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Xylitol: Development Study of a Liquid Sweetener Derived from Hemicellulose of Tomato Agricultural Wastes

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Abstract

The main purpose of this project was the eco-valorisation of the tomato plant residues. The chemical product design method was used to select the best idea based on 4 steps: needs, ideas, selection, and manufacturing.

Liquid xylitol is here proposed for the valorisation of tomato plant residues, which is an alternative sweetener with a lower glycemic index that can be produced from the hemicellulose found in leaves and stems. Its production would require an alkaline extraction with sodium hydroxide, enzymatic hydrolyses using endo-1,4-β-xylanase, and yeast fermentation with *Candida tropicalis*.

Liquid sweetener with 72% xylitol and other components (D-glucose, D-mannose, D-galactose, L-arabinose, and lignin), commercialised as *NITS - Natural Incredible Tomato Sweetener*, could be sold for 2.25€·L^{-1} for companies and the same price per bottle of 500 mL for individual consumption.

Author Keywords. Xylitol. Tomato Residues. Hemicellulose. Alkaline Extraction. Enzymatic Hydrolysis. Endo-1,4-β-xylanase. *Candida tropicalis*. Liquid Sweetener.

Type: Research Article

1. Introduction

Tomato production in Portugal generates an average of 1.3 million tons per year, which makes it the 3rd largest European producer of tomatoes, after Italy and Spain (Ministério da Agricultura 2021; Almeida et al. 2021). Portugal's cultivation is in an open field with a total production area of 13 thousand hectares, where about three quarters (74%) comes from crops in Alentejo, namely Ribatejo, followed by production in Lisbon metropolitan area, with 25%, and in the center, with less than 1% (Instituto Nacional de Estatística 2021). The preference for the Ribatejo region occurs because the soil is a fertile sediment deposit, mainly near the Tejo and Sorraia rivers, and the climate has ideal conditions, with dry summers and rain in some springs (Lezíria do Tejo, n.d.).

Tomato requires a relatively warm climate and plenty of light and is adaptable to various soil types. Nevertheless, preference is given to deep, well-drained soils with a loamy or sandy-clay texture. Since irrigation is critical for its production, the system used is usually drip irrigation to avoid water waste.

Currently, the harvest on a large scale is completely mechanised, where a machine separates the fruit from the branch by grinding the tomato plant. This contributes to reducing the proliferation of pests and diseases. On the other hand, it generates a huge amount of waste that has no purpose for the farmers and is usually incinerated[1] (Moura 2013). It is estimated that 26% of tomatoes' production weight is leaves and 23% is stem, resulting in 49% of tomato plant waste (Heuvelink 1996).

The amount of waste generated creates an opportunity to promote sustainable management and ensure its valorisation. In 2015, a Circular Economy Action Plan (CEAP) was approved by the European Union (EU) to promote sustainable development. The recovery of compounds present in tomatoes for reuse in other product categories is an interesting approach since several compounds can be extracted and applied in other products to valorise them.

The main goal of this work was the development of a product from the tomato plant agricultural wastes. The first part of this work aimed to develop strategies for selecting and elaborating a product that valorises tomato residues by brainstorming ideas related to the market needs. The product chosen was a liquid sweetener made mainly from xylitol, produced by the recovery of hemicellulose presented in tomato branches, with ethanol and lignin as byproducts. Then the manufacturing process and economic analysis of the chosen product were described and presented to ensure the feasibility of the business success. In order to commercialise, the product would have to be chemically and biologically tested to know if it is within the legal parameters and its nutritional information.

1.1. Raw material

The tomato plant (*Solanum lycopersicum*) is a plant cultivated essentially for its edible fruits. They are generally branched, 60 to 180 cm wide and reach up to 45 cm in length. In addition, tomato is also processed to produce tomato-based products such as canned tomatoes, tomato juice, ketchup, and others[2].

Regarding its compounds, there are a wide variety of properties in tomato stems and leaves, such as adhesive, thickener, emulsifier, gelling agent, and others (Costa et al. 2021; Khan, Lee, and Kim 2019; Reichembach and Petkowicz 2021). These compounds have several applications, such as electrical insulators, sponges, glues, biofuels, biopolymers, films, coatings, and leather, among others (Farhat et al. 2017b; Ferreira et al. 2015; Jusner et al. 2021; Qaseem, Shaheen, and Wu 2021; Reichembach and Petkowicz 2021; Singh and Kumar 2019; Yang et al. 2021; Yang, Xu, and Yang 2015). On the other hand, these active compounds have medicinal properties, such as antioxidant, antifungal and antibacterial properties, that can act to prevent cancer and cardiovascular diseases, help in dysphagia and reflux problems, bone regeneration, blood coagulation, and use as throat lozenges (Arab et al. 2019; Arvayo-Enríquez et al. 2013; Srivastava and Malviya 2011; Reichembach and Petkowicz 2021; Shah et al. 2021). Finally, these compounds are also used in the food industry as food preservatives, in the production of xylitol, as dietary fibers, probiotics, food supplements, in the clarification of wines and beers, etc. (Arab et al. 2019; Qaseem, Shaheen, and Wu 2021; Reichembach and Petkowicz 2021).

