U.Porto Journal of Engineering, 10:2 (2024) 22-34
ISSN 2183-6493
DOI: 10.24840/2183-6493_0010-002_002611

Received: 04 April, 2024
Accepted: 16 April, 2024
Published: 18 April, 2024

Pompan: A bread production alternative using apple pomace

Beatriz S. Coelho
Departamento de Engenharia Química, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 PORTO, Portugal (up201907292@edu.fe.up.pt) ORCID: 0009-0007-1343-2231

Inês M.P.F. Oliveira
Laboratory of Separation and Reaction Engineering – Laboratory of Catalysis and Materials (LSRE-LCM), 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 (up201906077@edu.fe.up.pt) ORCID: 0000-0003-2131-4650

Isabel M.M. Hilário
Departamento de Engenharia Química, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 PORTO, Portugal (up201905863@edu.fe.up.pt) ORCID: 0009-0005-5492-393X

João V.P. Nunes
Laboratory of Separation and Reaction Engineering – Laboratory of Catalysis and Materials (LSRE-LCM), 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 (up201900588@edu.fe.up.pt) ORCID: 0009-0008-6504-9469

Sofia D.P.P. Coelho
Departamento de Engenharia Química, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 PORTO, Portugal (up201905009@edu.fe.up.pt) ORCID: 0009-0009-7047-8601

Tiago D.V.C. Mendes
Departamento de Engenharia Química, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 PORTO, Portugal (up201905453@edu.fe.up.pt) ORCID: 0009-0005-2012-9156

Author Keywords

Apple Pomace, Bread, Leftovers, Fibers

Type: Research Article

Open Access
Peer Reviewed

Abstract

This work consists of developing a product that uses apple leftovers. The product selected was bread baked with a flour mixture of 5% (by mass) apple flour to wheat flour. Besides providing an easy-to-use solution for leftovers, this mixture also provides a higher fiber content to the food. After the process was designed, it was concluded that producing 5.4 million breads per year with about 23 tons of apple pomace was possible. In the end, the economic analysis was done, and the process should return a profit at the beginning of the second year, having an NPV of 0.88 M€, an IRR of 27.8% and a payback time of almost 4 years.

1. Introduction

This project aimed to develop a product from raw materials that consist mainly of residues. Therefore, the apple was chosen once it is a well-accepted fruit, it offers the most nutrients and vitamins, and has a large production in Portugal. Apple has its origins in Occidental Asia, which later spread throughout the rest of the world in areas with prosperous conditions for its creation. This fruit is grown in temperate, tropical, and subtropical climates and is considered the fourth most consumed fruit in the world. Nowadays, the world's largest apple producer is China, only followed by the United States of America (Lyu et al. 2020). This residue, also known as apple pomace (AP), is a heterogeneous mix of lumps, stems, seeds, and pulp (Cantero et al. 2022).

In Portugal, the national production area comprises the regions of Alcobaça, Nazaré, Óbidos, Caldas da Rainha, Porto de Mós, etc. The national product is called *Maçã de Alcobaça,* which is not a variety of apple itself. Nevertheless, it confines several varieties like Golden Delicious, Casa Nova, Royal Gala, and Granny Smith. This product is known for having an intense aroma, which is not very common among European apples, and for having a pleasant taste. The raw material used in this project is the result of apple processing to produce juice, cider, or wine. Apple juice production is one of the industries that produces the utmost quantities of by-products i.e., residues, in relation to the initial amount of processed fruit (Vidović et al. 2020). One of the solutions to reuse these leftovers is to integrate them into the flour production process. Due to the recent cereal crisis that Europe is facing, there is a need to implement a new vision of cereal production to overcome this problem. Thus, this work proposes a new alternative of bread production where the amount of cereals used decreases, while maintaining the same flavor. As far as the authors know, this method has not been implemented before. However, there are several studies regarding this topic. Bakery products added with apple pomace powder were evaluated sensorially and were well accepted. Therefore, flour made from apple leftovers constitutes a replacement source of food fibers (Coelho and Wosiacki 2010). It was also studied that apple pomace flour can be recommended as a flour fortifier and applied as an ingredient of functional products (Zlatanovic et al. 2019). This powder has also proved to be a feasible ingredient for gluten-free bread manufacturing because it makes a remarkable contribution to its nutritional quality (Cantero et al. 2022). To maintain the same odor and taste, investigations show that the bread should be made with 5% pomace (Lyu et al. 2020). Overall, consumers evaluations of several studies accepted this type of product. Thus, it was necessary to follow various steps to develop the product based on apple leftovers.

