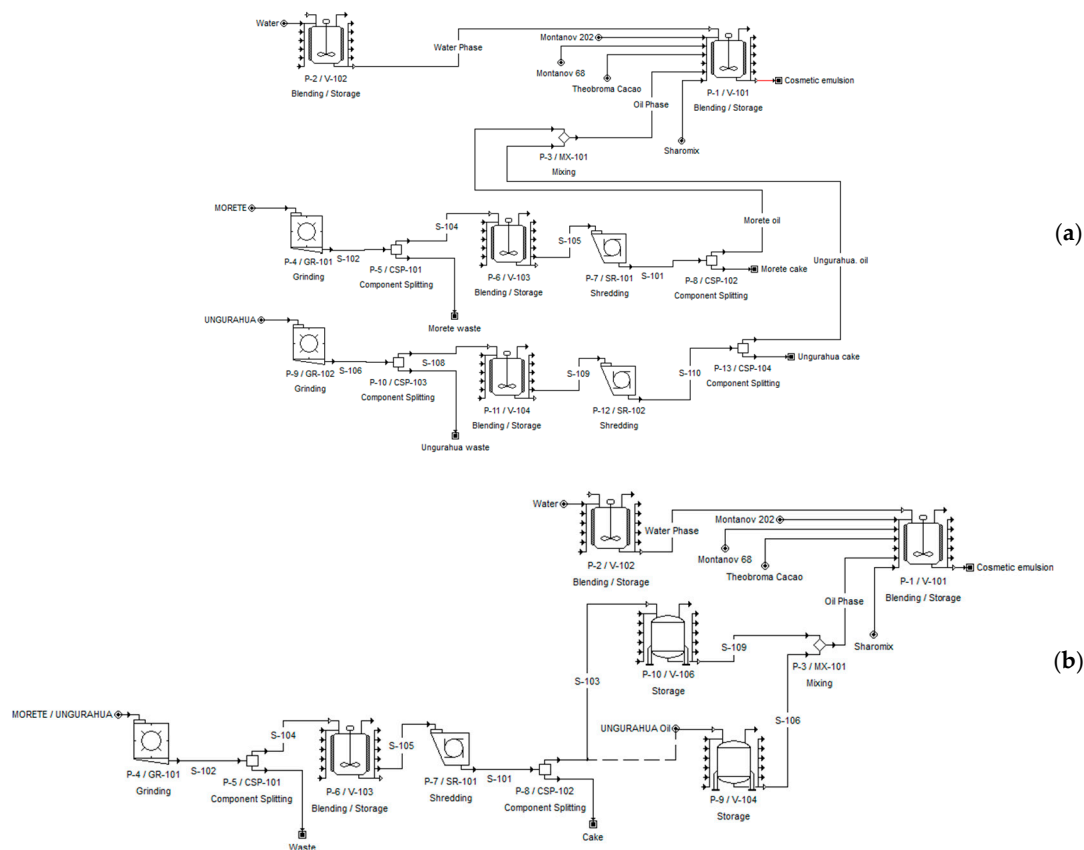


Figure 3. Process flow diagram (a); traditional [20]; (b) intensified. GR-101, GR-102 (grinding); CSP-101, CSP-102, CSP-103, CSP-104 (component splitting); SR-101, SR-102 (shredding); V-101, V-102, V-103, V-104 (blending/storage); P-102, P-103, P-104 (transfer pumps); M-103 (final mixing); Montanov 202, Montanov 68b, Theobroma cacao, Sharomix (ingredients for the oil phase of the emulsion); cosmetic emulsion (final product).

Table 1. Comparison of extraction methods, unit operations, and equipment for Morete and Ungurahua oils.

Environmental Indicator	Input/Output Current	Amount		Unit
		Traditional Technology	Intensified Technology	
Raw material consumption	Montanov 68	0.011	0.011	kg/kg
	Montanov 202	0.036	0.036	kg/kg
	Morete fruit	0.136	0.136	kg/kg
	Sharomix	0.011	0.011	kg/kg
	Cocoa butter	0.111	0.111	kg/kg
	Ungurahua fruit	0.563	0.563	kg/kg
Water consumption	Water	48.411	48.411	kg/kg
Energy consumption	Power consumption	5.86	5.86	kW·h/kg
	Steam consumption	10	10	kg/kg
	Refrigerated water	260	260	kg/kg
Discharge	Of gases	-	-	-
	Of liquids	-	-	-
	Of solids	0.56	0.56	kg/kg
Cosmetic emulsion		4717.48	4717.48	kg/yr