[1] *Wikifarmer*, s.v. "Técnicas de Cultivo do Tomate – Guia do Plantio de Tomate," accessed November 11, 2021, https://wikifarmer.com/pt-br/tecnicas-de-cultivo-do-tomate-guia-do-plantio-de-tomate/.
[2] *Encyclopaedia Britannica Online*, s.v. “Tomato,” last modified November 20, 2019, https://www.britannica.com/plant/tomato.

Cellulose, hemicellulose, and lignin represent more than half of the composition of stems and leaves, followed by chlorophyll, pectin, phenolic compounds, and proteins. In addition, other compounds such as carotenoids, tannins, tomatine and the sesquiterpenes, zingiberene and curcumin can be found in percentages of less than 1% (Ahmed et al. 2018; Arab et al. 2019; Reichembach and Petkowicz 2021; Taha, Elkafafy, and El Mously 2018; Wang et al. 2015).

1.2. Manufacture principles

Hemicelluloses are complex plant polymers constituted mostly of diverse monomeric units that include pentoses such as D-xylose and L-arabinose, and hexoses as D-mannose, D-glucose, and D-galactose.

The extraction of hemicellulose can be obtained by methods such as dilute acid pretreatment, alkaline extraction, alkaline peroxide extraction, liquid hot water extraction, steam treatment, microwave treatment and ionic liquid extraction. Alkaline extraction, with sodium hydroxide (NaOH) as a solvent, was chosen because of the higher extraction yield compared to other methods and its preference for lignin removal, leaving mostly hemicellulose as a product. Furthermore, the equipment costs are lower compared to the acid treatment. This treatment cleaves covalent linkages between lignin and hemicellulose, remaining only polymeric sugar chains (Farhat et al. 2017a). A previous study reported a yield of 7.91% of hemicellulose extracted from the tomato residues using this alkaline extraction, where 4.8% of this amount is lignin (Farhat et al. 2017b; Taha, Elkafafy, and El Mously 2018). Nevertheless, the large amount of NaOH required can become an environmental concern, and it would require water treatment, enabling its reuse in other processes.

Several methods could be used for water sodium removals, such as nanofiltration membranes, ionic resins, electric dialysis, distillation techniques, and reverse osmosis (Farhat et al. 2017a). In this work, reverse osmosis was the process chosen for water treatment, which has an economic advantage in terms of energy and investment requirements. Additionally, its efficiency can be affected by many factors, such as the initial concentration of NaOH, water composition flow rate and the equipment itself.

In order to guarantee the hemicellulose ability of sugar conversion, it was necessary a hydrolysis treatment since the hemicellulose was obtained in polymeric form during the extraction. Nevertheless, three possibilities were contemplated with the aim of xylans hydrolysis: acid, alkaline and enzymatic hydrolysis. Concentrated acids can be used to treat lignocellulosic materials; however, as much as they perform efficacious hydrolysis, they are toxic, corrosive, and hazardous. This method would imply removing the acid, so the process would not be economically viable. On the other hand, basic solutions can likewise be used. However, its proficiency depends on the lignin content (Sun and Cheng 2002). Regarding enzymatic hydrolysis, endo-1,4-β-xylanase would be used to hydrolyse the 1,4-β bonds, which transform lignocellulosic biomass into fermentable sugars. Therefore, enzymatic hydrolysis was chosen to be implemented since it has a 90% yield.

Focusing on the main product, xylitol ($C_5H_{12}O_5$) is a five-carbon sugar alcohol. One of the most common applications is in the food industry as a natural sweetener and in the pharmacy industry as an anti-cariogenic agent (Ko, Kim, and Kim 2006).

When it comes to its production process, there are two methods that could be used: chemical and biotechnological. Currently, xylitol is industrially mostly produced by chemical treatment through a catalytic reduction of pure D-xylose, requiring expensive purification steps. In this process, the yield of xylitol production is 50-60%, requiring high temperatures, pressure, and heavy metals (Parajó, Domínguez, and Domínguez 1998). Regarding biotechnological treatment, it could be done using fungi, yeasts or bacteria (Parajó, Domínguez, and Domínguez 1998). The production of xylitol by bacteria or fungi has been studied lesser than the yeast pathway, which is the best option to produce xylitol when compared to other microorganisms (Espinoza-Acosta 2020; Rafiqul and Sakinah 2013). In the first case, xylose is metabolised by fungi by oxidation-reduction reaction forming xylitol. In the second case, a bacterium is needed to convert xylose into xylitol by the enzyme xylose-isomerase. For that purpose, several yeasts could be used. A particular example is *Candida* species, which are the ones that present the highest yields, namely *Candida pelliculosa*, *C. boidinii*, *C. guilliermondii*, *C. tropicalis* and others (Rafiqul and Sakinah 2013). In comparison with the chemical treatment, the production of xylitol through a biotechnological process is limited by the control of culture conditions, such as temperature, pH, shaking, aeration, etc. This kind of process is usually more time-consuming, which can be less attractive for industrial-scale production. Oppositely, the biotechnological approach requires low investment since several expensive purification steps are not required (Silva and Afschar 1994; Rafiqul and Sakinah 2013). In addition, it can be an eco-friendly process, with moderate production conditions and the generation of less toxic effluents (Espinoza-Acosta 2020).