The first step was to identify the main compounds that can be extracted from the raw material and how much of them we can extract from the fruit. The next step consisted of searching for each compounds possible applications based on their properties to find something beneficial for the final product. Then, it was necessary to identify and analyze the market needs associated with the various compounds in the fruit to satisfy possible buyers. Then, with the needs in mind, a brainstorming session was held. These ideas would vary from being impossible to execute or being silly/redundant or interesting, and the best one was selected according to weighting factors that were found relevant. Finally, it was necessary to develop a manufacturing system where industrial quantities were defined. The respective economic analysis was also conducted to determine the feasibility of the production. This project aims to produce bread from apple pomace, where the residue is integrated into the flour.

2. Raw material

The variety of nutrients in AP is rich. This residue is a source of phytochemicals as well as small amounts of proteins, vitamins, and minerals (Lyu et al. 2020). Its major compounds are carbohydrates, which include soluble saccharides, such as pectin, starch, and other mono, di and polysaccharides and insoluble saccharides, such as cellulose and lignin (Zhang et al. 2021). AP is also rich in phenolic compounds like phenolic acids (hydroxycinnamic acids), flavonoids and anthocyanins (Reis et al. 2012).

Pectin is a soluble viscous fermentable fiber. It is an enzyme that acts on the pectic substances that occur as structural polysaccharides and has several applications in the food industry as a gelling agent, emulsifier, and thickener. Regarding its properties, pectin is soluble in pure water, and it also has gelation characteristics (Yadav et al. 2009).

Starch is a mixture of two polysaccharides and is the principal food reserve of plants. Pure starch is known for being a white, odorless, and tasteless powder that is insoluble in cold water and alcohol. The structural and compositional differences in starches from various sources determine their properties and how they interact with other compounds of foods. Therefore, it can be used as a food additive to control the uniformity and stability of foods to raise their shelf life (Whistler and Daniel 2000).

Cellulose is a complex carbohydrate and is the basic structural component of plant cell walls. This compound has no odor, is tasteless and it is biodegradable (Heinze 2015).

Lignin is a plant polymer made from phenylpropanoid building units, which contain most of the wood methoxy content. It has a glass transition temperature of 90 ˚C and a melting temperature of about 180 ˚C. Lignin is easily oxidizable, soluble in hot alkali and condensable with phenol (Biswas et al. 2021).

Pure phenol is a white crystalline solid. Phenolic compounds from AP affect organoleptic properties, such as color, odor, and flavor, as well as the antioxidant ability of food products. Thus, phenol can be used as a natural antioxidant and a functional ingredient (Quint et al. 1998).

Besides being used for bread production, AP can be applied in the cosmetic industry due to its antioxidant capacity, antibacterial properties, and gelling capacity. It can also be used for high-value products such as biofuels and pigments.

3. Chemical Product Design

3.1. Needs and Ideas

The first step of the product development process is the identification of the needs of the consumer. These needs steam from desires that cannot be fulfilled by the products already on the market.

Upon studying the AP characteristics, the group put together a set of needs, which were identified through studying the daily lives of the general population.

The following step is to classify these needs to have a better understanding of the importance that each one carries and come up with product ideas that could meet them.

Thus, the needs were divided into three categories: essential, useful and desirable. This distribution was made taking into account the relevance or immediacy with which they must be fulfilled. Therefore, essential needs prove to be the ones of utmost importance and, consequently, urgency since there is no product on the market able to meet them; these needs are connected to the survival or well-being of the population and return, for that reason, an innovative and successful product. The needs seen as useful are those that, despite not being of crucial demand as the ones previously mentioned, present great importance on the market because they may pose as comparison between products that fulfill essential needs. Lastly, desirable needs do not pose a priority to the product development team once the product is still viable, in the case in which they are not met but are still worth mentioning.

The consumer needs identified by the group are presented and organized in Table 1.

Needs		
Essential	**Useful**	**Desirable**
Food with lower fat index	Food for cattle	Components that provide strength and softness in the paper production
Low calorie food	Food with natural stabilizers	Natural antioxidants
Natural anti-inflammatory drugs with lower side effects	High protein food	Natural materials incorporated into PVA
Packed foods with higher shelf life	Energy source that can be integrated in various foods	Food with more fiber and polyphenols
Low sugar food	Biodegradable packaging	
Substitute for fodder cereals		
Alternative to fossil fuels		

Table 1: Consumer needs

After identifying and classifying the needs related to our raw material, the product development group came up with 36 product ideas that were divided into 7 categories: food, packages, energy, pharmaceuticals, additives, components in other products and composting. These ideas are shown in Table 2, divided, as mentioned, by category.

