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Jellyapic: Developing an Anti-Glycemic Gelatin

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Abstract

This work consists of developing a strawberry plant-based product, an anti-glycemic gelatin. The selected product is a vegan origin gelatin containing sinapic acid, extracted from the strawberry leaves. A Chemical Product Design (CPD) approach was used to satisfy the customers' needs with a new product. The main purpose of this gelatin is to value the strawberry leaves' wide variety of health properties, mainly its anti-glycemic property. After the definition of the production process, it was concluded that using the total amount of about 133 tons of dry strawberry leaves available per year in Portugal, it was possible to produce up to 26 million gelatin packets yearly. Finally, an economic analysis was performed to evaluate the product viability, resulting in profits from product sales from the third year forward. The net present value (NPV) and the internal rate of return (IRR) were also calculated, resulting in about 15 million euros and 30 %, respectively.

Author Keywords. Strawberry Plant. Sinapic Acid. Gelatin.

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1. Introduction

In the Product Engineering course, it was proposed to develop a product based on one of the four raw materials: strawberry plant, tomato branch, kiwi branch and lettuce's root and stem. These raw materials were chosen since they represent a waste of the agricultural industry and do not have any other way of reuse.

Due to its remarkable properties, abundant production, and relevance in the Portuguese market, the strawberry plant was the selected raw material.

Several stages had to be followed to develop the product based on the chosen raw material.

The first consisted of identifying and quantifying the active compounds which can be extracted from the strawberry plant, their extraction procedure, and the properties which could be valuable for the final product. Then, the Needs consisted of identifying and analyzing market needs that the product must satisfy. Next, at the Ideas stage, a brainstorming of product ideas that contained the active compounds took place. Afterward, selecting the best idea based on various weighting factors was necessary. Finally, at the Manufacture stage, the production process was selected and its execution in industrial quantities performed. After establishing the manufacturing process, an economic evaluation was made to evaluate the project's viability.

1.1. Strawberry plant

Since the 70s, Portugal has been an abundant strawberry consumer. Initially, the fruit was only consumed in the summer season; however, due to its increasing popularity and the discovery of its health benefits, its consumption has amplified, leading to consumption during the whole year (Palha 2020).

In Portugal, the strawberry plant is mainly cultivated in Ribatejo and West, Littoral Alentejo, and Algarve. In 2018, the total farming area was 323 ha, and its production volume was 10 620 tons (Palha 2020). According to Menzel and Smith (2014), an average of 785 g of strawberry and 9.86 g of dry leaves per plant is obtained. Therefore, it is estimated that the production volume resulted in approximately 133 tons of dry strawberry leaves residue.

Ideally, a strawberry plant can live up to six years; however, after three productive years, the production of strawberries begins to decline rapidly. Hence, producers need to plant new strawberry plants to have a profitable production of strawberries, meaning that old strawberry plants are wasted (Strawberry Plants 2022).

2. Raw Material

Strawberry plants, more specifically the leaves of the plant, are a rich source of minerals, easily digestible sugars, dietary fibers, and vitamins (Žlabur et al. 2020). Also, they contain high amounts of diverse phenolic compounds that possess beneficial properties favorable to human health and that activate defenses against microbiological infections (Kårlund et al. 2014). The possible medical benefits of dietary plant polyphenols as an antioxidant have attracted a lot of attention in recent years (Pandey and Rizvi 2009).

According to Dias et al. (2017), a wide variety of compounds can be extracted from strawberry leaves. Hence, from 100 g of plant leaves (dry weight basis), it is possible to extract 3.76 g of oxalic acid, 0.02 g of ascorbic acid, 1.58 g of succinic acid, and 98.54 mg of α-tocopherol with water and alcohol, followed by filtration. Through aqueous extraction, it is possible to obtain various catechins such as (+)-catechin, (−)-epicatechin, epigallocatechin, and epicatechin-3-gallate, and the amount extracted was 245.72 mg/L, 259.36 mg/L, 325.98 mg/L, and 120.50 mg/L, respectively. It was also possible to extract 175.06 mg/L of procyanidin B1 (Mudnic et al. 2009). With a microwave-assisted extraction with ethanol, the quantity of sinapic acid extracted was 55.74 mg/g of dry weight of plant leaves, making it the most abundant compound obtained through this method (Lin et al. 2020). All the possibly extracted compounds present a wide variety of uses, as described next.