From the previous analysis, the biotechnological process with *Candida tropicalis* was selected, producing xylitol with an average yield of 81% (Kim, Ryu, and Seo 1999; Walther, Hensirisak, and Agblevor 2001).

1.3. Market analysis

In Portugal, more than 41% of the adult population should not consume white sugar as a consequence of diabetes (13.6%) or intermediate hyperglycemia (28%) (Raposo 2020). At the same time, studies showed that more than 50% of the population suffer from overweight, highlighting the elderly with 81% of the total with the condition cited (Ministério da Saúde 2018). Besides that, the daily intake of sugars for cooking and preparing food or dishes is the highest contribution with 21.4%, followed by other sources of sugars such as sweets (16.8%) and non-alcoholic beverages (11.9%), for example. Even though teenagers and children are the groups with the largest daily sugar consumption, thus the group with the most percentage of obesity, as expected, in this case, the largest percentage is related to the elderly, followed by the adult population (Raposo 2020).

2. Chemical Product Design (CPD)

The chemical product design is the strategy used for product development from the raw material to its commercialization. The procedure was chosen to define and develop xylitol and it is divided into 4 steps: needs, ideas, selection and manufacturing (Cussler and Moggridge 2011).

2.1. Needs & Ideas

The first step of CPD was the identification of market needs. Four areas can be highlighted, namely pharmaceutical, food industry, materials and pest control.

- Pharmaceutical area: the beauty industry is growing faster, which is driven by the increasing desire for health and self-care products. That has also increased the consumption of natural products due to their features for reversing and correcting skin problems related to stress and pollution (Automat Technologies, n.d.). Regarding drugs, anti-inflammatories have been currently used to treat some diseases. In addition, the demand for biologic anti-inflammatory drugs has been increasing due to their fewer side effects than traditional drugs (Terdale and Sumant 2021). People are also even more concerned about prophylactic health measures and, for example, when there is a known hereditary condition in their family, the first step is to monitor and treat it as is possible;

- Food industry: antioxidating products are widely used because they can decrease cellular oxidation in humans and prevent oxidative damage to cells, reduce inflammation and protect against chronic diseases (Link 2020). When it comes to the sub-category of pet food, it is known that people have been more concerned with the well-being of their pets and the supply of animal food, e.g., fiber-based products;
- Materials' area: bio-based products as an alternative to conventional materials (e.g., in the packaging industry) have been widely considered to reduce carbon footprint. These products must be biodegradable to minimise the toxicity levels, which corresponds to the new concerns of the population (Markets and Markets 2021);
- Pest control: the demand for natural pest controllers is increasing due to the competitive prices and the reduction of harmful effects compared to traditional products (Mordor Intelligence 2021). On the other hand, problems related to plagues of ants can carry several germs and bacteria that can be harmful to humans and pets. Sprays are the most common type of control on the market. However, they cannot be used in all industries because of its toxicity and easiness of air dispersion. So, the alternatives are baits formulated as gels (Fortune Business Insights 2021).

Product ideas were proposed based on the main society needs for each category aforementioned. Only xylitol, ant repellent gel, biopolymers, medical adhesives and skin eruptions cream were chosen to be evaluated according to their added value and competitiveness.

2.2. Selection

The five ideas presented in the last section were evaluated based on seven criteria that were assigned a certain percentage weight that was exclusively dependent on the degree of importance.

The percentages weight for each criteria are: market acceptance - 20%; innovation - 20%; reduction of the environmental impact - 20%; easiness of production - 15%; market strength - 10%; added value - 10%; safety of use - 5%.

The evaluation of each idea was based on the comparison with a product in the market with the same or similar application. Xylitol was compared with white sugar, biopolymers with synthetic polymers, ant repellent gel with insecticide sprays, medical adhesives and anti-acne cream with the synthetic products in the market. It was attributed a value of a scale that varied from 1 to 10, where 5 corresponds to the equivalent product in the market. The given evaluations of each criterion and their respective weighting factor are in Table 1, as well as their respective compound (Almeida et al. 2021; Farhat et al. 2017b; Srivastava and Malviya 2011; Qaseem, Shaheen, and Wu 2021).

Xylitol is the selected idea, having the highest final score, 7.5. It distinguishes itself from other sweeteners on the market due to its lower glycemic level (Espinoza-Acosta 2020). For that reason, it would be easily accepted by the market and also, the terms of use would be less restricted, which translates to a safer consumer product. According to Table 1, the assigned value to market strength was still 7 and not higher since there is a great offer of white sugar products. According to the literature, its production is relatively easy to implement, and the environmental impact is less intensive because it uses tomato residues, avoiding its incineration. In addition, it is an alternative to white sugar, even for diabetics.