Categories	Ideas	
Food	Food for cattle	Yogurts
	Muffins	Low sugar flour
	Jam	Conversion of ethanol to be integrated into drinks
	Bread	Food for sea animals
	Meat	Pectinase to remove pectin from juice and wine
	Dairy Products	Pre-workout food
	Starch	Substrate for edible mushrooms
	Cookies	
Packaging	Bioplastics	
	Packaging made with cellulose nanocrystals	
	Antioxidant and biodegradable packaging	
	Antioxidant film for packages	
Energy	Conversion of ethanol to be integrated into biofuels	
	Methane	
	Biohydrogen	
	Hydrogen (from AP and glycerol)	
Pharmaceuticals	Cosmeceuticals (cosmetic + pharmaceutical)	
	Anti-inflammatory	
	Dermocosmetic gel	
Additives	Food colouring	
	Cooking oils with superior shelf life	
Components in other products	Vibrating membranes for speakers and microphones	
	Phenolic compounds	
	Triterpenoid acid	
	Citric acid	
	Carotenoids (pigment)	
Composting	Sewage sludge composting	

Table 2: Product ideas by category

3.2. Selection

The ideas were discussed in groups, and the decision was to eliminate the redundant ones in the first phase, those that did not have sufficient support in the literature, and those that were considered ultimately unfeasible. Thus, only the ten most seemingly feasible ideas remained: an anti-inflammatory, flour with a low glycemic index, cosmeceuticals, yogurts, pre-workout food, cooking oils with superior shelf life, antioxidant film for packages, biohydrogen, bread and starch.

After this, the objective was to have only three pre-final ideas. Therefore, a selection matrix was built and categorized by the authors, including six parameters that were scored from 1 to 5 depending on the product. To each parameter was assigned a weighting factor according to its relevance. Table 3 presents the selection matrix, in which the maximum score in each parameter corresponds to greater innovation, low market risk, easy implementation, low certification risk, more raw material quantity and bigger scientific maturity.

Parameters	I	MR	IE	CR	RMQ	SM	SUM
Weighting factors	**10%**	**15%**	**25%**	**15%**	**25%**	**10%**	**100%**
Anti-inflammatory	2.5	2	3	1	2	3	**2.25**
Flour with low glycemic index	4	3	4.5	2	4	3	**3.58**
Cosmeceuticals	3	2.5	3	1.5	1	1	**2.00**
Yogurts	1	4	5	2	3	5	**3.50**
Pre workout food	2	4	4.5	2	4	3	**3.53**
Cooking oils with superior shelf life	3	1	4	3	2	3	**2.70**
Antioxidant film for packages	5	5	4	5	3	4	**4.15**
Biohydrogen	5	1	1	4	4	2	**2.70**
Bread	1	5	5	2	5	3.5	**4.00**
Starch	2	4	4	2	5	4	**3.75**

I: Innovation, **MR:** Market risk, **IE:** Implementation Easiness, **CR:** Certification risk, **RMQ:** Raw Material Quantity, **SM:** Scientific Maturity

Table 3: Selection Matrix

As shown in Table 3, implementation easiness (IE) and raw material quantity (RMQ) are the parameters with the highest weighting factor. A project that uses less specialized equipment is more accessible to implement. Furthermore, the rawer the materials are used, the fewer useful resources are disposed of.

Market risk is also essential, as the target public must accept the product. Also, the importance of raw material quantity is notorious because it is crucial to introduce the product to the market per all the standards it must fulfill. Finally, innovation and scientific maturity allow a new and different product to be on the market.

After the analysis of the selection matrix, the three best-ranked ideas in ascending order were starch (3.75), bread (4.00), and the antioxidant film for packages (4.15). The needs associated to these products were categorized into useful, desirable, and essential and are shown in Table 4.

	Needs		
	Useful	Desirable	Essential
STARCH	Natural stabilizer for food	Energy source used in different packaged foods	Health benefits
BREAD	Cheaper bread	Food with more fiber content	New alternative of cereal production in Europe
ANTIOXIDANT FILM FOR PACKAGES	Alternative to traditional packages	Use of natural antioxidants instead of petroleum-based ones	Increase food shelf life

Table 4: Needs of the three final ideas

It was concluded that bread was the most promising idea, as it could fulfill more needs. Hence, bread with apple pomace is the final chosen product, as it has a higher fiber content than the common bread. The value of fiber content that AP adds to the bread was estimated by analyzing its constituent ingredients, resulting in about 3.1 g per 100 g, which is higher when compared to conventional bread varieties. Also, since cereals in Europe are becoming more expensive, this represents a good solution as it reduces their respective amount used. Bread was considered a viable idea; thus, the idealization of its process was carried out.

4. Manufacture

Once the idea is selected, it is necessary to determine the product's manufacturing process. The global process is divided into two parts: the first is related to the production of apple flour, and the second is the preparation of the bread itself.
For the design of the process, all the equipment was consulted in *Alibaba* to know their respective capacities and technical sheets.