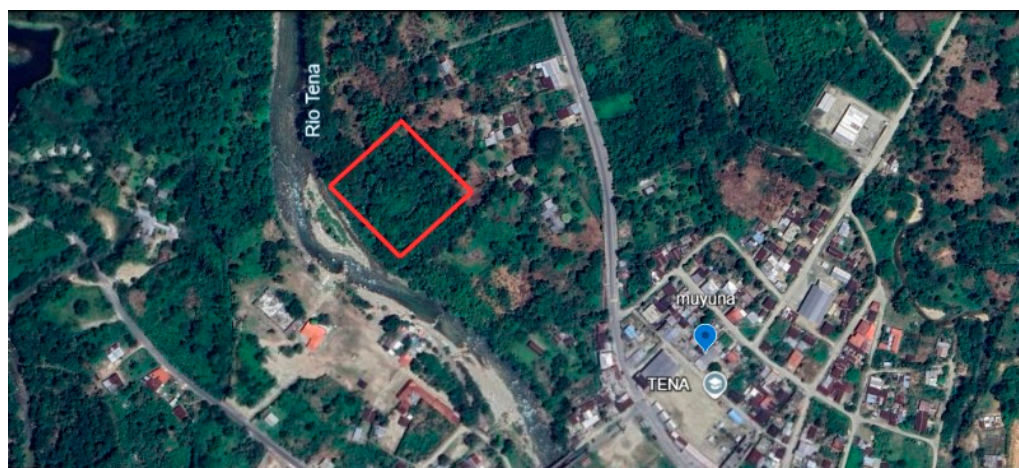


Figure 4. The location of the processing plant. The red box indicates the possible location of the plant.

3.1.7. Sizing of Equipment and Cost of Acquisition

To determine the equipment size and calculate acquisition costs, it is crucial to define the entire manufacturing process for both traditional and intensified technologies. Table 2 lists the equipment used in the processes of extracting plant oils and preparing EC, along with their design parameters, quantities, and purchasing costs. The total cost to purchase equipment for the traditional technology is USD 126,000.00, while the cost for the intensified technology is USD 88,000.00, reflecting a reduction in the amount of equipment.

Table 2. Equipment acquisition cost.

Quantity	Name	Design Parameter	Cost (USD)	
			Traditional Technology	Intensified Technology
1	Turbo-emulsifier	Tank volume = 22.47 L	20,000	20,000
1	Turbo-emulsifier	Tank volume = 14.66 L	20,000	20,000
1	Pulper	Nominal Yield = 2.55 kg/h	14,000	14,000
1	Pulper	Nominal Yield = 10.58 kg/h	14,000	
1	Jacketed tank	Tank volume = 2.62 L	10,000	10,000
1	Jacketed tank	Tank volume = 8.95 L	10,000	
1	Shredder	Nominal Yield = 2.55 kg/h	1000	6000
1	Shredder	Nominal Yield = 2.16 kg/h	1000	
1	Press	Nominal Yield = 12.98 kg/h	6000	
1	Press	Nominal Yield = 45.82 kg/h	6000	
1	Storage tank	Tank volume = 1.11 L	-	1000
1	Storage tank	Tank volume = 2.58 L	-	1000
	Equipment not listed		25,000	18,000
	Total		126,000	88,000

3.1.8. Economic Analysis and Feasibility

The Total Plant Direct Cost (TPDC) of the intensified design (Table 3) demonstrated an approximate 31% reduction, compared to conventional technology. This reflects the impact of the decreased number and size of equipment, optimized layout, and streamlined installation processes on this cost. This reduction in investment expenses results in an approximate 29% overall decrease in total investment cost. Consequently, the intensified process offered an economic advantage by requiring significantly less capital for plant investment.

Table 3. Estimated investment costs of traditional vs. intensified technology.

Cost Items	Cost (USD)	
	Traditional Technology	Intensified Technology
3A. Total Plant Direct Cost (TPDC)		
1. Equipment Purchase	126,000	88,000
2. Installation	51,000	34,000
3. Process Piping	44,000	31,000
4. Instrumentation	50,000	35,000
5. Insulation	4000	3000
6. Electrical	13,000	9000
7. Buildings	57,000	40,000
8. Yard Improvement	19,000	13,000
9. Auxiliary Facilities	50,000	35,000
TPDC	414,000	287,000
3B. Total Plant Indirect Cost (TPIC)		
10. Engineering	103,000	72,000
11. Construction	145,000	100,000
TPIC	248,000	172,000
3B. Total Plant Indirect Cost (TPIC)		
3C. Total Plant Cost (TPC = TPDC + TPIC)		
TPC	662,000	459,000
3D. Contractor's Fee and Contingency (CFC)		
12. Contractor's Fee	33,000	23,000
13. Contingency	66,000	46,000
CFC = 12 + 13	99,000	69,000
3E. Direct Fixed Capital Cost (DFC = TPC + CFC)		
A. DFC	761,000	528,000
B. Working Capital	217,000	165,000
C. Startup Cost	38,000	26,000
D. Up-Front R&D	0	0
E. Up-Front Royalties	0	0
F. Total Investment (A + B+C + D+E)	1,016,000	719,000
G. Investment Charged to This Project	1,016,000	719,000

After the intensification process, the total annual operating cost is reduced from USD 441,000 to USD 324,000 (Table 4). Most of the savings result from a relevant decrease in costs depending on the plant and the elimination of waste treatment expenses. Although staff costs still account for nearly half of the total budget, process intensification reduces the need for facilities and inputs, thereby lowering operating costs without compromising product quality.