Sinapic acid (3,5-dimethoxy-4-hydroxycinnamic acid) is an orally bioavailable phytochemical (Chen 2016). Its solubility in water is 7.082 g/L at 25 °C and has a melting point of 192 °C (National Center for Biotechnology Information 2022a). This compound has antioxidant, anti-inflammatory, anticancer, antimutagenic, anti-glycemic, neuroprotective, and antibacterial properties (Chen 2016). Because of its pharmacokinetics, therapeutic, and protective potential, it has a big future in the food processing, cosmetics, and pharmaceutical industry (Hameed, Aydın, and Basaran 2016).

Catechins are polyphenolic compounds with potent antioxidant properties (Bernatoniene and Kopustinskiene 2018). Catechins have protective power against UV radiation, anti-microbial, anti-viral, anti-inflammatory, anti-allergenic, and anti-cancer properties. They can increase the penetration and retention of healthy functional foods and bio beauty care products into the body and skin (Bae et al. 2020). Furthermore, they exhibit strong anti-viral activities against foodborne viruses (Amankwaah et al. 2020). Catechins are expected to make many advancements in the food, cosmetics, and pharmaceutical industries (Bae et al. 2020). The extracted Procyanidin B1, a proanthocyanidin consisting of (-)-epicatechin and (+)-catechin units (National Center for Biotechnology Information 2022b), has shown promise as a liver cancer anti-tumor drug since it inhibits migration and proliferation of liver cancer cells (Na et al. 2020).

Ascorbic acid is a natural water-soluble vitamin (Vitamin C). It is a powerful reducing and antioxidant agent able to fight bacterial infections, detoxify reactions, and create collagen in fibrous tissue, teeth, bones, connective tissue, skin, and capillaries (National Center for Biotechnology Information 2022c).

Succinic acid is a promising chemical with a wide range of uses, including food and drinks, medicines, polymers, paints, cosmetics, and inks. It is used to make a variety of bulk chemicals, polymers, and resins, among other things (Ladakis et al. 2020).

Alpha-tocopherol is one of the eight isoforms of vitamin E, the most powerful fat-soluble antioxidant in nature (Tucker and Townsend 2005). Alpha-tocopherol can limit free radical formation, oxidative stress, and lipid peroxidation (Bruno and Mah 2014; Engelking 2015).

Oxalic acid is used worldwide in material protection processes. It has been added to commercial hydrometallurgical solvent formulations to remove iron oxides due to its excellent dissolving capability on rust to get rid of fouling (Giacomelli et al. 2004).

3. Chemical Product Design (CPD)

3.1. Needs

This phase is highly important in developing a product since it consists of identifying and analyzing market needs that the product must satisfy. In this case, the identified needs were categorized into essential, desirable and useful. While essential needs must be prioritized, desirable ones value the product compared to the competition. The useful needs are not fundamental but must be considered, as they add positive value to the product.

Thus, these needs must be considered when designing the product to ensure its market success. Table 1 presents the most important needs.

Essential	Health benefits Vegan product
Desirable	Low environmental impact of the process and product National product
Useful	Low market price

Table 1: Enumeration and classification of needs

In the present project, the health benefits are the main needs to be satisfied, along with the vegan characteristics of the product, given the importance of animal preservation nowadays. The low environmental impact of the process and product and its national origin are considered to be desirable needs, as consumers seek these features. Lastly, the low market price is a relevant aspect that consumers value.

3.2. Ideas & Selection

The research of the strawberry plant, its composition, properties, and functions culminated in several product ideas. Those ideas should be "out of the box" in order to create an innovative product.

Therefore, a selection of ideas is required to achieve the concept with the highest potential. The first step is eliminating redundant ideas and those that cannot be put into practice.

In this project, there were initially twenty ideas, later reduced to thirteen based on scientific knowledge acquired during the research. Those ideas included an anti-aging or acne cream, hair growth gums, anti-caries toothpaste, vasodilator tea, food supplements, anticoagulant pills, wood coating, wood scouring pad, air freshener, vitamin E-rich animal food, anti-glycemic gelatin, and meat packaging.