4.1. Flour Production Process

The apple flour production process involves the preparation of the flour following the flowsheet shown in Figure 1. In this process, it is used, 2 blenders, 1 dryer, 1 grinding machine, and 1 sieve. The quantities and the energy shown in the diagram correspond to one day of bread production (production of 18,000 loaves of bread).

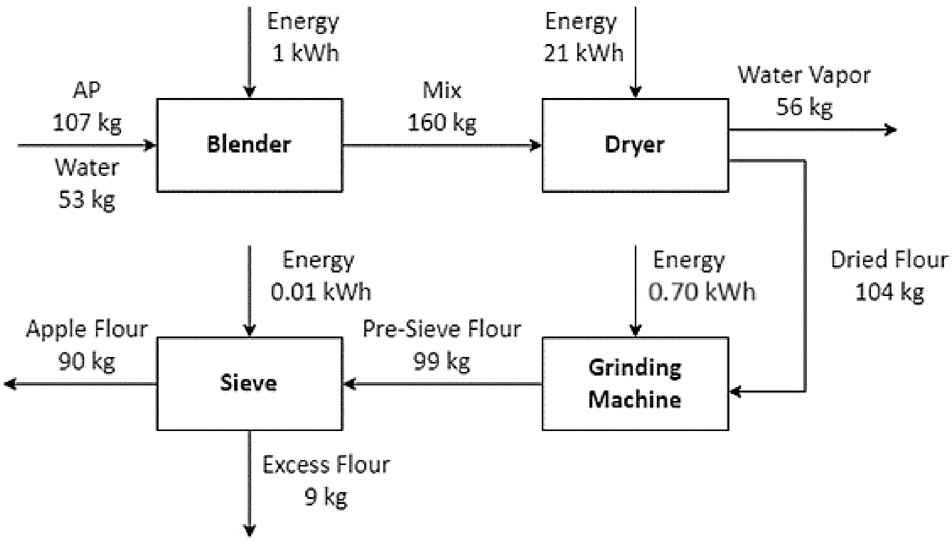

Figure 1: Apple flour production process

The process begins with the addition of AP and water in a 1:2 ratio (Gupta 2006), in the mixer. The water is added because it helps to soften the pomace, which improves its texture making it easier to process into the flour. Also, it facilitates the subsequent drying step as it distributes the humidity evenly throughout the AP, making it easier to remove the moisture. With the mixture prepared, it enters a dryer where the humidity of the mixture is removed, which constitutes 54% of the weight of the mixture (56 kg). With the dry flour, it enters the mill, where a loss of 5% of the dry flour (5 kg) was assumed. The process ends with the input of the pre-sifted flour, where a loss of 10% of the input (10 kg) was assumed.
The value of 54% weight loss of the mixture was determined by effectuating an experiment where a mixture of 206 g of AP and water was prepared and let dry until most of the water had evaporated. The final mass of the mixture was 119 g, a loss of 54% of water. The operating time of the mixer, grinder and sieve were assumed, and the operating time of the dryer was determined from the technical sheet of the device, which has a maximum of 18 kg·h^{-1} of extracted water vapor. The system has a water vapor output of 16.1 kg·h^{-1}.
The amount of energy spent on each machine (Figure 1) was determined by knowing their respective power, taken from the technical sheet for each device, and their operating time. The operating time and power spent by the machines are represented in Table 5.

Machine	Operating Time	Power (W)
Blender	20 min	1500
Dryer	3.5 h	6000
Grinding Machine	18 min	2200
Sieve	5 min	180

Table 5: Power and operating time of the machines

4.2. Bread Production Process

For the bread production part, it was considered 1 mixer, 1 divider machine, 15 fermentation chambers and 3 ovens. To calculate the tray's capacity of the machines, it was assumed that the diameter of one bread fully cooked is about 14 cm.

Now that the area of one bread is determined, the tray and the equipment capacities can be obtained using their datasheet to check the area of one tray and how many trays fit in each of them. The initial system is represented in Figure 2.

The amount of ingredients that will be used in each run is represented in Table 7:

Ingredient	Quantity (kg)
Flour (Wheat + AP)	300 (285 Wheat+ 15 AP)
Yeast	12
Sucrose	18
Vegetable fat	9
Salt	4.5
Powdered milk	15
Ascorbic acid	0.018
Water	180
Total	538.5

Table 7: Amount of ingredients per run

The mixer takes 6 minutes to mix its full capacity into a uniform dough. Since the amount of ingredients is over the mixer capacity, it needs 18 minutes (3 times its capacity) to finish the total amount. The ingredients need to be mixed in the proportion shown in Table 7 (Masoodi and Chauhan 1998, 256-257) and the flour has a 5% (by mass) of apple flour (Lyu et al. 2020, 3-4).