Figure 5a shows that for traditional technology, the investment cost for 260 batches is USD 1,016,000.00, while the annual production cost is USD 441,000.00. In contrast, for intensified technology (Figure 5c), the investment cost for 260 batches is USD 747,000.00, and the annual production cost is USD 357,000.00.

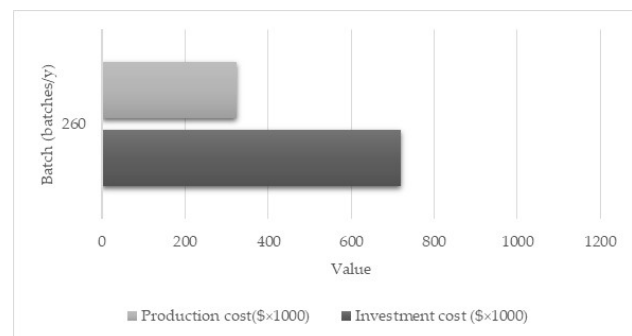
Both traditional and intensified technologies for producing emulsion cream are cost-effective, but intensified technology provides greater economic benefits. While traditional technology has a Net Present Value (NPV) of USD 216,000.00 (Figure 5b), intensified technology achieves an NPV of USD 577,000.00 (Figure 5d), indicating a significantly higher return on investment in a shorter time.

Table 4. Estimated production costs in US dollars: Traditional vs. intensified technology.

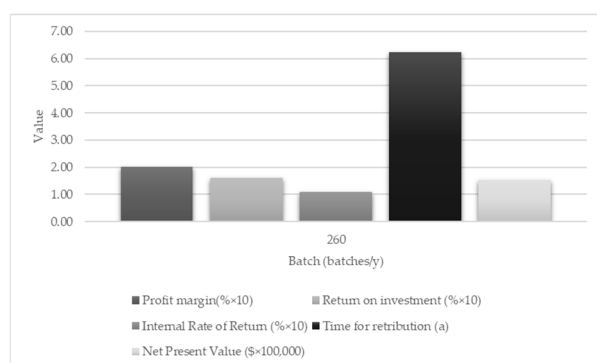
Cost Items	Traditional Technology (USD)	Percent	Intensified Technology (USD)	Percent
Raw Materials	27,000	6.12	27,000	8.33
Labor-Dependent	217,000	49.21	161,000	49.69
Facility-Dependent	161,000	36.51	112,000	34.57
Laboratory/QC/QA	33,000	7.48	24,000	7.41
Consumables	0.00	0.00	0.00	0.00
Waste Treatment/Disposal	3000	0.68	0.00	0.00
Utilities	0.00	0.00	0.00	0.00
Transportation	0.00	0.00	0.00	0.00
Miscellaneous	0.00	0.00	0.00	0.00
Advertising/Selling	0.00	0.00	0.00	0.00
Running Royalties	0.00	0.00	0.00	0.00
Failed Product Disposal	0.00	0.00	0.00	0.00
Running Royalties	0.00	0.00	0.00	0.00
Failed Product Disposal	0.00	0.00	0.00	0.00
Total	441,000	100.00%	324,000	100.00%



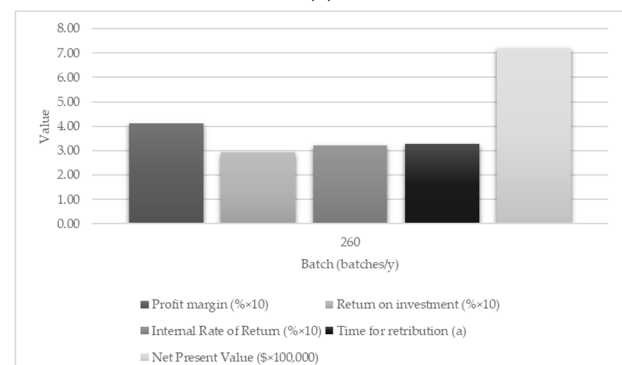
(a)



(c)



(b)



(d)

Figure 5. The results of the economic analysis; investment and production cost: (a) traditional [20]; (c) intensified; (b) dynamic economic and profitability indicators. (b) Traditional [20]; (d) intensified.

3.2. Plant Layout

The plant layout is the result of applying the Systematic Layout Planning (SLP) in its qualitative form. Priority was given to proximity relationships and functional flow between areas, without relying on distance or travel time metrics. Thus, the processes are grouped and sequenced in a logical manner, despite the absence of specific numerical indicators of operational efficiency.

The proposed layout for the ECC production plant, illustrated in Figure 6, begins at the unloading zone, followed by the raw material reception area (Z1), which includes designated sections for Morete and Ungurahua fruits. The production process initiates with the extraction of plant oils, represented by yellow arrows, and includes the following unit operations: selection (A), washing (B), softening (C), pulping (D), and pressing and filtration (E). Conveyor belt systems, shown with brown arrows, are integrated into pulping and pressing to facilitate the removal of solid waste.

