U.Porto Journal of Engineering, 8:5 (2022) 122-134
ISSN 2183-6493
DOI: 10.24840/2183-6493_008.005_0011

Received: 13 June, 2022
Accepted: 12 September, 2022
Published: 26 September, 2022

Product Development of an Animal Shampoo from Lettuce Waste

Ana Catarina Rebelo[1], Diana Campinho[2], Guilherme Amaral[3], Gonçalo Pereira[4], Rui Matias[5], Ana F. Freitas[6]

[1]Department of Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (up201806239@edu.fe.up.pt) ORCID 0000-0002-9483-3083; [2]Department of Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (up201806226@edu.fe.up.pt) ORCID 0000-0001-9790-1478; [3]Department of Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (up201806722@edu.fe.up.pt) ORCID 0000-0002-7736-5759; [4]Department of Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (up201806737@edu.fe.up.pt) ORCID 0000-0002-0329-6252; [5]Department of Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (up201806812@edu.fe.up.pt) ORCID 0000-0003-2108-3434; [6]LSRE-LCM-Laboratory of Separation and Reaction Engineering-Laboratory of Catalysis and Materials, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal; LEPABE-Laboratory for Process, Environment, Biotechnology and Energy, Chemical Engineering Department, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal; ALiCE-Associate Laboratory in Chemical Engineering, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal (affreitas@fe.up.pt) ORCID 0000-0003-1322-3660

Abstract

Overexploitation of natural resources is one of the global environmental problems, so it is crucial to use waste to achieve a more sustainable world. This paper proposes the development process of a product using ingredients extracted from leaves and stems of lettuce waste. To identify and satisfy the customer needs, the Chemical Product Design procedure was followed by discussing the four stages: Needs, Ideas, Selection and Manufacture. The final product - LettPet Shampoo - consists of an Animal Shampoo that has two formats: bottles of 0.2 L and 5 L. The bioactive compounds extracted add properties to the shampoo, such as fur loss prevention, strengthening, and antioxidant properties. According to the economic analysis, 50 thousand bottles would be sold in the first year, and at the end of the 5th year, sales would be doubled. The company would obtain a positive cash flow until the 4th semester and settle the debt after three years.

Author Keywords. Lettuce Waste. Triterpenes. Animal Shampoo. Product Develop ment.

Type: Research Article

1. Introduction

Earth's population growth has led to an over-exploration of its natural resources, meaning these resources have become scarcer over the years. Due to this phenomenon, it is crucial to optimise their use to achieve a more sustainable world. Besides this, society generates tons of organic waste every year, ending in landfills (San Martin, Ramos, and Zufía 2016).

In this way, the scientific community has made a considerable effort to use this waste as a source of bioactive compounds and biodegradable materials (Papargyropoulou et al. 2014). Beyond being a more sustainable way to treat the generated waste, the valorisation of vegetable by-products would also increase resource efficiency and promote the competitiveness of companies by using a more sustainable raw material which reduces the dependence on current ones (San Martin, Ramos, and Zufía 2016).

However, the use of vegetables has some disadvantages that can limit its viability. For instance, vegetables have a high water content (>80%) which requires a drying process, and it is challenging to separate bioactive compounds (the extraction yield is low). Also, the composition of the raw material can vary throughout time, which means that producers have to change their formulations regularly (San Martin, Ramos, and Zufía 2016).

According to the Instituto Nacional de Estatística - INE, the average lettuce production in the last five years was around 53 thousand tons per year in Portugal (INE 2021), and 61% of it is produced in Ribatejo (INE 2002). For this reason, the place chosen for the company was Carregado, Lisbon District and Ribatejo Region. On the other hand, as estimated by the United Nations Food and Agriculture Organization (FAO), one-third of the food produced in the world is wasted (FAO 2014), which means around 16 thousand tons of lettuce are squandered per year in this country.

This work aims to evaluate the use of lettuce waste (leaves, stems and roots) to develop a product. To fulfill the goal of this work, it was necessary to know the bioactive components of lettuce, the extraction process, the extraction yield and the concentration of each component in the extract. According to Popkin, D'Anci, and Rosenberg (2010), lettuce is 90 to 99% of water, so it was considered an average of 95%.