The previously-stated ideas were grouped into categories, with the first two belonging to the cosmetics category, the following five to the pharmaceutical products, and the following three to the household products category. Finally, the last three ideas are included in the edible products category. Then comes the phase from which should outcome the final idea. A matrix with numerous parameters was performed to evaluate the ideas and select the one with the highest score. Parameters were weighted according to their relevance and scored from 0 to 5. The maximum score in each parameter corresponds to less impact, greater innovation and maturity, less complexity, greater ease of certification, more product longevity, and less competition. Table 2 shows the matrix of selection. The highest value for the innovation weighting factor (0.20) reflects the importance of introducing an innovative product in the market. The highest weighting factor was also assigned to the extraction complexity since it is a very determining factor in manufacturing a product. Finally, the market competition factor also corresponds to the highest weighting factor, as a different product is crucial to compete in the existing market. The environmental impact is also important, and the product should have the lowest possible impact. Scientific maturity and product longevity are essential for product viability. Finally, ease of certification is also relevant for introducing the product in the market while meeting its demanding standards.

Ideas	EI	I	SM	ExC	EaC	PL	MC	SUM
Weighting factor	**0.15**	**0.20**	**0.10**	**0.20**	**0.05**	**0.10**	**0.20**	**1**
Anti-aging cream	3	2	4	3	3	4	1	2.60
Acne cream	3	1	4	5	3	4	1	2.80
Hair growth gums	5	3	4	4	4	3	1	3.45
Anti-caries toothpaste	3	3	4	4	2	3	1	2.85
Vasodilator tea	5	1	5	5	3	5	1	3.30
Food supplements	5	1	5	4	2	4	1	2.95
Anticoagulant pills	5	2	5	3	2	5	2	3.25
Wood coating	4	3	4	4	5	5	2	3.55
Wood scouring pad	3	3	3	4	4	5	4	3.65
Air freshener	3	2	5	4	4	5	1	3.05
Animal food rich in vitamin E	4	3	3	4	2	5	2	3.30
Anti-glycemic gelatin	4	5	2	3	2	5	4	3.80
Meat packaging	2	3	2	5	2	5	1	2.90

EI: Environmental impact | I: Innovation | SC: Scientific Maturity | ExC: Extraction Complexity | EaC: Ease of Certification | PL: Product Longevity | MC: Market competition

Table 2: Matrix of selection of the ideas

After the matrixial analysis, three products stood out with the highest score: the anti-glycemic gelatin, the wood scouring pad, and the metal coating.

The anti-glycemic gelatin is a health-beneficial gelatin capable of lowering blood glucose concentration. It also allows bowel function, bone health improvement and the control of cholesterol levels. It is a vegan product that does not contain sugars, fats, or gluten. It was designed for personal consumption, especially for people with difficulties regulating blood glucose levels.

The wood scouring pad would effectively clean surfaces without using any other cleaning product. It is intended for household use.

The wood coating offers high resistance to UV radiation, given the ability of catechins to create a barrier against this type of radiation. This product was designed to preserve the wood aspect in household applications.

As previously mentioned, the most promising idea was the gelatin. Thus, to effectively conclude its viability, the feasibility of producing and marketing this product was analyzed.

Several reasons can turn an idea into a non-viable one, such as high production costs, the inability of the product to succeed in the market compared to others, and an insufficient amount of active compound in the raw material for the desired production. In this case, gelatin production and commercialization were considered viable, and the idealization of its process was carried out.

4. Manufacture

4.1. Extraction method

First, it is important to ensure the extraction of the active compound from the strawberry leaves. After research, it was concluded that the best method for extracting the sinapic acid, which resulted in higher yields and better applicability on an industrial scale, was microwave-assisted extraction (MAE), a green extraction technique.

The extraction of phenolic compounds from the strawberry leaves was optimized using a solvent made of ethanol and water. The MAE yield was maximized by optimizing process variables such as extraction time, microwave power, liquid-solid ratio and solvent composition (Lin et al. 2020). Optimal conditions were determined as 40 seconds extraction time, 300 W of microwave electric power, ethanol concentration of 51.1 %, and solid-liquid ratio of 1 gram of dry leaves per 61.6 milliliters of solvent. These operating conditions resulted in the following yields for phenolic compounds: 55.74 ± 2.45 mg/g of sinapic acid, 2.61 ± 0.34 mg/g of chlorogenic acid, and 2.57 ± 0.47 mg/g of caffeic acid. The following amount of flavonoids was also recovered: 8.08 ± 0.87 mg/g of rutin, 5.35 ± 0.94 mg/g of (−)-epicatechin, and 3.07 ± 0.65 mg/g of (+)-catechin (Lin et al. 2020). According to Pietta (2000), the last mentioned compound has anti-allergenic, anti-viral, anti-inflammatory, vasodilating activity, and mainly antioxidant activity.