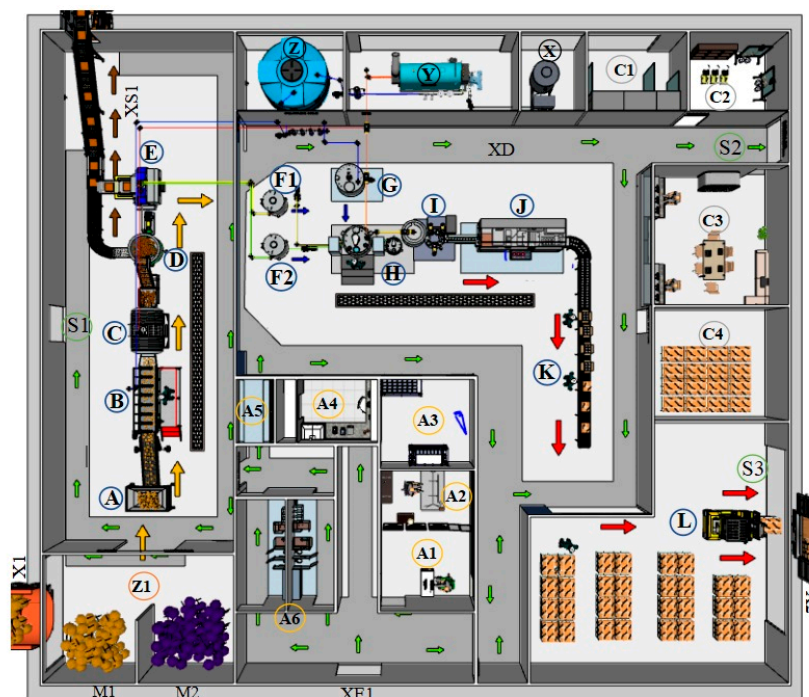


Figure 6. The distribution of the plant for producing emulsion creams. Production area: A. Selection; B. Washing; C. Softening; D. Pulping; E. Pressing and filtering; F1. Morete oil; F2. Ungurahua oil; G. Turbo-emulsifier aqueous phase; H. Turbo-emulsifier oil phase; I. Packaging machine; J. Labeling; K. Packaging; L. Storage; M1. Morete fruits; M2. Ungurahua fruits. Administration area: A1. Secretary; A2. Administrator; A3. Inputs and ingredients; A4. Laboratory; A5. Disinfection chamber; A6. Dressing rooms. Maintenance and control area: C1. Electrical systems; C2. Maintenance warehouse; C3. Control room; C4. Container and label warehouse. Complementary areas: X. Boiler fuel; X1. Discharge area; X2. Discharge area of finished products; XE1. Main entrance; XD. Staff movement area; XD. Waste exit; Y. Boiler; Z. Water storage. Emergency exits: S1., S2., S3. Discharge area: Z1. Initial disposal of the raw material. Cargo area.

After oil extraction, the oils are stored in dedicated tanks (F1) for Morete oil and (F2) for Ungurahua oil. The oil phase is then prepared in the turbo-emulsifier (H), and the aqueous phase (G) is added based on defined operational parameters. This sequence is indicated by blue arrows. The final processing stages include packaging (I), labeling (J), and boxing (K), concluding with final storage and a designated loading area (L). The production flow progresses linearly from (A) to (L), ensuring a streamlined, non-redundant workflow throughout the plant.

3.2.1. Principle of Integration

Specific areas are established for the movement of workers, marked in gray with green arrows, thus keeping all the following areas separate: production, administration, complementary systems, and a control and maintenance area.

Exclusive personnel routes were established to strategically group the production, administrative, and maintenance areas, minimizing interference between activities and ensuring a continuous, continuous process flow.

3.2.2. Principle of the Minimum Distance Traveled

Five strategic points are identified in the process: (1) placement of raw materials (Z1); (2) and (3) an analysis of oil samples (F1, F2) and cream (H) in the laboratory (A4); (4) the addition of inputs (A3) into the turbo-emulsifier for the fatty phase (H); and (5) the supply of materials from (C4) to the packaging (I), labeling (J), and final packing stations (K). By arranging these points in a logical sequence, unnecessary movements are removed, as each activity directly receives inputs from the previous stage without intersecting paths.

3.2.3. Material Flow

The production area begins with the oil extraction, involving unit operations A through E, indicated by yellow arrows. This constitutes the first operational zone in the process sequence. The extracted oils (F1 for Morete and F2 for Ungurahua) are stored, after which the turbo-emulsifier is initiated: first, the aqueous phase (G) is prepared and subsequently incorporated into the fatty phase (H) to form the emulsion. This progression is represented by blue arrows. The process then advances to the packaging unit (I), labeling station (J), and final packing and storage (K and L), as indicated by red arrows.

Additionally, this flow principle applies to the disposal of by-products from the pulping (D) and pressing (E) stages. These residues are transported out of the facility via conveyor belts, illustrated with brown arrows in Figure 6, ensuring efficient waste management without interfering with the main production line.