After the mixing step, the dough is taken to the divider machine. This machine cuts the dough into bread-sized portions (180 g per bread). This process takes about 17 minutes to be completed.

When the divider machine cuts all the 3,000 portions, they are headed for the fermentation chambers. The fermentation step takes 2.5 hours. The dough gets significantly bigger because the yeast consumes the sucrose and produces carbon dioxide (and ethanol); this gas gets stuck in the dough, making it swell.

In the oven, the dough gets even bigger because the gas trapped inside of it expands due to the heat; the alcohol produced before evaporates along with a major part of the water. The bread takes half an hour to be ready at 230 °C in the oven. The final mass is around 120 g per bread.

To determine the daily production, it is known that it was produced 3,000 breads in about 4 hours (the sum of the times taken from the beginning to the end), and this cycle can be repeated 6 times per day, so the daily production is 18,000 (6 times the total produced in one run).

To calculate the energy consumed per machine, we need to check their power in their datasheet and multiply it by the run time. The fermentation chamber and the oven have their powers multiplied by 15 and 3, respectively, because the system has 15 chambers and 3 ovens. The daily energy consumption as well as the final system, designed for 1-day production, are represented in Table 8 and Figure 3, respectively:

Machine	Run time (h/day)	Power (kW)	Energy (kWh/day)
Mixer	1.8	34.8	62.6
Divider machine	1.7	1.8	2.9
Fermentation chamber	15.0	40.5	607.5
Oven	3.0	276.0	828.0

Table 8: Amount of energy used to meet the daily production.

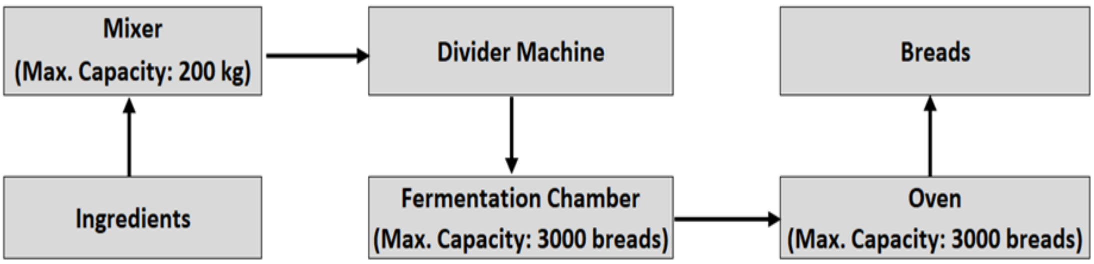

Figure 2: Bread production initial process

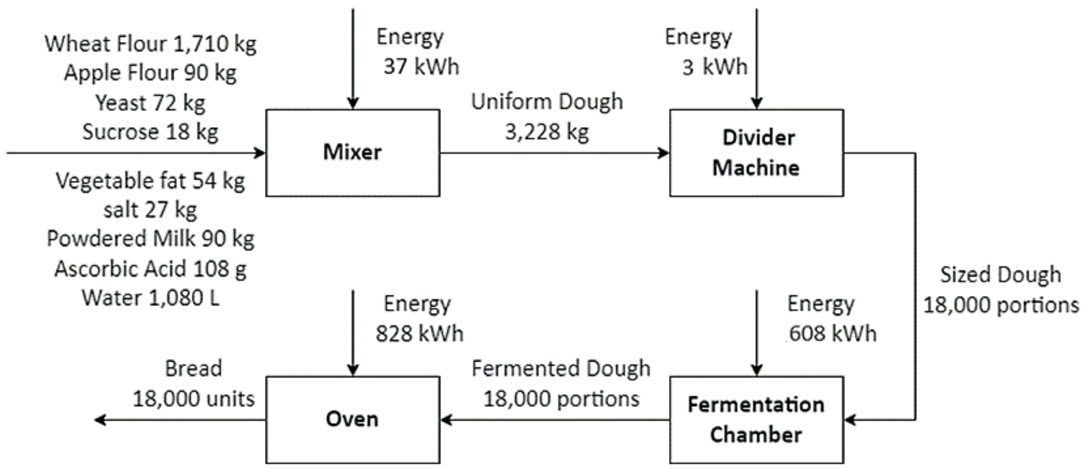

Figure 3: Schematic representation of the daily bread production process

5. Economic analysis

To evaluate the project's viability, it is necessary to carry out an economic analysis. Therefore Table 9 represents the Gantt chart, in which it is possible to see the time progression for 5 years, divided into quarters, of different stages of the project.