It is also worth pointing out that the extract is not pure sinapic acid, although it represents the most abundant compound in strawberry leaves, with approximately 71.2 % of the total contents (Lin et al. 2020). As all other compounds in the extract are known for their human health benefits, there was no need to separate them, meaning that the extract can be directly incorporated into the gelatin powder. Although further testing is necessary to prove and quantify the extracts' health-benefiting properties, positive effects are predicted.

4.2. Industrial scale-up

Knowing how to extract the active principle, it was considered that the optimized conditions found by Lin et al. (2020) could be maintained for the industrial process. The industrial process then would first involve solvent preparation, in parallel with the drying and crushing of the leaves. The solvent and crushed leaves both go into the industrial microwave, where the extraction occurs. The extract then needs to be separated from the solvent using spray-drying technology, resulting in recycled solvent being reused in the process and powder extract mixed with agar-agar powder to prepare the gelatin. The obtained mixture is packed, stored, and shipped to markets and retailers. The whole process is summarized in Figure 1.

4.2.1.Solvent preparation

Ethanol is bought weekly and kept in a 100 m^3 tank to be used during the week. Water is taken from the local provider company, treated in a deionizer with a capacity of 500 liters per hour, and mixed with ethanol in the pipes. Since ethanol and water have similar properties and are miscible, the expected composition can be achieved by controlling the flows with valves. The mixture is then stored in another 100 m^3 tank that feeds the microwave.

4.2.2.Drying and crushing of leaves

The industry receives sorted strawberry leaves residues weekly from local agriculture. The raw material is heated in an industrial oven with a drying capacity of 200 kg/h at 40˚C (Lin et al. 2020). Dry leaves are then fed manually into a 70 kg capacity crusher that can crush 400 kg of leaves per hour. Crushed dry leaves are fed directly into the microwave, where the extraction occurs. Daily, about 550 kg of dry leaves are used for the extraction process in order to achieve the amount of sinapic acid required.

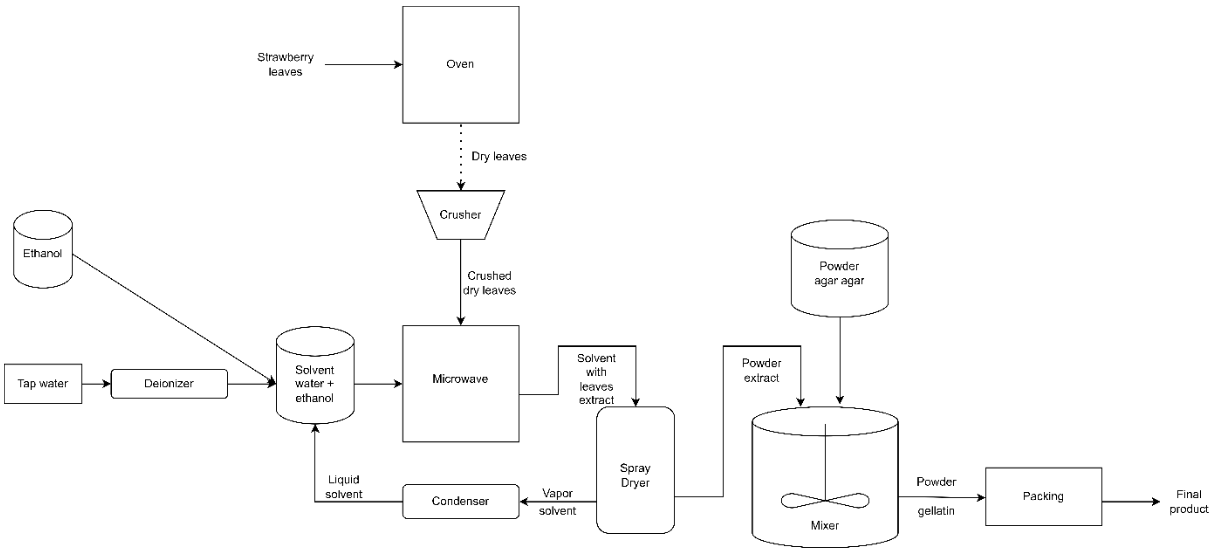

Figure 1: Flow diagram of the industrial process.