This sequential configuration ensures a continuous and unidirectional flow of materials and waste across all areas, by positioning extraction, emulsification, and packaging as contiguous stages, thereby eliminating cross-traffic.

3.2.4. Cubic Space Principle

Water flow is supplied to both the washing (B) and softening (C) stages during the oil extraction process. For cream preparation, filtered water is specifically allocated to the aqueous phase (G). Superheated steam is available in the extraction area to facilitate softening (C), while in the cream formulation stage, it is used both to heat the aqueous phase (G) and to regulate the temperature of the oil phase (H).

Through the designation of dedicated water and steam supply points for each stage—washing, softening, and formulation—pipeline overlap is eliminated, and spatial utilization is optimized without the need for volumetric calculations.

3.2.5. Principle of Satisfaction and Security

The administrative area is organized into distinct sections, including secretary (A1), administrator (A2), supply and material warehouse (A3), laboratory (A4), disinfection chamber (A5), and separate dressing rooms for men and women (A6), ensuring both staff satisfaction and product safety. This structured approach extends to the control and maintenance department (C3). The oil extraction and cream production processes are managed from a central control room, supervised by qualified staff. Additional dedicated spaces are provided for the electrical control system, maintenance storage, and the storage of labels and containers. In the complementary systems area, spaces are physically separated by solid walls to prevent heat transfer to the water (Z) and fuel (X) storage areas during operation, thereby minimizing the risk of accidents. In the case of an accident at the plant, three emergency exits were designed (S1, S2, S3).

The well-defined separation of offices, laboratories, and control areas reduces functional conflicts and enhances safety, as staff move through designated zones without interfering with critical operations.

3.2.6. Principle of Flexibility

The production area, comprising both the oil extraction and cream manufacturing processes, is designed with sufficient space to facilitate maintenance and accommodate the integration of additional, mobile, and easily removable equipment. The layout also incorporates the administration, complementary systems, and control and maintenance areas. This systematic and organized approach minimizes operational delays, enhances spatial efficiency, and supports smooth plant operation. Incorporating space for maintenance and movable equipment enables the plant design to adapt to future changes without requiring a complete layout reconfiguration, thereby ensuring operational continuity.

4. Discussion

The application of process intensification principles to the design of a pilot plant for cosmetic emulsion (CE) production using Morete and Ungurahua oils has demonstrated the efficient utilization of available raw materials [20]. The extraction and processing of these traditionally underutilized oils have been optimized to maximize cream production yield per kilogram of input, achieving 1.46 kg of CE/kg. This result confirms the feasibility of converting local seasonal fruits into high value-added products while strengthening supply chains in the Amazon region [20]. Locating the plant in Tena (Ecuador) and establishing supply agreements with local associations or communities is expected to ensure a steady flow of raw materials despite the seasonality of harvests.

Moreover, this study demonstrated that the use of local raw materials is not only applicable but also improves the final product by introducing elements of differentiation and sustainability [20]. Morete and Ungurahua oils, rich in essential fatty acids and antioxidants, provide superior cosmetic properties (hydration, repair, and skin barrier protection) that allow the CE to be positioned competitively in both regional and national markets, while also generating employment opportunities [18].

The integration of circular economy principles into the design enables the repurposing of pressing by-products into exfoliant ingredients or raw materials for biofertilizers, thereby closing the production loop and minimizing solid waste generation [33]. A major finding of this study is the relevant reduction in capital investment, driven by technological enhancements and strategic operational planning. By unifying the extraction lines for both oils with intermediate cleanings, the number of main equipment units was reduced from 12 to 9, and CAPEX (capital expenditure) decreased from USD 126,000 to USD 88,000. Simulation using SuperPro Designer V10 indicated a NPV of USD 577,000 and a payback period of 3.93 years—parameters that confirm the economic feasibility of an intensified scheme over a conventional design [34,35]. The reduction in fixed capital investment leads to decreased financial risk and a shorter payback period—key factors in attracting investment for sustainable agro-industrial initiatives. In addition, the study offers a comprehensive and well-structured representation of the plant layout, developed using the Systematic Layout Planning (SLP) methodology. The linear arrangement of processing areas—from raw material reception and extraction to turbo-emulsification and final packaging—reduces internal movement by 15%, minimizes downtime, and facilitates maintenance without interrupting production. The strategic zoning of thermal, humidity, and auxiliary systems, along with the incorporation of three emergency exits and service corridors, ensures compliance with international safety and ergonomic standards for pilot-scale operations. This

schematic representation provides a solid foundation for the future construction of the pilot facility and serves as a valuable tool for training operational personnel.

The analysis of resource consumption and waste generation indicates the use of 48.4 kg of water, 10 kg of steam, and 5.86 kWh of electricity per kilogram of cream produced, along with the generation of 0.56 kg of solid waste per kilogram of cosmetic emulsion (CE). The water consumption results presented in the intensified design of this study were lower than those reported by Nydrioti et al. [37] which were 81.6 kg/kg of product in a natural cosmetics plant. Furthermore, in terms of energy consumption, traditional plants of the same size reported an expenditure varying between 8 and 10 kWh/kg of cream and an estimated carbon footprint of 3.5–4.0 kg CO₂e/kg product [36].