Nafed Mughrbi and Auzi (2020) studied the composition of lettuce stem and leaves extract, using petroleum ether as solvent. The two varieties studied (*L. sativa* var. *longifolia* and *L. sativa* var. *capitata*) were found to be the predominant ones produced in Portugal (Tavares 1988). The major bioactive compounds found were triterpenes (47.2%), phytosterols (22.86%), and fatty acids (10%), among others (Nafed Mughrbi and Auzi 2020). The yield of this extraction was 0.91%. Cellulose is also present, according to Zhang et al. (2019). After the same method, experimental studies were conducted to understand the quantity of cellulose available, and an extraction yield of 1% was achieved.

Triterpenes, the most abundant bio-compound in lettuce waste, have many applications due to their anti-inflammatory, antiviral, antimicrobial, antitumoral and immunomodulatory properties (Ríos 2010; Agra et al. 2015). Beyond that, they have also been used as proliferative agents on human follicle dermal papilla cells (Sagayama et al. 2019). It has been suggested that phytosterols, another major compound of lettuce waste (in particular β-sitosterol), are involved in the reduction of plasma total LDL-cholesterol (LDL-C) concentration (Lombardo et al. 2018) and also help in hair density increase (Zanzottera et al. 2017). Lactucins, also present in the roots, present anti-inflammatory, antitumoral (Chadwick et al. 2013) and sedative properties (Wesołowska et al. 2006).

β-carotene, a Vitamin A precursor and an excellent source of this vitamin, was also identified in lettuce waste (Duan, Shin, and Lee 2019). Beyond this, it possesses antioxidant properties (Sies, Stahl, and Sundquist 1992). Due to its elevated nutritional values, β-carotene is commonly used to strengthen the hair/fur and to prevent hair/fur loss in different cosmetic products available on the market.

2. Chemical Product Design (CPD)

To identify and satisfy the customer needs, the Chemical Product Design procedure was followed by discussing the four stages: Needs, Ideas, Selection and Manufacture (Cussler and Moggridge 2011).

2.1. Needs & Ideas

Firstly, it was necessary to list all the needs that were identified and classify them into: essential, desirable and useful. To be successful, the product should fulfill all these needs. It is essential to satisfy those who buy the product and those who benefit from it. The needs and needs classification are expressed in Cussler and Moggridge (2011).

The main goal of this project is to make use of the wasted lettuce by creating a product. The product manufacture should be done in a factory located in Portugal since people value national products. Furthermore, an inexpensive product is useful to increase the interest of the consumers.

Twenty-five different ideas with various degrees of complexity, quality and feasibility were conceptualised, based on the properties of the active compounds that can be extracted from the lettuce, and always having in mind the needs that should be satisfied. For better organisation and to help decide what the best ideas were, the ideas were divided into five different categories: Medicine (if the product is a medicine), Cosmetic (if the product is a cosmetic), cellulose (if the product is made by cellulose), Food supplements/additives (if the product is an aliment or additive for food) and Independent. The ideas present in the independent category were outliers since they did not fit in any other category and were different from any other idea, even among themselves. Table 1 presents all the ideas, divided by category.

Medicine	Cosmetic	Cellulose	Food Supplements	Independent
Analgesic	Natural Shampoo	Paper	Juice with additives	Ink
Treatment for asthma and cough	Lotion for face and body	Textile	Tea	Pesticide/Insecticide
Treatment for diabetes	Suntan Lotion	Nanocomposite	Vitamin A/E Supplements	Vegetable Oil
Cholesterol-lowering	Nail Polish	Nanofibers	Supplement for cholesterol reduction	Animal fur Shampoo
Anti-inflammatory ointment		Bio-Butanol	Food Preservative	

Table 1: Ideas and their categories

Ideas in the Medicine group were the ones where the final product involved producing ointments, capsules or syrups, mainly using triterpenes, phytosterols or lactucin derivatives to treat various diseases. As the name implies, cosmetic ideas pretend to develop a cosmetic using the already mentioned compound β-carotene. The ideas in the Cellulose group are a bit different since the raw material used in them is only cellulose and does not require using other active compounds, making the ideas in this category different from the rest. Cellulose has many uses, so it justifies having its type of ideas. Food Supplements/Additives are a category filled with ideas in which the final product can be added to meals to get some added benefits or something to preserve the meals for longer times without the food starting to decompose. Finally, the independent ideas cannot be part of any other group since they range from controlling pests to various types of inks or vegetable oil.

2.2. Selection

Since the ideas were already sorted and organised, we needed to evaluate the ideas (first through qualitative methods and then through quantitative methods) to select the best quality and feasibility. A subjective opinion was collected from each author on the quality and feasibility of each idea to have understood the authors' consensus regarding the ideas that should be interesting to study and develop and those that did not seem attractive at all or were too hard to develop.