4.2.3.Microwave extraction

As mentioned before, the solid-liquid ratio, microwave power, and extraction time from the optimized laboratory extraction are kept at an industrial scale. After 40 seconds of extraction time, the extract and solvent leave the microwave and are sent to separation. Time between subsequent extractions will be 30 minutes. The used microwave has a capacity for 2 100 liters of solvent plus 34 kg of crushed leaves per extraction.

4.2.4. Spray-dryer

In this step, the powder extract will be produced using a spray-dryer able to evaporate 200 kilograms of water per hour by operating at an inlet air temperature of 140.36 ˚C and compressed air flowrate of 9.13 L/min, which are the optimized conditions of spray-dried Moldavan balm extract powder (Rahmati, Sharifian, and Fattahi 2020). With these conditions, drying performances of 65.7% can be achieved with the moisture of only 7%, and since the extract composition is similar to the strawberry leaf extract in terms of phenolic contents and flavonoids, these conditions are valid for the extraction of the desired active principle. The solvent steam will then be recycled and passed through a condenser that will change its state to liquid so it can be stored in the solvent tank. An 80 % recovery of the solvent fed is expected, which is equivalent to roughly 27 thousand liters of solvent per day. The extract will then leave the spray-dryer in powder form.

4.2.5. Gelatin production

Powder extract will then be mixed with agar-agar powder, which will be bought weekly and stored in a 1 m^3 tank. The amount of extract to be used was determined to be non-toxic to humans. Based on the study of Hameed, Aydın, and Basaran (2016), humans can safely consume 500 to 2000 µM of sinapic acid, the equivalent of 0.28 g/l in mass concentration. Since this acid composes 71.2% of the extract, it was decided that each packet of gelatin would have 388 mg of the extracted powder to be non-toxic to humans. To get the same consistency of gelatin, it is needed eight times less agar-agar (Chatelain 2018). So, the amount of agar-agar would be 2 402 mg, producing packets of 2.79 grams of powder. This mass is necessary to make a liter of gelatin by adding half a liter of hot water and half a liter of cold water. To achieve these proportions, agar-agar and extract powder are fed to the 5000 m^3 mixer in a 6.18 to 1 proportion. The mixed powder will be sent to an automatic filter tea bag packing machine that can pack 15-60 bags per minute. It is then stored to be shipped to markets and retailers.

Table 3 lists the prices of the industrial equipment required for the production process, based on the information found in Alibaba[1], as well as their most relevant dimensions.

Quantity	Equipment	Price(€/unit)	Dimensions(m)
2	**Liquid storage tank**	40 000	Diameter – 4.80 Hight – 5.67
1	**Deionizer**	5 300	-
1	**Oven**	14 100	31.30 x 1.80 x 2.30
1	**Crusher**	180	-
1	**Microwave**	80 000	-
1	**Spray-dryer**	5 300	-
1	**Condenser**	4 000	-
1	**Solid storage tank**	5 300	1.140 x 1.140 x 1.615
1	**Mixer**	6 000	3.90 x 1.64 x 2.70
4	**Packing machine**	13 000	1.20 x 0.90 x 1.90
	Total	**173 180**	

Table 3: Prices (including taxes) of the industrial equipment required for the process

[1]Alibaba. 2022. "Industrial equipment". Accessed January 18, 2022. https://www.alibaba.com/.

5. Economic Analysis

After the product development, it is necessary to perform an economic analysis to evaluate the project's viability.

5.1. Gantt's Diagram

Gantt's diagram is an important graphic tool that illustrates the progression of each project stage over time. Figure 2 represents this diagram, considering the first four years of the project.

On the left side, it specifies the project's main tasks, while at the top, it represents a time scale divided into years and quarters. Also, the color intensity allows for predicting the contribution of each task.