Criteria	Weighting Factor	Xylitol	Biopolymers	Medical Adhesives	Ant Repellent Gel	Skin eruptions cream
Market Acceptance	0.2	9	8	6	6	7
Innovation	0.2	7	7	6	10	5
Reduction of Environmental Impact	0.2	6	9	8	7	6
Easiness of Production	0.15	7	3	4	2	4
Market Strength	0.1	7	7	6	4	3
Added Value	0.1	10	8	9	5	9
Safety of Use	0.05	7	7	5	5	5
Total	1	7.5	7.1	6.5	6.1	5.7
	Compounds	**Hemicellulose**	**Hemicellulose**	**Pectin**	**Sesquiterpenes, zingiberene and curcumene**	**Tannin**

Table 1: Screening the ideas

3. Manufacture

3.1. Production process

The production process is here proposed to produce xylitol from the hemicellulose extracted from tomato agricultural wastes. As an initial approach, it was only considered for treatment, 49% of initial tomato residues, which corresponds to 304 thousand tons per year, due to the large capacity of equipment required and the limitation of investment for that. This production process would be carried out in 3 cycles per day, which corresponds to 400 tons of raw material per cycle. Considering five working days per week, the production rate would be able to provide 11 thousand cubic meters of liquid sweetener, 357 cubic meters of ethanol and 182 thousand cubic meters of lignin per year.

The main steps involved in the production of xylitol are represented in Figure 1. First, the raw material should be converted into a powder by a mill (Taha, Elkafafy, and El Mously 2018). The method to extract the hemicellulose is alkaline extraction with 10% wt. NaOH at 50 ˚C for 3 hours in a reactor with a capacity of 300 m^3 since studies in the literature pointed out a greatest performance for this method (Taha, Elkafafy, and El Mously 2018). After 3 hours, the suspension is filtered through an automated filter press system at a flow rate of 100 $m^3 \cdot h^{-1}$ to remove lignin and sodium ions in liquid form and hemicellulose with a low percentage of lignin in the solid phase (Taha, Elkafafy, and El Mously 2018). Since the percentage of lignin in the solid phase is very small, it can be consumed and there is no need for an additional process to remove it (Hillman et al. 1985).

From filtrate, it is possible to obtain 76 to 96% wt. of the initial hemicellulose (Farhat et al. 2017b). Nevertheless, it was considered in this work an average between these two values, i.e., 86%. It is also important to ensure that the optimum concentration of NaOH is 10% because there is a degradation of hemicellulose at higher concentrations, and for lower ones, the yield decreases (Farhat et al. 2017b).

After filtration, it is also necessary to wash the product in order to ensure sodium concentration does not exceed 50 $mg \cdot L^{-1}$. The dilution is achieved by adding enough water to implement a dilution factor of 283 times. For this, the entire solid would be submitted to an automated water pressure system.

Then, water should be submitted to a reverse osmosis treatment, with a removal equipment efficiency of 75%, as it can be reused again in the last step towards a more sustainable process.