The Medicine group of ideas was discarded. Although interesting, the products were very hard to produce, requiring exhausting manufacturing, rigorous quality tests, and higher production costs. However, the most important drawback is the certification process of these products since it takes much time to acquire the production authorisation for the national or international market. Due to this, they were considered not feasible in this project's scope. Simple ideas, like the tea or the juice, seemed uninteresting and were eliminated.

Nonetheless, a quantitative method was needed to get a final answer to what was the best (and worst) option. An analysis involving matrixes was performed, in which all the ideas were evaluated through various criteria. These criteria had different weighing scores established by the developer group. It was decided to apply the following criteria and their respective weighing factor in parentheses: Implementation (0.3), Production Cost (0.1), Needs/Market (0.2), Ease of Use (0.1), Scientific Maturity (0.1) and Innovation (0.2). The total weighing is 1, and each idea was evaluated on a scale from 1 to 10.

Producing an interesting and innovative product was a priority. However, feasibility having in mind the lack of experience, was also crucial. So, the implementation and innovation criteria were given higher weighting scores. A product that satisfies the consumers and their needs and that is different from those available in the various over-saturated markets is also desirable. For that reason, the Needs/Market and Ease of Use criteria were also considered in this evaluation. Finally, the production cost of the product is also considered as well as science maturity, since this project's scope is not to be a pioneer in a scientific area but to use the available wastes and produce an interesting product.

The matrixes were separated into the five idea groups defined previously in order to be easier to compare similar ideas and choose the best in each category so that the best idea can be selected after analysing each matrix. The matrixes are presented in tables in the Supplementary Data. Table 2 shows the ideas with the highest scores.

Criteria	Weighting Factor	Face and body/Suntan lotion	Textile	Animal Shampoo	Vegetable Oil
Implementation	**0.3**	10	7	7	6
Production Cost	**0.1**	9	6	8	7
Needs/Market	**0.2**	4	7	6	8
Ease of Use	**0.1**	10	10	9	9
Scientific Maturity	**0.1**	10	10	8	10
Innovation	**0.2**	3	6	8	6
Total	**1**	7.3	7.3	7.4	7.2

Table 2: Matrix compiling the best ideas

Although the face and body/suntan lotion had a straightforward implementation and a high scientific maturity, its market is oversaturated, resulting in less innovation. The textile was also an idea that the development group considered exploring since it has a high degree of innovation. Nonetheless, extracting cellulose from lettuce with reasonable yields is not feasible, so the idea was not selected. The vegetable oil was a good idea in itself. However, the complexity of extracting only the fatty acids and not knowing if the fatty acids could even produce an edible oil led the group to other, more feasible ideas. Lastly, the animal shampoo proved to be promising since it is a new market that required some innovation, while the product itself does not have a complex production and manufacture. Therefore, the animal shampoo proved to be the best idea of the twenty-five the group proposed.

3. Manufacture

With the best idea selected, the following step is to transform it into a usable product. The following sub-sections will explain, in some detail, how to manufacture an animal fur shampoo enriched with the active compounds found in lettuce stems, roots and leaves.

3.1. Extraction process

As already reported, Nafed Mughrbi and Auzi (2020) determined the composition of lettuce extract. In their study, 100 g of leaves and stem powder of each variety were macerated in 500 mL of petroleum ether (40-60°C) for three days at room temperature. After filtration, the filtrate was concentrated by solvent evaporation at room temperature. Thus, this extraction was scaled up to produce an industrial amount of extract to use in animal shampoo.

3.2. Production prospect

The pretended business model consists of selling animal shampoo bottles for Animal Saloons in bigger bottles (5 L) and selling smaller bottles (200 mL) of the product online.

A market study was performed by asking several Animal Saloons in Portugal how many shampoo bottles were used per month, how much they cost, and the capacity of each bottle. It was concluded that an average of 2 bottles (5 L) were used per month in each salon, costing 50 euros per bottle. According to *portugalio.com*, a Portuguese company directory, there are around 500 Animal Saloons in Portugal. This number was used for further calculations, even though it is considered that the real number is higher since several companies bathe dogs but are not registered like that. For the first year, a 5% market share for the company was estimated.

Portugal had around 6.7 million domestic animals in 2015, of which 38% were dogs (Pinto 2016). This number is expected to be much higher these days, according to the evolution of the numbers of domestic animals before 2015. It was considered that 50% of the dogs are bathed at home by the owners (even though it is believed this number is considerably higher), that each dog is washed three times per year, that 200 mL of the shampoo is enough to 4 baths and that the market share is also 5%.