These figures reflect competitive environmental performance, remaining within acceptable limits for small-scale cosmetic manufacturing processes [37]. Furthermore, the valorization of press cake offers promising opportunities for integrating circular economy principles—for instance, through the extraction of residual phenolic compounds for cosmetic formulations or the fermentation of pulp to produce high-value biofertilizers [36].

Studies of chemical characterization of pressing cakes (e.g., argan, sunflower, and sesame) have shown total phenolic contents in the range of 3–10 mg GAE/g DM and DPPH antioxidant activities exceeding 15–78%, identifying them as rich sources of bioactive compounds [38].

Furthermore, analyses of commercial cosmetic formulations have reported that anti-aging and sunscreen products (13.2% and 5.2%, respectively) incorporate phenolics such as resveratrol, ferulic acid, or chrysin, leveraging their photoprotective and antioxidant properties to mitigate solar damage and oxidative stress [39].

These findings indicate that pressing cakes contain bioactive compounds which, if extracted, could serve as raw materials for formulating antioxidant tonics, anti-aging creams, or sunscreens of renewable origin—thus closing the production cycle within the framework of the circular economy and providing more affordable and sustainable ingredients for the cosmetic industry.

5. Conclusions

The proposed design of the CE production plant optimizes material flow and space utilization while ensuring operational safety for plant personnel. The layout of the plant is divided into several key areas: production, which includes plant oil extraction and cream formulation processes, discharge and loading zones, administration, supporting systems, and areas for control and maintenance. The process design was initially defined, followed by the application of integration principles such as minimizing material travel distances, ensuring efficient flow, optimizing cubic space, and prioritizing the safety and well-being of plant personnel interacting with the technology.

Additionally, the proposal for an intensified process in plant oil extraction and EC production reduces the amount of equipment, thus lowering both capital expenditure and overall investment. This streamlined approach demonstrates superior efficiency and profitability, resulting in a NPV of USD 577,000.00, a profit margin of 35.48%, and a reduced payback period of just 3.93 years.

Future research should explore emerging technologies such as ultrasound-assisted extraction and microwave treatments, which have the potential to increase yields while reducing processing times. The implementation of a digital twin, supported by a mathematical assistant and real-time sensor data to monitor operational parameters, would enable the predictive optimization of critical variables and facilitate preventive maintenance, thereby ensuring consistent CE quality. This holistic approach not only strengthens the compet-

itiveness of the Amazonian cosmetic agro-industry but also establishes a foundation for future sustainable innovation and the valorization of the region's endogenous resources.

Author Contributions: Conceptualization, A.P.M. and E.G.Y.; methodology, E.W.S.C., L.L.G. and I.N.A.T.; software, A.P.M. and R.A.-N.; formal analysis, L.S., M.R. and L.R.B.S.; investigation, E.G.Y., L.L.G. and L.R.B.S.; writing—original draft preparation, R.A.-N. and L.S.; writing—review and editing, M.R. and E.G.Y.; supervision, A.P.M. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by Universidad Estatal Amazónica in Puyo, Ecuador, and has been completed as part of the project: Desarrollo de Nuevos Productos Agroindustriales de Alto Valor Agregado a Partir de Aceites Fijos, Esenciales y Extractos de Plantas Ricos en Metabolitos Antioxidantes o Antimicrobianos [Development of New Agro-Industrial Products with High Added Value from Fixed Oils, Essential Oils, and Plant Extracts Rich in Antioxidant or Antimicrobial Metabolites].