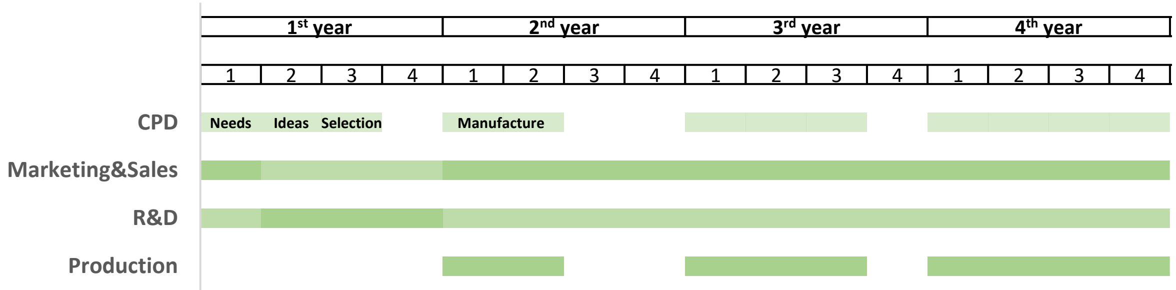

Figure 2: Gantt's Diagram for the different activities in a 4-year projection

Analyzing Figure 2, it is possible to conclude that CPD is predicted to last for the first three quarters of the first year and includes the identification of Needs and Ideas and the Selection. This task starts again at the beginning of the second year with the Manufacturing stage.

The Marketing and Sales department represents the main role in market research during the first stage by identifying the customers' needs. Until the beginning of the manufacturing stage, this sector is required to promote the product and develop marketing strategies to ensure high product demands. This is essential to commercialize the product at the beginning of the second year.

Although the Research and Development department is required throughout the whole project time, it has a major role during the project's first year, ensuring the creation of a high-quality product that satisfies the customer's needs while ensuring compliance with regulations.

Finally, observing Figure 2, although the Production has had a constant activity since the start of the sales in the project's second year, it often has some breaks. These breaks consider a wise introduction of the product in the market, considering it is an innovative product, and leave space for the project expansion, assuming an initial approach only to big box stores, then to healthy food stores, and, later on, a potential worldwide growth through exportation. That way, it was taken into account that, during the second year, the production used only 50% of the total raw material available in Portugal and would grow annually by 25% until it reaches maximum capacity. It was considered that the factory would only operate the amount of time corresponding to the percentage of raw material used per year. For example, the first year's production time would be one semester. This strategy ensures a more rentable working time and an energy reduction. The non-production time is used to develop marketing strategies and the factory does not receive any raw material.

This approach can be adjusted at any time during the project to satisfy the volume of sales by increasing the production time. Also, in case of a lack of raw materials, importation from other countries (for example, Spain) is a possible solution.

5.2. Sales volume prediction

As already mentioned, product sales start at the beginning of the second year, considering only the national market. By the end of the second year, it is predicted that the volume sales will correspond to 5 million gelatin packets, with the unit price of 0.80 € to the stores and 1.00 € to the consumers. Considering a 15 % percentage of growth for the first two-quarters of production, followed by an increase of 10% in the next three quarters, 5% in the following three and finally 1%, for the last ones a total of 25 million packets sold by the end of the fourth year is expected. Taking into account that 13.6% of the total Portuguese population, aged between 20 and 79 years old, suffer from diabetes, it is considered that this volume of sales is reachable (Raposo 2020).

5.3. Costs

The economic analysis also involves the evaluation of the costs associated with the project, namely the purchase of the required equipment for production, resulting in 360 000 €, and marketing expenses, considering an investment of 25% of the revenue in the first year and 15% in the others (The CMO Survey 2021). It should also be considered the reagents costs, the transport of the raw material, the energy (EDP 2022) and water (Deco Proteste 2021) costs, and the salaries of the company's employees, resulting in a total of about 100 000 € per month.

Furthermore, considering that the factory must be located in the south of Portugal since this is the predominant area for strawberry production (Palha 2020), its construction resulted in a cost of about 1 million euros (Idealista 2021a, 2021b).

5.4. Economic viability

All the already mentioned costs associated with the gelatin production and the revenues were considered to evaluate the economic viability.

Figure 3 represents the accumulated cash flows over the years of the project. The cash flows represent the financial flux coming from the projects' activity. That way, it is based on revenues and economic costs and allows an overview of the company's financial reality (Sinnott and Towler 2020).