With these predictions, it is possible to estimate the total amount of bottles that will be sold and how much raw material and solvent will be needed to achieve all the market needs. According to the estimated market share evolution, it is possible to understand all these requirements per year. All these data can be found in Table 3 and the fraction of lettuce waste used. A stagnation of the market share evolution is predicted after the 5th year.

Year	Market Share (%)		Units sold per year		Lettuce Waste (ton)	Solvent per year (m^3)	Lettuce Waste Reused (%)
	200 mL bottles	5 L bottles	200 mL bottles	5 L bottles			
1	5	5	47,737	600	1,073	2.68 x 10^2	6.7
2	7	7	66,832	840	1,445	3.61 x 10^2	9.0
3	8	10	76,380	1,200	1,631	4.08 x 10^2	10.2
4	10	15	95,475	1,800	2,101	5.25 x 10^2	13.1
5	10	20	95,475	2,400	2,397	5.99 x 10^2	15.0

Table 3: Evolution of the sales, needs and lettuce waste reused for the first five years

3.3. Manufacturing process

The production of an animal shampoo is relatively simple, only being needed a vessel or a reactor to mix all the ingredients. However, the order in which these are added is important. In this vessel, first, water must be added in large quantities since it is the main ingredient.

Then it is required to heat this vessel to a temperature in a range between 55 and 60 °C (Deeksha, Malviya, and Sharma 2014). This step will aid the dilution and hydration of other ingredients. The primary surfactant, as well as the secondary surfactant, if needed, is added, and this ingredient will be the base of the shampoo. The surfactant must be added first since some ingredients will make its dilution much harder, particularly those which affect viscosity. Sodium lauryl ether sulphate was chosen as a primary surfactant. After adding the surfactant, conditioners and other necessary ingredients can be added to the vessel. Some of the necessary ingredients are germicides, conditioning agents, pearlescent agents, sequestrants, thickening agents and finally, some material to conserve the shampoo. Lettuce has active compounds that can fulfill some of these necessities. The triterpenes can act as germicides and the fatty acids present in its stems and leaves can act as a conditioning agent. So, in this stage, it is added a small quantity of triterpenes, fatty acids, β-carotenes and all the other components extracted from the lettuce, 4-methyl-7-diethylamino coumarin, which is a pearlescent agent, a sequestrant like sodium salt of EDTA, a thickening agent like methylcellulose and finally formaldehyde to preserve the shampoo and extend its life span. After mixing these ingredients and reaching a homogeneous substance, the pH must be adjusted to a required level. Finally, some sodium chloride is added along with some viscosity modifiers and some substances to give fragrance and colour to the shampoo (Deeksha, Malviya, and Sharma 2014; Sarovar Reddy et al. 2015). This whole process was assumed to take as long as 5 hours to achieve the best shampoo quality possible (Divone 2013).

The Shampoo composition is shown in Table 4. Note that these are only estimates obtained through the study of similar products and assuming average values since the development group did not produce any samples necessary to assess different compositions and compare their quality. It is also important to keep in mind that the triterpenes, β-carotenes and the fatty acids, shown in Table 4 with an asterisk, can be obtained from the lettuce, hence these ingredients will be added whenever the lettuce extract is added.

This mixture will then proceed to the test stage. The test stage is necessary since some of the components of the shampoo can be harmful when present in high concentrations. The tests are also important since the development group could not produce a sample of the animal shampoo, even at a laboratory scale. When the tests are complete, the shampoo can then be packaged, labeled and distributed to the market.

Ingredient	wt%
Water	82.3
Triterpenes*	1.0
β-carotenes*	0.5
Fatty Acids*	0.2
Sodium Lauryl Ether Sulphate	12.0
4-methyl-7-diethylamino coumarin	1.0
Sodium salt of EDTA	1.5
Methyl cellulose	1.0
Formaldehyde	0.5

Table 4: Composition of the Animal Shampoo - LettPet

3.4. Industrial equipment

The previous section (3.2) shows that it will be produced 55.8 L of shampoo per day of production (4 days a week of shampoo production). To fulfill this goal, the company will operate 5 days a week and it will need two tanks. Considering the yield of extraction (0.91%) and the triterpenes composition, 5159 kg of lettuce will be needed per day, which contains

95% of water (Popkin, D'Anci, and Rosenberg 2010). Thus, a dryer will be needed to dry all the lettuce. In this process, the water will be recovered to be used in another step of the process. To grind the dried lettuce, a grinding milling machine will be needed. The lettuce powder would then be conducted to a tank with petroleum ether to macerate for 3 days.