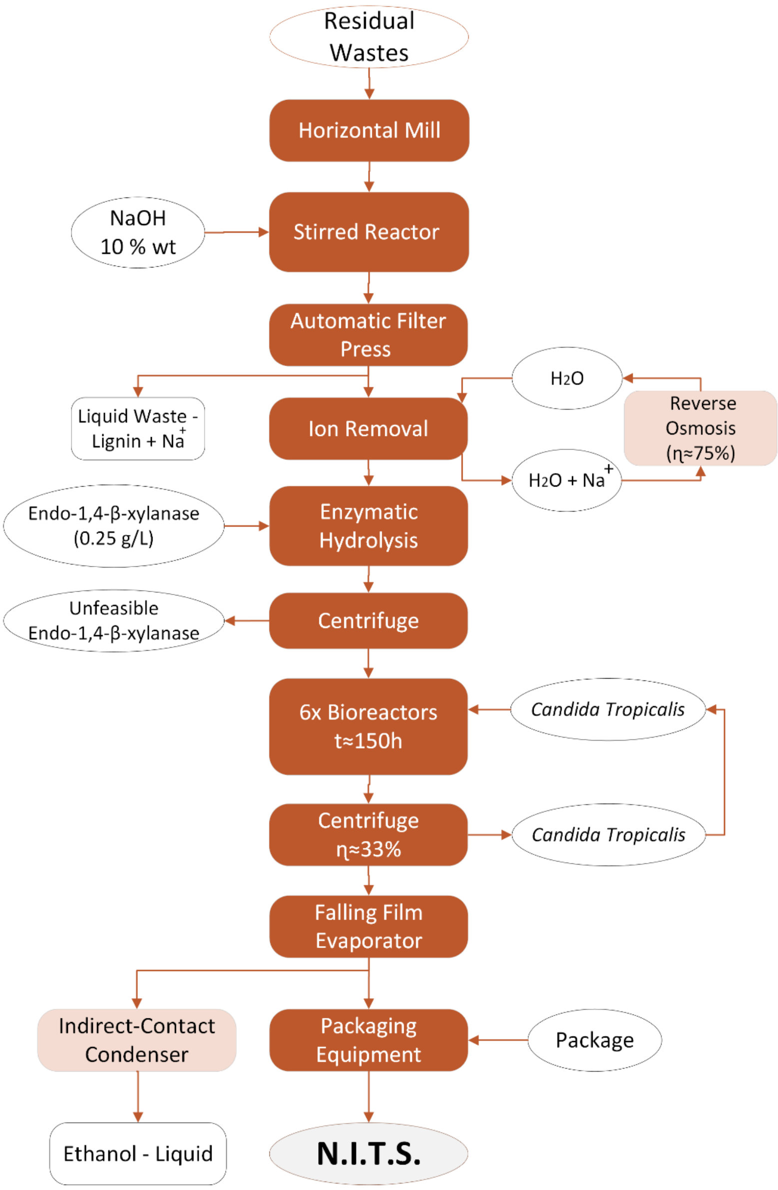

Figure 1: Xylitol production steps

After obtaining hemicellulose with a low percentage of lignin, the next step would be hydrolyzation, aiming for the sugars' separation in monomers for upcoming treatments. The method selected was enzymatic hydrolysis using 0.25 $g \cdot L^{-1}$ endo-1,4-β-xylanase enzyme with buffer conditions, pH 5, and around 40 ˚C. This step requires 5 hours of aseptic incubating time, with intermittent rotation of 150 rpm, originating 90% efficiency. Then, the solution was submitted to a centrifugation process for 10 minutes at 4 ˚C to remove infeasible enzymes (Sun and Cheng 2002).

The production of xylitol was carried out according to the chosen biotechnological treatment, i.e., the production of xylitol using *Candida tropicalis*.

For the fermentation, it would be necessary to prepare an inoculum at a laboratory scale and scale it up to a 180 m^3 bioreactor. This step would take 150 hours, and since this process is much more time-consuming, it would be necessary 6 bioreactors in order to be a continuous process. Those reactors operate at 30 ˚C, pH=6 and an aeration rate of 90 $m^3 \cdot min^{-1}$ (Kim, Ryu, and Seo 1999).

After that, the mixture would be centrifugated at 4 ˚C for 5 minutes to remove the yeasts that could be reintroduced into the process up to 14 times with a yeasts reuse efficiency of 33% (Kim, Ryu, and Seo 1999; Kim et al. 2004). Long-term cell recycling should be used to produce xylitol instead of the simple batch method because higher yields and volumetric productivity are obtained. Fermentation times are shorter and substrate rates are higher due to the higher state development of cells when using recycled cells (Kim et al. 2004). The number of yeasts that are required per reactor is 8×10^{13} cells (Gong et al. 2018). As yeasts are very expensive and the quantity needed in the process is high, it was chosen to produce them instead of purchasing.

In fermentation, D-glucose was the first sugar consumed from yeasts to promote cell growth, and then other sugars were simultaneously consumed. Ethanol was also produced mainly from D-glucose consumption (Kim, Ryu, and Seo 1999; Walther, Hensirisak, and Agblevor 2001).

In the case of an edible product, the ethanol must be removed. Thus, a falling film evaporator at 80 ˚C integrated with an indirect contact condenser at 30 ˚C could be used. The temperature for the evaporator was chosen to guarantee ethanol's total evaporation without evaporating the other sugars, according to the boiling point of each component.

The final manufacturing phase corresponds to liquid sweetener packaging, except for the ones sold to food industries.

3.2. Product formula

Since there are no patents on the same production methods or the same product formula before xylitol began to be produced and commercialised, this process must be patented in the Portuguese Institute of Industrial Property. Liquid xylitol is marketed as 72% of xylitol and the remaining 28% corresponds to other components (D-glucose, D-mannose, D-galactose, L-arabinose and lignin) (Kim, Ryu, and Seo 1999; Walther, Hensirisak, and Agblevor 2001).

3.3. Product specifications

The specifications related to liquid sweeteners are summarised in Table 2.

Product Specifications	Description
Precursor	Hemicellulose
Uses	It is an alternative to sugars and sweeteners. Natural sweetener with low glycemic content can be consumed by diabetic people. Add to shakes, cakes, cereals, yogurts or other dishes.
Origin	Portugal
Warnings	Do not exceed recommended sugar dosage per day (NHS, n.d.). Keep out of reach of children. This product should not be used as a substitute for a varied and balanced diet and a healthy lifestyle. This product should not be used in case of hypersensitivity or allergy to any of the constituents
Secondary effects	Its excessive use causes laxative effects
Store	Store in a cool and dry place. Expiration date: see bottom of the label
Food supplier	Manufactured in Portugal. Distributed by: NITS, LDA.

Table 2: Product specifications

4. Economic Analyses

The final step of this work was to provide an economic evaluation for this project, which includes the start-up of this business and all the costs and investments involved.

4.1. Company

NITS - Natural Incredible Tomato Sweetener would be created with the purpose of valorising the agricultural wastes of tomato plantations in Portugal. As so, the operations center could be an industrial area of Santarém, Portugal. This location was chosen according to the majority of tomato production, which is located close by and so the transport of the raw materials would be affordable. Santarém is connected to the main motorways in Portugal, airports, and train stations, which would provide an easier and faster interconnection. The company logotype is shown in Figure 2. It is based on the name and the principle of valorisation of agricultural residues. Figure 2 also shows the product packaging, with a capacity of 500 mL for individual consumers to buy. Note that *NITS* could be sold on an industrial scale for industries that can use it for the development of their own products, which is business to business (B2B) model. On the other hand, it can be sold directly to the consumer, i.e., business to consumer (B2C) model.

Figure 2: Company logotype and individual product packaging

Since it is an innovative product, the marketing department has an important role in the product's recognition on the market.