	Year 1				Year 2				Year 3				Year 4				Year 5			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
R&D																				
Equipment and Construction																				
Staff																				
Start-up																				
Production																				
Sales																				

Table 9: Gantt chart

The R&D costs, which correspond to research and development costs, were estimated at around 15,900 € per month, which makes a total of 95,400 €. This value considers the subcontracting of a research team with around 6 trainee researchers and 1 coordinating researcher.

Equipment costs are shown in Table 10 and are divided into 2 parts, the equipment needed for apple pomace flour production and the equipment required for bread production. Construction costs were estimated at 2.132 M€, spread over the last 2 quarters of the first year, based on the costs of purchasing the land and building the factory.

	Type of Equipment	Quantity	Unit Cost (€)
Flour	Blender	2	6,000
	Dryer	1	22,000
	Grinding machine	1	484
	Sieve	1	4,316
Bread	Fermentation chamber	15	1,072
	Oven	3	23,440
	Mixer	1	38,000
	Divider Machine	1	10,400

Table 10: Equipment costs

Staff-related costs were calculated based on the function of each employee, their number, and the cost per year spent with each employee, as represented in Table 11. For the calculations, it was assumed that the factory operates 300 days a year and 24 hours a day.

Function	Number of employees	Cost (€/year)
Operator	15	18,000
Supervisor	2	26,000
Engineer	1	32,000

Table 11: Staff costs

Since there is a total of 8 machines in the process, it was thought that 15 operators were a solid number to cover the day and night shift, which also justifies the need for two supervisors, thereby necessitating the employment of two supervisors. For the calculation of start-up costs, it was assumed that they correspond to 20% of equipment and construction costs (Cussler and Moggridge 2011).

Production costs were calculated as the sum of the cost of acquiring raw materials and the energy required for each process. Table 12 shows the costs per year of raw materials and energy.

To calculate the total cost of raw materials and energy, it was assumed that 90 kg of apple pomace flour and 18,000 loaves of bread are produced per day. In this way and knowing the necessary equipment for each process, its capacity and power, the energy cost per day were calculated.

Type of Cost	Cost (€/year)
Raw materials	729,397
Energy	148,158

Table 12: Production costs

Regarding sales, each piece of bread will be sold for 0.5€.

With all the costs and earnings, it is possible to determine the cash flow, corresponding to the difference between earnings and costs.

It is also possible to determine the accumulated costs and accumulated earnings and calculate the NET cash-flow with the difference between them.

In Figure 4, it is possible to visualize the accumulated costs and accumulated earnings over the 5 years, divided into quarters. With this graph, it can be concluded that only between the 13th and 14th quarter do the 2 lines intersect. In this way, the Payback time, which is the time it takes until the investment is paid, occurs between the 13th and 14th quarter.

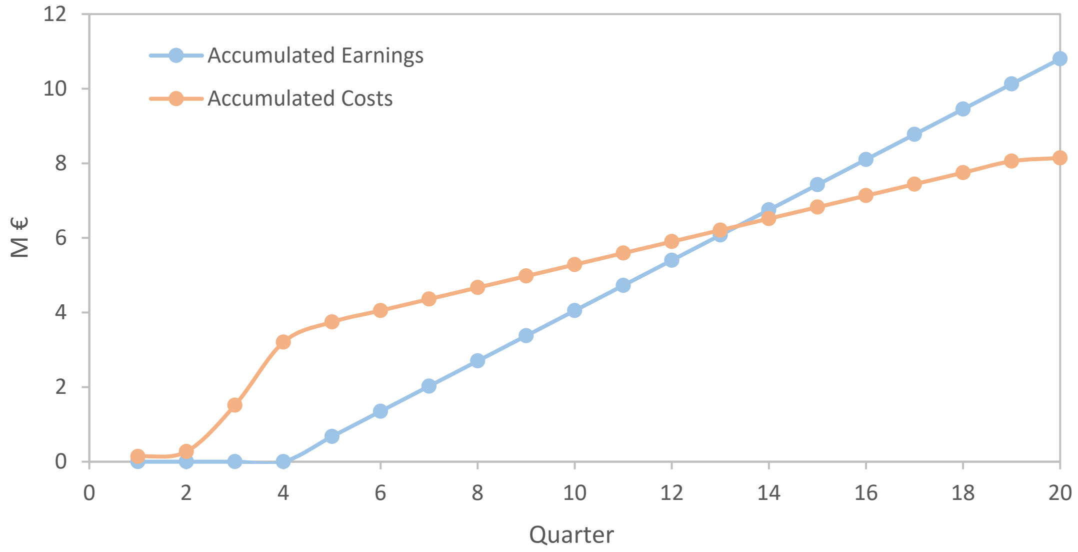

Figure 4: Accumulated costs and accumulated earnings, over the first 5 years

Figure 5 shows the Present Value Cash Flow (PV Cash Flow) and the Present Value Accumulated Cash Flow (PV NET Cash Flow). PV Cash Flow ($PV\ CF_i$) was calculated by Equation 1,

$$PV\ CF_i = \frac{CF_i}{(1+j)^i} \tag{1}$$

where CF_i represents Cash Flow for each quarter (i) and j represents the rate of return, which in this case was 15%.