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

Acknowledgments: The authors wish to thank Helen Pugh for proofreading the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Ferreira, M.; Matos, A.; Couras, A.; Marto, J.; Ribeiro, H. Overview of Cosmetic Regulatory Frameworks around the World. *Cosmetics* **2022**, *9*, 72. [\[CrossRef\]](#)
2. Ruilova Accini, P.V.; Sempertegui Seminario, C.A.; Guerrero Muñoz, M.K. Calidad Del Servicio de Las Empresas Asociadas a La Industria Cosmética En El Ecuador. *Soc. Tecnol.* **2019**, *4*, 298–311. [\[CrossRef\]](#)
3. Mancheno Saá, M.; Gamboa Salinas, M.J. El Branding Como Herramienta Para El Posicionamiento En La Industria Cosmética. *Univ. Soc.* **2018**, *10*, 82–88.
4. Basurto Jimbo, E.; García Mir, V.; Rueda Rodríguez, E.; Noles Ramón, K. Elaboración de Una Crema Cosmética a Partir de Extractos *Coriandrum sativum* L. (Culantro). *Publicación Cuatrimest.* **2021**, *6*, 153–166.
5. Cobos Yanez, D.B. Elaboración de Una Crema Nutritiva Facial a Base de La Pulpa de Chirimoya (*Annona Cherimola*, Annonaceae). Master's Thesis, Universidad Politécnica Salesiana, Quito, Ecuador, 2015.
6. Capp Zilles, J.; Vallenot Lemos, M.A.; Anders Apel, M.; Kulkamp-Guerreiro, I.C.; Rigon Zimmer, A.; Vidor Contri, R. Vegetable Oils in Skin Whitening—A Narrative Review. *Curr. Pharm. Des.* **2025**, *31*, e13816128361413. [\[CrossRef\]](#)
7. Jašek, V.; Figalla, S. Vegetable Oils for Material Applications—Available Biobased Compounds Seeking Their Utilities. *ACS Polym. Au* **2025**, *5*, 105–128. [\[CrossRef\]](#)
8. Pupiales Martínez, S.A.; Torres Cando, T.E. Obtención de Aceites Esenciales a Partir de Pino (*Pinus*), Eucalipto (*Eucalyptus*), Menta (*Mentha*), Caléndula (*Caléndula Officinalis*), y Su Aplicación En La Elaboración de Una Crema Con Fines Terapéuticos. Bachelor's Thesis, Universidad Estatal de Bolívar, Guaranda, Ecuador, 2023.
9. Madurga, M. El Papel de La Cosmética: Excipientes y Conservantes. *Rev. De Pediatría De Atención Primaria* **2009**, *XI*, 81–100. [\[CrossRef\]](#)
10. Montalván, M.; Malagón, O.; Cumbicus, N.; Tanitana, F.; Gilardoni, G. Análisis Químico de Aceites Esenciales Amazónicos de Una Comunidad Shuar Ecuatoriana. *Granja* **2023**, *38*, 32–44. [\[CrossRef\]](#)
11. Pons, G.A. Aceites Vegetales, Hacia Una Producción Sostenible. *Hombre Máquina* **2015**, *46*, 9–19.
12. Guardado Yordi, E.; Radice, M.; Scalvenzi, L.; Pérez Martínez, A. Diseño Del Proceso Sostenible Para La Obtención de Una Emulsión Cosmética Desde Un Enfoque de Biocomercio. *Rev. Politécnica* **2024**, *54*, 35–46. [\[CrossRef\]](#)
13. Mosquera, T.; Noriega, P.; Tapia, W.; Pérez, S.H. Evaluación de La Eficacia Cosmética de Cremas Elaboradas Con Aceites Extraídos de Especies Vegetales Amazónicas: *Mauritia flexuosa* (Morete), *Plukenetia Volubilis* (Sacha Inchi) y *Oenocarpus Bataua* (Ungurahua). *La Granja* **2012**, *16*, 14. [\[CrossRef\]](#)
14. Proaño, J.; Rivadeneira, E.; Moncayo, P.; Mosquera, E. Aceite de Maracuyá (*Passiflora Edulis*): Aprovechamiento de Las Semillas En Productos Cosméticos. *Enfoque UTE* **2020**, *11*, 119–129. [\[CrossRef\]](#)
15. Rivera, J.; Luna, S.; Rodríguez, N.; Dahua, R. Evaluación de Las Propiedades Antioxidantes y Físicas de Una Crema Exfoliante Desarrollada a Partir de La Cáscara de *Mauritia flexuosa* L. (Morete). *Polo Conoc.* **2024**, *9*, 491–510.
16. Campos, D.A.; Gómez-García, R.; Vilas-Boas, A.A.; Madureira, A.R.; Pintado, M.M. Management of Fruit Industrial By-products—A Case Study on Circular Economy Approach. *Molecules* **2020**, *25*, 320. [\[CrossRef\]](#)