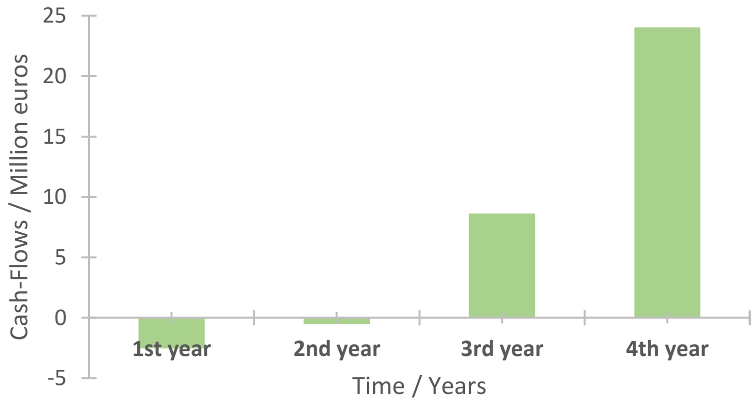

Figure 3: Representation of the accumulated cash-flows along the years

By analyzing Figure 3, it is possible to observe that the accumulated cash flows are positive since the third year, proving the project is economic viabile

Lastly, Figure 4 represents the accumulated revenues and costs.

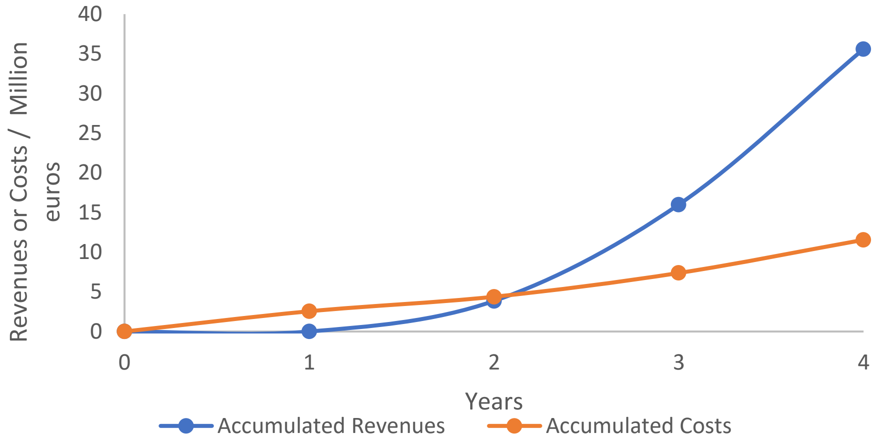

Figure 4: Graphical representation of accumulated revenues and costs over the years

By the interpretation of Figure 4, it is seen that the revenues line is above the costs line since the beginning of the project's third year, meaning that there is profit since then, and the initial investment is fully liquidated. This graphic also concludes that the payback time corresponds to three years.

The economic analysis also culminated in the calculation of the net present value, NPV, which was about 15 million euros, and an internal rate of return, IRR, of 29.80 %.

Since the NPV is positive and the IRR is higher than the refresh rate taken into account (15 %), the project is economically viable.

6. Conclusions

In this project, a product based on raw material, the strawberry plant, was developed. This development consisted of many phases, starting with identifying the active compounds and market needs. Next followed the ideas stage and its selection, the manufacture, and the project's economic analysis.

After the first steps, the chosen product was a gelatin containing sinapic acid conferring anti-glycemic properties. Then, the manufacturing process was defined and analyzed. To extract the sinapic acid from the strawberry leaves, they first had to be dried and crushed, and the solvent prepared. Then, these are added into an industrial microwave, where the extraction occurs. After the extraction, the extract is separated from the solvent in a spray-dryer. The solvent is recycled for reuse, while the powder extract is mixed with agar-agar powder to finalize the gelatin. The obtained mixture is packed, stored, and shipped to markets and retailers.

With the industrial process defined, it was necessary to perform an economic analysis. Considering the many dispenses in CPD, Marketing&Sales, R&D, and Production and balancing them with the sales volume production, profits are expected from the third year forward. The positive NPV and the IRR calculated indicate the project's economic viability, especially since the third year.

In a final remark, it is important to refer that the development of the product would need further investigation as the gelatin production was not performed. Hence, it would be necessary to perform tests at a laboratory scale and then scale up this process to an industrial scale.

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