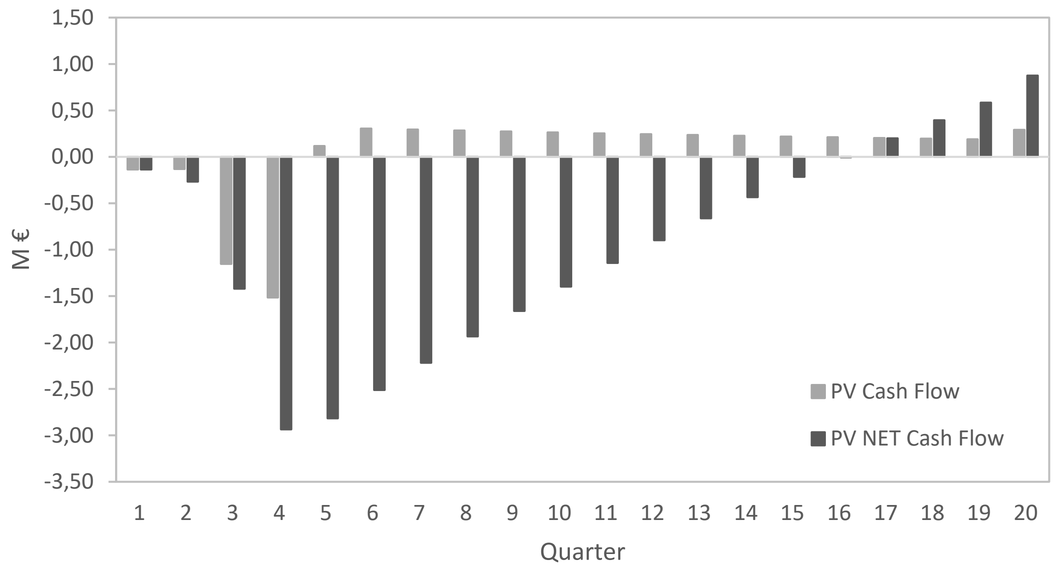

Figure 5: PV Cash Flow and PV NET Cash Flow, over the first 5 years

With the PV Cash Flow, it is possible to know the Break-even point, which is the point when revenues and costs equal each other and, thus, the company begins to be viable. In this way, the Break-even point occurs when the PV Cash Flow is equal to zero. This happens between the 4th and 5th quarter.

It is also possible to determine the Net Present Value (NPV), which is 0.88 M€, calculated by Equation 2 and the Intern Rate of Rentability (IRR), which is 27.8%, calculated by Equation 3.

$$NPV = \sum_{i=1}^{n} \frac{(NET\ Cash\ Fow)_i}{(1+j)^i} \tag{2}$$

$$IRR = \sum_{i=1}^{n} \frac{(NET\ Cash\ Fow)_i}{(1+IRR)^i} \tag{3}$$

As the NPV is greater than zero, the company could be profitable, and the production of bread using apple residues is viable according to the payback time, which will take less than 4 years to pay the investment.

6. Conclusions

The product chosen was a bread made with, besides the other ingredients, a mixture of 5% (by mass) apple flour for wheat flour. This mixture provides a higher fiber content to the bread, and the 5% usage of the apple powder allows the production of many units with a little apple pomace.

Briefly, the system consists of mixing the apple pomace with water, drying it, grinding it, and then sifting the grains to have a more uniform distribution. The powder obtained is mixed with wheat flour in the proportions described above, and the bread is made like in any traditional recipe. This system allows the use of the entire apple pomace, a common leftover from the juice industry that is not much valued. It is very unlikely to encounter any issues due to the extensive know-how and thorough understanding of each step involved in the process, coupled with the reliability of the product's formulation and manufacturing procedures. The economic analysis was made by considering the costs of energy, raw materials, equipment, staff, start-up, construction, R&D, and sales incomes. Finally, the analysis showed that the process is viable, having an NPV of 0.88 M€, a breakeven point of 1 year and a payback time of almost 4 years.