17. Del Rio Osorio, L.L.; Flórez-López, E.; Grande-Tovar, C.D. The Potential of Selected Agri-Food Loss and Waste to Contribute to a Circular Economy: Applications in the Food, Cosmetic and Pharmaceutical Industries. *Molecules* **2021**, *26*, 515. [[CrossRef](#)] [[PubMed](#)]
18. Machado, M.; Silva, S.; Costa, E.M. Byproducts as a Sustainable Source of Cosmetic Ingredients. *Appl. Sci.* **2024**, *14*, 10241. [[CrossRef](#)]
19. Mondello, A.; Salomone, R.; Mondello, G. Exploring Circular Economy in the Cosmetic Industry: Insights from a Literature Review. *Environ. Impact Assess. Rev.* **2024**, *105*, 107443. [[CrossRef](#)]
20. Guardado Yordi, E.; Guambuete Guaman, I.S.; Freire Fuentes, M.E.; Radice, M.; Scalvenzi, L.; Abreu-Naranjo, R.; Bravo Sánchez, L.R.; Pérez Martínez, A. Conceptual Design of the Process for Making Cosmetic Emulsion Using Amazonian Oils. *Processes* **2025**, *13*, 1770. [[CrossRef](#)]
21. Romero, D.; Aillón, F.; Freire, A.; Radice, M. Design of an Industrial Process Focused on the Elaboration of Cosmetics from Amazonian Oils: A Biotrade Opportunity. *Mol2Net* **2016**, *2*, 1–5. [[CrossRef](#)]
22. Cerda-Mejía, V.; González-Suárez, E.; Guardado-Yordi, E.; Cerda-Mejía, G.; Pérez Martínez, A. Producción de Gel Hidroalcohólico En Tiempos de COVID-19, Oportunidad Para Diseñar El Proceso Que Garantice La Calidad. *Cent. Azúcar* **2021**, *48*, 88–97.
23. Beltrán Chacón, J.P.; Aguayo Carvajal, V.R. Estudio Técnico: Localización y Diseño de Plantas Agroindustriales. *Braz. J. Bus.* **2022**, *4*, 1951–1960. [[CrossRef](#)]
24. Rodríguez Cortina, J. Contribución al Estudio de La Intensificación Del Proceso de Secado de Tomillo (Thymus Vulgaris L.): Aplicación de Ultrasonidos de Potencia y Secado Intermitente. Ph.D. Thesis, Universitat Politècnica de València, Valencia, Spain, 2013.
25. Rodriguez Barragan, O.A. Intensificacion de Procesos de Transferencia de Materia Mediante Ultrasonidos de Potencia. Aplicacion al Secado Convectivo y a La Extraccion Con Fluidos Supercriticos. Ph.D. Thesis, Universidad de les Illes Balears, Illes Balears, Spain, 2014.
26. Dimian, A.C. *Integrated Design and Simulation of Chemical Processes*; Gani, R., Ed.; Elsevier: Amsterdam The Netherlands, 2003; Volume 13, ISBN 978-0-444-62700-1.
27. Pérez-Martínez, A.; Cervantes-Mendieta, E.; Julián-Ricardo, M.C.; González-Suárez, E.; Gómez-Atanay, A.; Oquendo-Ferrer, H.; Galindo-Llanes, P.; Ramos-Sánchez, L. Procedimiento Para Enfrentar Tareas de Diseño de Procesos de La Industria Azucarera y Sus Derivados. *Rev. Mex. Ing. Quim.* **2012**, *11*, 333–349.
28. Stankiewicz, A.I.; Moulijn, J.A. Process Intensification: Transforming Chemical Engineering. *Chem. Eng. Prog.* **2000**, *96*, 22–34.
29. Linnhoff, B.; Akinradewo, C.G. Linking Process Simulation and Process Integration. *Comput. Chem. Eng.* **1999**, *23*, S945–S953. [[CrossRef](#)]
30. Linnhoff, B.; Townsend, B.W. Designing Total Energy Systems. *Chem. Eng. Prog.* **1982**, *78*, 7.
31. Frosch, R.A.; Gallopoulos, N.E. Strategies for Manufacturing. *Sci. Am.* **1989**, *261*, 144–153. [[CrossRef](#)]
32. Dimian, A.C.; Bildea, C.S.; Kiss, A.A. Chapter 2—Introduction in Process Simulation. In *Computer Aided Chemical Engineering*; Elsevier: Amsterdam The Netherlands, 2014; Volume 35, pp. 35–71.
33. Muther, R. *Planificación y Proyección de La Empresa Industrial: (Método S.P.L., Systematic Layout Planning)*; Carreras Fontseré, L., Ed.; Editores Técnicos Asociados, S.A.: Kansas City, MO, USA, 1968; Volume 1.
34. Suhardini, D.; Septiani, W.; Fauziah, S. Design and Simulation Plant Layout Using Systematic Layout Planning. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *277*, 012051. [[CrossRef](#)]
35. Álvarez Arias, D.; De Ávila Moore, J.; Hurtado Rivera, J. Aplicación de Metodología SLP Para Redistribución de Planta En Micro Empresa Colombiana Del Sector Marroquino: Un Estudio de Caso. *Boletín Innovación Logística Oper.* **2022**, *4*. [[CrossRef](#)]
36. Rocca, R.; Perossa, D.; Fumagalli, L. Analysis and Modelling for Industrial Energy Efficiency in the Cosmetics Industry: A Real Industrial Case in an Italian Manufacturing Company. *Cosmetics* **2024**, *11*, 161. [[CrossRef](#)]
37. Nydrioti, I.; Moutsaki, M.-M.; Leounakis, N.; Grigoropoulou, H. Implementation of the Water Footprint as a Water Performance Indicator in Industrial Manufacturing Units Located in Greece: Challenges and Prospects. *Environ. Sci. Pollut. Res.* **2024**, *31*, 803–819. [[CrossRef](#)]
38. Hallouch, O.; Ibourki, M.; Asbbane, A.; Devkota, K.; Giuffrè, A.M.; Majourhat, K.; Gharby, S. Exploring the Bioactive Potential of Argan Oil Cake: A Comprehensive Physicochemical Comparison with Various Seeds Cakes. *Curr. Res. Nutr. Food Sci. J.* **2025**, *13*, 77–100. [[CrossRef](#)]
39. Jesus, A.; Ratanji, S.; Cidade, H.; Sousa, E.; Cruz, M.T.; Oliveira, R.; Almeida, I.F. Phenolics as Active Ingredients in Skincare Products: A Myth or Reality? *Molecules* **2025**, *30*, 1423. [[CrossRef](#)] [[PubMed](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.