According to previous studies, 84% of customers are internet users, 77% are active in social media and the ages that most watch social media advertising are between 18 and 54 years old (DataReportal 2021). In addition, it was found that the establishment of new businesses on the market is made mostly by recommendations or by advertisements on TV, the internet and social media, namely *YouTube* and *Facebook* (DataReportal 2021). Based on this, the target audience is the population over 18 years old, and the product has to be advertised on television, *YouTube*, *Facebook,* and through its own website. Besides that, testing samples for consumers and companies will be distributed in order to make NITS known.

Currently, there are some alternatives on the market, such as sweeteners, which are suitable for people with diabetes; For example, coconut sugar, which is healthier and more nutritious than white sugar; or sweetener stevia, which is also suitable for people with diabetes and comes from a medicinal plant. However, it is important to emphasise that, although they are present on the market, those alternatives are not accessible to everyone, mostly due to their cost, which, compared to sugar, is much higher. As an example of Portugal's supermarket prices, white sugar can be sold for 0.79 euros per kilogram, and if it is biological, it is around 7.6 euros per kilogram. Besides that, liquid sweeteners can be found at around 17.52 euros per kilogram.

According to section 3, the process generates some byproducts that are valuable. Therefore, dissolved lignin in NaOH and ethanol could be sold to other companies to increase the business profit. For instance, the lignin could be sold to probably more than one company that produces energy by burning biomass. Nevertheless, as the lignin formed is liquid, the price per liter will be smaller.

Figure 3 presents a Gantt Diagram, which controls the project schedule and determines the intensity of work of which department per term.

Year	0 (2022)				1 (2023)				2 (2024)				3 (2025)				4 (2026)				5 (2027)			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Project Phases	Needs	Ideas	Selection						Manufacture															
Marketing	*	*	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	*	*	*	.	.	.
R&D	-	-	*	*	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Engineering	*	-	-	-	-	-	-	-	-	*	*	*	*	.	.	.	.	.	.	.	.	.	.	.
Purchasing	.	.	.	.	-	-	-	-	-	*	*	*	*	.	.	.	.	.	.	.	.	.	.	.
Human Resources	.	.	.	.	.	*	-	-	-	*	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sales	.	.	.	.	.	.	.	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Production	.	.	.	.	.	.	*	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

-	Heavy Involvement
*	Average Involvement
.	Minor Involvement

Figure 3: Gantt's Diagram

In summary, the year 0, which corresponds to 2022, will be destined to search the needs of the Portuguese population, propose some ideas to fulfill those needs and finally, select the best one. In the 1st year, marketing, engineering and purchasing departments would be intensively involved in the decisions on the final product. Equipment should be purchased, material and raw materials. Besides that, human resources have an important role to perform during this period, especially when the recruiting process is running. Additionally, the sales department must search for possible clients and the operators will require some general training and specific machine training. Finally, from year 2 afterward, when manufacturing starts, it would be required a strong involvement of sales and production departments as well as marketing. When that target is achieved, the investment in marketing will decrease.

4.2. Economic evaluation

The economic evaluation is an essential criterion for the product feasibility study, ensuring the highest return on investment possible.

For the implementation of this project, five business partners would be needed. Each one would invest 1.8 million for 10% of the company. Besides that, a loan of two million will be where 143 thousand euros will be to equipment, throughout the five-year quarters, with a two-and-a-half-year payment grace period and a 2.578% effective annual interest rate, which was recalculated to the correct pay period. And finally, 700 thousand euros of share capital will be needed.

Regarding the expenses of the manufacturing facilities and equipment, namely the mill, the stirred reactor, the automatic filter press, the refrigeration chambers, the reverse osmosis equipment for water treatment, the washing equipment to reduce the ions concentration, the aseptic incubator, the bioreactors, the centrifuges and the falling film evaporator combined with a condenser, 6 million euros from the credit available would be required.

As mentioned, it would be made an application to a national patent for liquid sweetener from tomato agricultural residues and its manufacturing process, which has a duration of 20 years. The costs of the request, the reply notification, the mandatory exploration license application, and other costs make a total of 150 euros. As the annuities are only paid from the 5th year, there are no more costs to be considered until 2027.

Other equipment, such as chairs, tables, computers, cabinets, among others, should also be considered as the initial investment in the first quarter. This corresponds to 34 thousand euros. However, over the manufacturing years, it will also be necessary to amortize them at the cost of 20 thousand euros per quarter.

On the other hand, depending on the department's level of involvement, the budget changes from 150 to 900 thousand euros for marketing and 5 to 100 thousand euros for R&D, respectively, per quarter.

Regarding the raw materials, agricultural wastes, equipment consumables, chemicals and yeasts are required. Since the tomato producers usually incinerate all the wastes, stems, and leaves, they would provide the company for free with the condition that the company is responsible for the collection of that wastes. Regarding the equipment consumables, they refer to all components of the equipment for water treatment that must be changed after one year or more, depending on the item specification. In addition, the production process will only be needed sodium hydroxide for the alkaline extraction, 0.6 €·L^{-1}. A quantity of 20 ampoules of *Candida tropicalis*, estimated at 112 € each, and endo-1,4-β-xylanase, estimated at 1.50 €·kg-1 would be purchased.