After the maceration process, the tank content would be filtrated. Then, the previous extract would be pumped into an evaporator to remove the petroleum ether. In this process, an estimative of 80% of solvent will be possible to recover. After this process, the extract (2.33 kg) would be pumped to a mixing machine, where it would be mixed with the remaining ingredients, as mentioned in section 3.2. It remains for about 5 hours in the machine.

Figure 1 displays the equipment necessary to yield the desired quantity of active compounds (triterpenes, fatty acids, β-carotenes) to produce the number of shampoo bottles projected in section 3.2. The equipment images are from *Alibaba*. The production will only occur four days a week since maceration needs about three days.

Figure 1: Industrial process for extraction of active compounds from lettuce and production of 55.8 L per day of animal shampoo

4. Economic Analyses

After product development, it is necessary to perform an economic analysis to assess the project's profitability and predict the future development of the company. It was considered that the place chosen for the company was Carregado, Lisbon District and Ribatejo Region since 61% of lettuce production in Portugal is from this region (INE 2002). It was assumed that lettuce, since it is a waste of supermarkets and restaurants, for example, and from the farmers themselves, and is not used, will not be considered an expense for the company. However, the transport of lettuce to the factory installations was considered. Figure 2 shows all stages of the project.

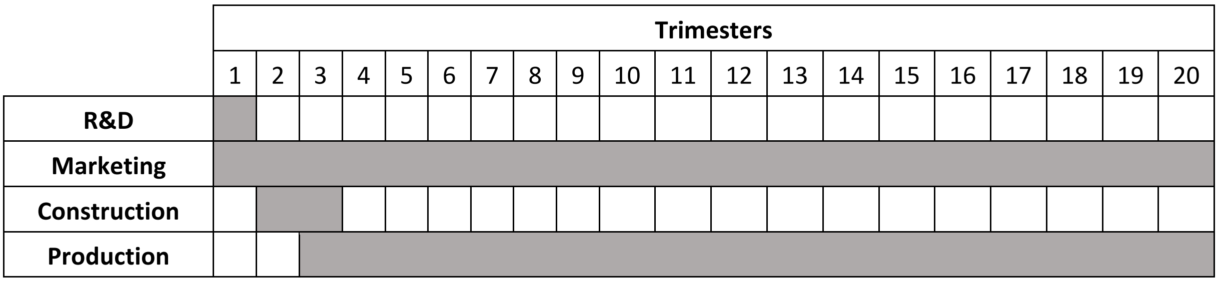

Figure 2: Gantt Diagram for the different activities in a 5-year projection

In the company's first trimester, it was considered that there were only expenses in the research and marketing sector. The research sector is important to guarantee a high-quality product for consumers and to research the possibility of a cheaper and less toxic solvent but equivalent to the one used. Also, the marketing sector has high importance at this stage to carry out market research to understand the needs of consumers. Finally, it was considered that the construction of the company was done in the second and third trimesters, and production started in the third trimester.

To determine the price of the product, it is necessary to assess the ingredients' costs. Initially, it is necessary to use petroleum ether as a solvent in the lettuce extraction process. It is necessary to use 1031 kg daily at a price/kg of 1.15€, making a total of 1186€/ day. However, 80% of petroleum ether used in the evaporator is recovered, thus reducing the expenses associated with the solvent. Table 5 shows the prices and quantities of the rest of the ingredients.

Ingredient	Price (€/kg)	Quantity per day (kg)	Price per day (€)
Sodium Laury Ether Sulphate	0.8	6.696	5.36
4-methyl-7-diethylamino coumarin	20	0.558	11.16
Sodium salt of EDTA	3.5	0.837	2.93
Methyl cellulose	3.5	0.558	1.95
Formaldehyde	1.29	0.279	0.36

Table 5: Prices and quantities of each ingredient for a production of 55.8 L/day of shampoo

For the economic analysis, it was also necessary to consider all associated costs, from the acquisition of land and its construction, acquisition of equipment and all expenses inherent to transport to the cost of production, namely ingredients, energy, water and salary. Table S6, presented in the supporting information, shows all the associated values for the different categories. The values presented in the table are based on estimates and therefore have an associated error. After analysing all costs and initially considering a market share of 5%, the sale price for salons was set at 49.99€ and for the final consumer at 7.99€. With these values, it was possible to obtain a positive cash flow in the fourth trimester of the 1st year, and, finally, it was possible to settle the debt after 3 years; that is, from the 3rd year, the accumulated income is higher than the accumulated expense. Figure 3 shows the accumulated income/expenses over the trimester. An increase of 2% per year in production costs was considered to justify possible price inflation.