7. Acknowledgments

This work was developed within a framework of awareness for the valorization of natural residues for the manufacture of added-value products, under the scope of the Chemical Product Engineering course of the Master's in chemical engineering at the Faculty of Engineering of the University of Porto. Professor Cláudia Gomes and Doctors Ricardo Santos and Yaidelin Manrique, supervisors of this work, are members of LSRE-LCM – Laboratory of Separation and Reaction Engineering - Laboratory of Catalysis and Materials, supported by national funds through FCT/MCTES (PIDDAC): LSRE-LCM, UIDB/50020/2020 (DOI: 10.54499/UIDB/50020/2020) and UIDP/50020/2020 (DOI: 10.54499/UIDP/50020/2020); and ALiCE, LA/P/0045/2020 (DOI: 10.54499/LA/P/0045/2020).

8. References

Coelho, Laylla Marques, and Gilvan Wosiacki. 2010. "Avaliação sensorial de produtos panificados com adição de farinha de bagaço de maçã." Food Science and Technology, 30: 582-588. DOI: 10.1590/s0101-20612010000300003.

Cussler, E. L. and G. D. Moggridge. 2011. "Chemical Product Design". 2 ed. Cambridge Series in Chemical Engineering. Cambridge: Cambridge University Press. DOI: 10.1017/CBO9781139035132.

Gupta, Radhna. 2006. "Incorporation of dried apple pomace pulp powder in bread." Journal of Dairying, Foods and Home Sciences, 25.3 and 4:200-205.

Heinze, Thomas. 2015. “Cellulose: Structure and Properties.” Advances in Polymer Science, 1–52. DOI: 10.1007/12_2015_319.

Lyu, Fengzhi, Selma F. Luiz, Denise Rosane Perdomo Azeredo, Adriano G. Cruz, Said Ajlouni, and Chaminda Senaka Ranadheera. 2020. “Apple Pomace as a Functional and Healthy Ingredient in Food Products: A Review.” Processes 8, no. 3: 319. DOI: 10.3390/pr8030319.

Masoodi, F. A., and G. S. Chauhan. 1998. “Use of apple pomace as a source of dietary fiber in wheat bread.” Journal of Food Processing and Preservation 22, no. 4: 255–63. DOI: 10.1111/j.1745-4549.1998.tb00349.x.

Quint, U., R. T. Muller, and G. Muller. 1998. “Characteristics of Phenol.” Archives of Orthopaedic and Trauma Surgery 117, no. 1–2: 43–46. DOI: 10.1007/bf00703438.

Reis, S. F., Rai, D. K., and Abu-Ghannam, N. 2012. “Water at room temperature as a solvent for the extraction of apple pomace phenolic compounds”. Food Chemistry, 135, 3, 1991-1998. DOI: 10.1016/j.foodchem.2012.06.068.

Vidović, S., Horecki, A. T., Vladić, J., Šumić, Z., Gavarić, A., and Vakula, A. 2020. “Apple”. Valorization of Fruit Processing By-Products, 17-42. DOI: https://doi.org/10.1016/B978-0-12-817106-6.00002-2.

Whistler, Roy L., and James R. Daniel. 2000. “Starch.” Kirk-Othmer Encyclopedia of Chemical Technology, December 4. DOI: 10.1002/0471238961.1920011823080919.a01.

Wu, Eddie. 2024. Alibaba. Accessed 4 April, 2024. https://www.alibaba.com/?src=sem_ggl&field=UG&from=sem_ggl&cmpgn=9922923043&adgrp=97780318062&fditm=&tgt=kwd-14739453&locintrst=&locphyscl=1011759&mtchtyp=e&ntwrk=g&device=c&dvcmdl=&creative=432272606776&plcmnt=&plcmntcat=&aceid=&position=&gad_source=1&gclid=CjwKCAjw_LOwBhBFEiwAmSEQAVHLaXTNfGPHYIEJbg1inBGTyxN9bIrqtko189kdn9t9NLNlf2HUhRoCoSsQAvD_BwE.

Yadav, Sangeeta, Pramod Kumar Yadav, Dinesh Yadav, and Kapil Deo Singh Yadav. 2009. “Pectin Lyase: A Review.” Process Biochemistry 44, no. 1: 1–10. DOI: 10.1016/j.procbio.2008.09.012.

Zhang, F., Wang, T., Wang, X., and Lü, X. 2021. “Apple pomace as a potential valuable resource for full-components utilization: A review”. Journal of Cleaner Production, 329, 129676. DOI: 10.1016/j.jclepro.2021.129676.

Zlatanovic, Snežana, Ana Kaluševic, Micic, Jovanka Lalicic-Petronijevic, Nikola Tomic, Sanja Ostojic, and Stanislava Gorjanovic. 2019. “Functionality and Storability of Cookies Fortified at the Industrial Scale with up to 75% of Apple Pomace Flour Produced by Dehydration.” National Library of Medicine, November 8. DOI: 10.3390/foods8110561.