Another important aspect is the subcontracting companies, which corresponds to 875 thousand euros per quarter. This value concerns subcontractors that will provide and wash the uniforms, the company that will guarantee all the transportation needed, packaging, maintenance, analysis and tests needed, certifications and pest control.

Other aspects to consider are expenses related to energy, water, sanitation, and communication tariffs. The sanitation and communication fees have a fixed cost of 3 thousand euros per quarter, and the energy cost of 130 thousand euros per quarter was calculated based on the power of each equipment as well as the price wielded by the biggest energy company in Portugal, 0.14 €·kWh^{-1}.The water cost of 1.5 thousand euros per quarter was calculated based on the amount of water needed for the ion removal and the price wielded by the local water company for non-domestic plus the flat rate, 2.5€·m^{-3}·month^{-1}. These costs were based on the year 2021; however, depending on the global economic situation, they could suffer adjustments.

This business would create 35 jobs, distributed in different sectors as administration, receiving 14 000 €·month-1, human resources with 3 000 €·month-1, sales department with 4 400 €·month-1, marketing with 4 600 €·month-1, quality department with 5 700 €·month-1, R&D with 4 400 €·month-1, production leaders with 3 000 €·month-1, engineers with 6 000 €·month-1 and finally operators and cleaners with 12 750 €·month-1 each. Considering 14 payments with all the costs associated for each employee, in manufacture years are spent 185 thousand euros per quarter on salaries. All the employees would also need insurance of 75 €·year-1 each and constant personal development, 70 €·year-1 each. The business would have three sources of profits: sale of *NITS* and byproducts like liquid lignin for biomass combustion and ethanol for biofuel production.

Considering that all the lignin produced would be sold by 0.013 €·L^{-1} since it is in liquid form and with other components for companies that produce energy by burning biomass. Ethanol would be sold by 0.6€·L^{-1} for closed refineries (Santos 2011). Note that around 6% of profits are from selling these byproducts. The remaining 94% concerns the sale of *NITS*, considering that it is sold for factories, 80%, for 2.25€·L^{-1}, and for individual consumers, 20%, for 2.25€ per bottle of 500 mL. Regarding the selling rates, it was considered that it will start in 40% of the maximum production, which represents 2400 thousand euros profits, and it will increase 10% every two quarters, which means in 2027, 5th year, the profits became 10 million euros in the sale of *NITS*, only. Those prices were analysed based on market studies, more specifically on the supermarket price of white and brown sugar, honey, liquid and solid sweetener, and pure xylitol, which showed that only the white and brown sugar are cheaper than *NITS*. Liquid sweeteners would be 3.6 times more expensive than white sugar, 1.7 times cheaper than biological white sugar and 3.9 times cheaper than liquid sweeteners.

Figure 4 shows the present values of cash flow ($PV\ CF_j$) and the accumulated ones ($NPV\ CF_j$). Note that $PV\ CF_j$ is calculated by Equation (1) and $NPV\ CF_j$ by Equation (2), where i is the interest rate, CF_j is Cash Flow for time period j, in which j varies from 0 to 5.

$$PV\ CF_j = \frac{CF_j}{(1+i/4)^j} \quad (1)$$

$$NPV\ CF_j = \frac{CF_j}{(1+i/4)^j} + \frac{CF_{j-1}}{(1+i/4)^{j-1}} \quad (2)$$

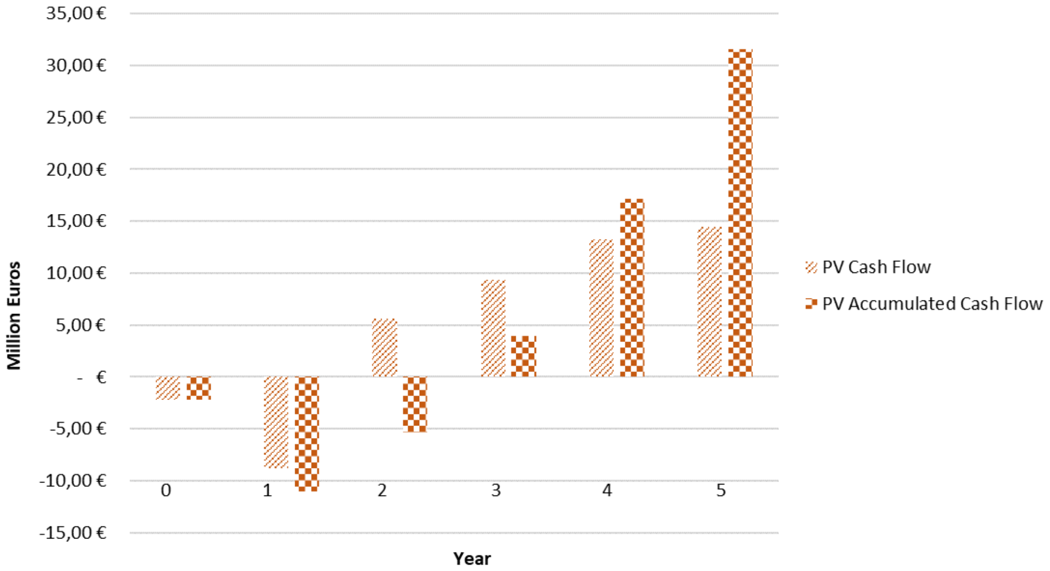

Figure 3: PV Cash Flow and PV Accumulated Cash Flow throughout the years

In years 0 and 1, $PV\ CF$ is negative, as expected, since the product manufacture just starts in year 2. After the beginning of the manufacture, the business the $PV\ CF$ became positive. According to the initial investment estimated, the $NPV\ CF$ is only positive in 3rd year.