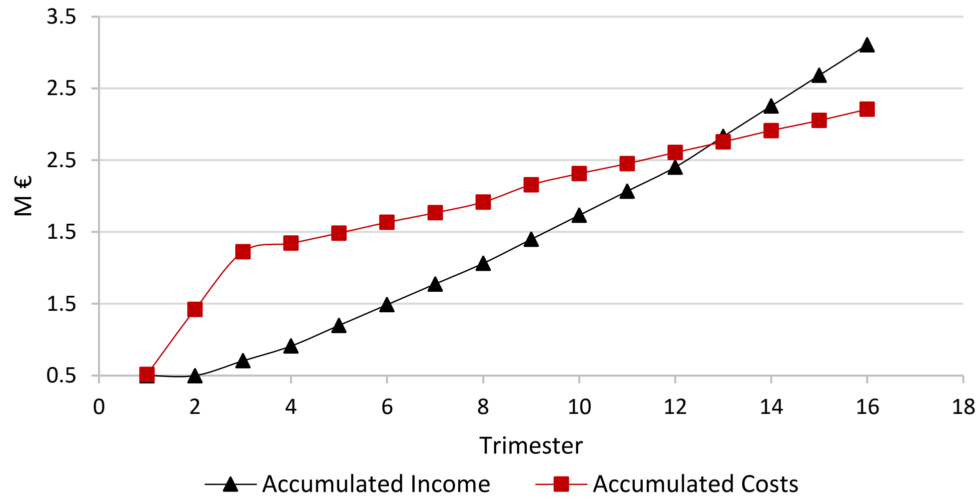

Figure 3: Cash-Flows related to “LettPet Shampoo”

5. Conclusions

In this work, to avoid agricultural waste and promote eco-valorization, the use of lettuce residues (leaves and stems) to develop an animal shampoo with lettuce extract was evaluated. For this, it was necessary to follow the various stages of the design of a product, namely. The main needs were to use the wasted lettuce as a raw material for a product, which must be non-toxic to animals and humans and be easily applied. In the second step, products that would satisfy the needs were conceived, and around twenty-five different ideas were obtained. Then, in the selection stage, the less relevant ideas were eliminated and a matrix analysis was carried out. The animal shampoo for dogs was the most punctuated idea since it does not have complex manufacture and is a new market that required some innovation.

Finally, the viability of this product was evaluated and the manufacturing process was developed. It was decided to extract triterpenes and other important components from lettuce due to their properties. To extract this bio-compound from the vegetable, the lettuce passed through a maceration process. Afterward, water, a surfactant, conditioners and lettuce extract are added to a vessel. Next, the ingredients are mixed until a homogeneous substance is reached. Finally, after adding chloride, viscosity modifiers and substances to give fragrance and colour, the mixture is ready to proceed to the test stage. That being done, the shampoo can be packaged, labeled and distributed to the market.

The intended business model consists in selling bottles of Animal shampoo for Animal Saloons in bigger bottles (5 L) at 49.99€ and selling smaller bottles (200 mL) at 7.99€ of the product online. For the first year, a 5% market share for the company was estimated, which would require the annual use of 1,073 tons of lettuce waste to fulfill the expected demand of 12,547 L of shampoo. However, a progression of the market share is expected to achieve the maximum production capacity pretended by the company. This amount of sales, with the predicted market share increase, allows the company to obtain positive cash flow by the 4^{th} semester and settle the debt after 3 years of operation.

References

Agra, L. C., J. N. S. Ferro, F. T. Barbosa, and E. Barreto. 2015. "Triterpenes with healing activity: A systematic review". *Journal of Dermatological Treatment* 26, no. 5: 465-70. https://doi.org/10.3109/09546634.2015.1021663.

Chadwick, M., H. Trewin, F. Gawthrop, and C. Wagstaff. 2013. "Sesquiterpenoids lactones: Benefits to plants and people". *International Journal of Molecular Sciences* 14, no. 6: 12780-805. https://doi.org/10.3390/ijms140612780.

Cussler, E. L., and G. D. Moggridge. 2011. *Chemical Product Design*. 2nd ed. Cambridge Series in Chemical Engineering. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139035132.