Regarding the project profitability, that is, whether the investment can be recovered, remunerate invested capital at 15% rate and still generate profits, it is necessary to take into account the following indicators: net present value (NPV), profitability index (PI), internal rate of return (IRR), $Payback\ Time$ (PT) and return on investment (ROI). These indicators were calculated based on Equations (3), (4), (5), (6) and (7), respectively. Note that k refers to the quarters and $NPV\ CF_k\ investment$ to the maximum negative value of $NPV\ CF_k$.

$$NPV = \sum_{k=1}^{24} NPV\ CF_k \quad (3)$$

$$PI = \frac{\sum_{k=9}^{24} NPV\ CF_k}{\sum_{k=1}^{8} NPV\ CF_k\ investment} \quad (4)$$

$$\frac{CF_j}{(1+IRR/4)^j} + \frac{CF_{j-1}}{(1+IRR/4)^{j-1}} = 0 \quad (5)$$

$$\sum_{PT=1}^{24} NPV\ CF_{PT} = 0 \quad (6)$$

$$ROI = \frac{NPV\ CF_k}{NPV\ CF_k\ investment} x100 \quad (7)$$

Table 3 shows all the indicators referred to above and the $NPV\ CF$ of year 5.

$NPV\ CF$ (M €)	NPV (M €)	IRR (%)	PT (years)	PI (€)	ROI (%)
31.4	75.2	27	3.5	3.70	270

Table 3: NPV, IRR and PT of NITS

In summary, the company generates a profit of 31.4 million euros, so it is favorable to invest in NITS business because the investments will be recovered in 3.5 years. The NPV indicator is also positive and IRR is 27%. Finally, from PI, 1€ invested the company receives that euro, recover the capital invested at a rate of 15% and remunerate a profit of 2.70€, and from ROI, it is known that by the end of the investment, the company recovered 270% of the money invested.

4.3. Risk analysis

Risk analysis will demonstrate if the project is viable even in crisis situations. The first contingency plan to be considered is the scarcity of raw materials. In that situation, the network with agriculture producers will be extended to other Portugal regions or countries, for example, Spain. Regarding the increase in sodium hydroxide prices, a study considering twice the current price is shown in Table 4. This study shows that the business would not be significantly affected. Even though the company is still able to remunerate at 15% rate, all indicators decreased: $NPV\ CF$ decline 1.31 times, NPV 12.8 times, IRR 1.69 times, PI 1.21 times and ROI 1.31 times.

$NPV\ CF$ (M €)	NPV (M €)	IRR	PT	PI	ROI
24.0	5.9	16%	4 years	3.06 €	206%

Table 4: NPV, IRR and PT of the risk analysis

5. Conclusions

In this work, the manufacture of xylitol is proposed as a valorisation of agricultural tomato wastes in Portugal. This study was based on the principles of chemical product design: needs, ideas, selection, and manufacture. Additionally, it was made an economic analysis.

A manufacturing project was chosen to maximise the xylitol yield production. Xylitol would be extracted from hemicellulose presented in steam and leaves of 7.91% wt. tomato wastes.

The initial approach considered that only 49% of residues could be treated by this process, which corresponds to 304 thousand tons per year, as a consequence of the equipment required and the limitation of investment for that. Firstly, the raw material is grinded onto the alkaline extraction reactor achieving a recovery of 86%. Since hemicellulose is recovered in a polymeric form, enzymatic hydrolysis with endo-1,4-β-xylanase would be performed with 90% efficiency. Following, a fermentation step by *Candida tropicalis* enabled the conversion of D-xylose into liquid sweetener, with an 81% yield. The final product contains 72% of xylitol and other components (D-glucose, D-mannose, D-galactose, L-arabinose and lignin). This strategy would provide 11 thousand cubic meters of liquid sweetener, 357 cubic meters of ethanol and 182 thousand cubic meters of lignin per year.

Regarding the byproducts, ethanol would be sold by 0.6€·L^{-1} for biofuel production and lignin sold by 0.013€·L^{-1} for biomass combustion. The liquid sweetener would be sold for 2.25€ per bottle of 500mL for individual consumers (20%) and 2.25€·L^{-1} for factories (80%).

The initial investment would be 12 million euros. The expected payback time would be 3.5 years and the internal rate of return of 27%. In the 5th year of investment, the company would be able to recover 270% of the investments and generate 31.4 million euros of profit. A risk analysis was also considered in this work.

In summary, from the eco-valorisation of tomato wastes, it is possible to create and commercialise diverse value-added products, namely xylitol, whose market, as an alternative option to sugar, with a low glycemic index. At the same time, a more sustainable world can be reached by the implementation of a circular economy where these residues are reused in a production process.

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