Deeksha, R. Malviya, and P. K. Sharma. 2014. "Advancement in shampoo (A dermal care product): Preparation methods, patents and commercial utility". *Recent Patents on Inflammation and Allergy Drug Discovery* 8, no. 1: 48-58. https://doi.org/10.2174/1872213X08666140115110727.

Divone, P. 2013. "Semi-continuous manufacturing of personal care liquids". Presented in Integrated Continuous Biomanufacturing Conference, Castelidefeis, Spain, October 2013.

Duan, B.B., J.-A Shin, and K.-T. Lee. 2019. "The contents of β-carotene and cholesterol in selected types of agricultural and processed foods in Korea." *Korean Journal of Agricultural Science* 46, no. 2: 315-22. https://doi.org/10.7744/kjoas.20190017.

FAO (Food and Agriculture Organization of the United Nations). 2014. *Definitional framework of food loss - Working paper*. https://www.fao.org/3/at144e/at144e.pdf.

INE (Instituto Nacional de Estatística). 2002. *Estatísticas da Horticultura: 1995-2001*. Lisboa. https://www.ine.pt/xurl/pub/140013.

———. 2021. *Estatísticas Agrícolas: 2020*. Lisboa. https://www.ine.pt/xurl/pub/437147278.

Lombardo, L., F. Grasso, F. Lanciano, S. Loria, and E. Monetti. 2018. "Broad-spectrum health protection of extra virgin olive oil compounds". In *Studies in Natural Products Chemistry*, edited by Atta-ur-Rahman, 41-77. Elsevier. https://doi.org/10.1016/B978-0-444-64057-4.00002-8.

Nafed Mughrbi, H., and A. A. Auzi. 2020. "Lactuca sativa stems as the source of bioactive compounds as well as the leaves". *Journal of Pharmacy and Pharmacology* 8: 143-50. https://ssrn.com/abstract=3827730.

Papargyropoulou, E., R. Lozano, J. K. Steinberger, N. Wright, and Z. B. Ujang. 2014. "The food waste hierarchy as a framework for the management of food surplus and food waste". *Journal of Cleaner Production* 76: 106-15. https://doi.org/10.1016/j.jclepro.2014.04.020.

Pinto, C. 2016. "Portugal tem 6,7 milhões de animais de estimação". https://www.veterinaria-atual.pt/na-clinica/portugal-tem-67-milhoes-de-animais-de-estimacao/.

Popkin, B. M., K. E. D'Anci, and I. H. Rosenberg. 2010. "Water, hydration, and health". *Nutrition Reviews* 68, no. 8: 439-58. https://doi.org/10.1111/j.1753-4887.2010.00304.x.

Ríos, J. L. 2010. "Effects of triterpenes on the immune system". *Journal of Ethnopharmacology* 128, no. 1: 1-14. https://doi.org/10.1016/j.jep.2009.12.045.

Sagayama, K., N. Tanaka, T. Fukumoto, and Y. Kashiwada. 2019. "Lanostane-type triterpenes from the sclerotium of Inonotus obliquus (Chaga mushrooms) as proproliferative agents on human follicle dermal papilla cells". *Journal of Natural Medicines* 73, no. 3: 597-601. https://doi.org/10.1007/s11418-019-01280-0.

San Martin, D., S. Ramos, and J. Zufía. 2016. "Valorisation of food waste to produce new raw materials for animal feed". *Food Chemistry* 198: 68-74. https://doi.org/10.1016/j.foodchem.2015.11.035.

Sarovar Reddy, V., S. Prasanthi, C. Gopinath, and K. M. Rao. 2015. "Shampoos: An overview". *International Journal of Advances in Pharmaceutical Research* 6, no. 11: 384-87.

Sies, H., W. Stahl, and A. R. Sundquist. 1992. "Antioxidant functions of vitamins: Vitamins E and C, Beta-Carotene, and other carotenoids". *Annals of the New York Academy of Sciences* 669: 7-20. https://doi.org/10.1111/j.1749-6632.1992.tb17085.x.

Tavares, H. M. R. 1988. *A cultura da Alface*. Ministério da Agricultura, Pescas e Alimentação.

Wesołowska, A., A. Nikiforuk, K. Michalska, W. Kisiel, and E. Chojnacka-Wójcik. 2006. "Analgesic and sedative activities of lactucin and some lactucin-like guaianolides in mice". *Journal of Ethnopharmacology* 107, no. 2: 254-58. https://doi.org/10.1016/j.jep.2006.03.003.

Zanzottera, F., G. Bizzaro, A. Michelotti, and V. Nobile. 2017. "Efficacy of a nutritional supplement, standardized in fatty acids and phytosterols, on hair loss and hair health in both women and men". *Journal of Cosmetology & Trichology* 3, no. 2: 1000121. https://doi.org/10.4172/2471-9323.1000121.

Zhang, G., F. Wu, T. Ma, B. Zhang, A. Manyande, and H. Du. 2019. "Preparation and characterization of cellulose nanofibers isolated from lettuce peel". *Cellulose Chemistry and Technology* 53, no. 7-8: 677-84. https://doi.org/10.35812/CelluloseChemTechnol.2019.53.66.

Acknowledgments

This work was developed under the scope of the course unit of Product Engineering of the Master in Chemical Engineering at the Faculty of Engineering of the University of Porto, during the 1st semester of the 2021/2022 academic year. Professor Cláudia Gomes, Doctor Ricardo Santos, and Doctor Yaidelin Manrique, supervisors of this work, are members of the Associate Laboratory LSRE-LCM funded by national funds through LA/P/0045/2020 (ALiCE), UIDB/50020/2020 and UIDP/50020/2020 (LSRE-LCM), funded by national funds through FCT/MCTES (PIDDAC). We would also like to thank Hanin Nafed Mughrbi for sharing additional information regarding his article, crucial to better understand the yield of bio-active compounds from lettuce waste.

Supporting Information

A. Annexes

A.1. Matrixes for selection

To help decide what were the best ideas, they were divided in 5 different categories: Medicine (Table S1), Cosmetic (Table S2), Cellulose (Table S3), Food supplements/additives (Table S4) and Independent (Table S5).

Criteria	Cholesterol lowering	Analgesic	Treatment for asthma and cough	Anti- inflammatory ointment	Treatment for diabetes
Implementation	2	1	1	2	1
Production Cost	4	8	2	8	2
Needs/Market	8	6	10	4	10
Ease of Use	9	9	8	10	8
Scientific Maturity	8	10	7	10	7
Innovation	4	3	7	3	7
Total	5.1	4.8	5.4	4.8	5.4

Table S1: Matrix for medicinal ideas

Criteria	Natural Shampoo	Face and Body/Suntan Lotion	Nail Polish
Implementation	7	10	6
Production Cost	7	9	9
Needs/Market	4	4	1
Ease of Use	10	10	10
Scientific Maturity	10	10	10
Innovation	3	3	2
Total	6.2	7.3	5.3

Table S2: Matrix for cosmetic ideas

Criteria	Paper	Textile	Nanocomposite	Nanofibers	Bio-butanol
Implementation	7	7	3	3	5
Production Cost	8	6	4	5	7
Needs/Market	6	7	8	7	6
Ease of Use	10	10	9	9	6
Scientific Maturity	10	10	2	3	8
Innovation	4	6	10	9	6
Total	6.9	7.3	6	5.8	6

Table S3: Matrix for Cellulose ideas

Criteria	Vitamin A supplement	Tea	Food preservative	Supplement for cholesterol reduction	Juice with additives
Implementation	7	9	5	7	9
Production Cost	6	9	5	6	9
Needs/Market	3	3	9	5	3
Ease of Use	10	10	6	10	10
Scientific Maturity	9	9	3	8	9
Innovation	3	1	8	4	1
Total	5.8	6.3	6.3	6.3	6.3

Table S4: Matrix for Food Supplements ideas

Criteria	Ink	Vegetable Oil	Animal Shampoo	Insecticide	Pesticide
Implementation	5	6	7	5	5
Production Cost	5	7	8	5	4
Needs/Market	4	8	6	5	6
Ease of Use	9	9	9	7	6
Scientific Maturity	9	10	8	8	8
Innovation	4	6	8	6	6
Total	5.4	7.2	7.4	5.7	5.7

Table S5: Matrix for independent ideas

A.2. Economic Analyses

After product development, it is necessary to perform an economic analysis to assess the project's profitability and predict the future development of the company, as presented in Table S6.

M€	1st year	2nd year	3rd year	4th year
Costs				
R&D	-0.093	-0.108	-0.108	-0.108
Equipment	-0.117	-0.004	-0.051	-0.004
Start + Marketing	-0.611	-0.060	-0.060	-0.060
Production	-0.102	-0.115	-0.127	-0.129
Total Costs	-0.922	-0.286	-0.346	-0.301
Income	0.206	0.576	0.670	0.853
Cash Flow	-0.716	0.290	0.325	0.551

Table S6: Economic Analyses