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TECHNOLOGICAL SOLUTION DEVELOPMENT FOR THE COCOA SUPPLY CHAIN

Rodrigo Magno Silva Cabral Ferreira, *Antonio Carlos Peixoto Bitencourt and Antonio Gabriel Souza Almeida

Institute Federal of Bahia

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****Corresponding author:***
Antonio Carlos Peixoto Bitencourt,

ABSTRACT

The objective of the present study is to present the informational and conceptual stages of the development of a technological solutionfor obtaining cocoa butter. The development of the product project was based on the Integrated Product Development Process (PRODIP); this model breaks down the design of the project into four sequential phases called informational design, conceptual design, preliminary design and detailed design. Small producers in southern Bahia were selected as a reference during the informational process, which ultimately defined the project specifications. After completion of the conceptual project, it was concluded that the product design that best suited the current job was the screw press. This was made up of a screw with a constant pitch and tapered shaft, as well as an oil drainage system consisting of a single piece.

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INTRODUCTION

Cocoa beans are the main raw material in the manufacture of chocolate.They are also used to make many other derivatives (oil, butter, powder, nibs, among others). According to data from the Brazilian Ministry of Agriculture, Livestock and Supply (Mapa) (2019), Brazil has an average cocoa production of 250 thousand tons per year.This makesthe country the seventh largest cocoa producer in the world. Bahia is home to 95% of the total Brazilian cocoa agribusiness (Bahia, 2006 apud Gonçalves et al., 2010) and is the region with the largest production in the country (Brazilian Ministry of Agriculture, 2019). Figueiredo et al. (2019) presentthe cocoa market in Bahia. After planting, handling and harvesting, small and medium-sized producers sell to forwarders or directly to processing companies (mills). It is a market which is strongly dominated by forwarders, who represent 70% to 80% of the origins of purchases. Another significant fact is that only three mills process about 97% of all Brazilian cocoa (Rasi, 2018). None of the three are Brazilian. One of the main characteristics of medium and some large northeastern agroindustries is that they are producers of raw materials for the industry responsible for the second transformation. Such semi-processed raw materials are destined for medium or large domestic and foreign industries, resulting in products ready for consumption, therefore of greater added value, such as chocolates, confectionery, sauces and condiments, among others. Despite its socioeconomic importance, the cocoa supply chain has weaknesses, especially with regard to small producers, due to the lack of institutional organization, limited capital and asymmetry of technological and market information between the different production links (Gonçalves *et al.*, 2010). According to a strategic sectoral analysis of cocoa in the south of Bahia carried out by the Brazilian Micro and Small Business Support Service (Sebrae) (2019), small producers find it very difficult to make cocoa crops profitable, and are forced to supplement their income with other activities. The analysis also lists some characteristics of small producers: family farmers and sharecroppers, land reform settlements, diversified income and selling to small intermediaries. It is estimated thatcocoa farming occupies about 176 thousand people in the countryside of Brazil, and at least half of the workers have other fixed or temporary occupations, cocoa not being their main source of income. In addition, the average age of the producers is 61 years, and their children do not continue to work with cocoa (Rasi, 2018). The objective of this article is to discuss the development of a technological solution for the cocoa supply chain adapted to the socioeconomic reality of the small producer in southern Bahia. The focus is on the extraction of cocoa oil to obtain butter. The product project development was based on the Integrated Product Development Process (PRODIP).This model breaks down the project elaboration into four phases called informational design, conceptual design, preliminary design and detailed design. In the informational design phase, engineering specifications are defined. In the conceptual phase, in turn, the product design is developed. This article presents the two initial stages of the product design development, and proposes a solution conception for the problem identifed.

Bahia; and (2) the specific characteristics of the cocoa bean.In order to determine the producer's needs, the customer needs matrix was developed to make use of the concept of the basic attributes of the product, analyze each phase of the life cycle and, in each one, identify the needs of the project (Back et al., 2008). Figure 1shows what the technological solution project for extracting cocoa oil to obtain butter must have or how it must be. To ensure that the matrix is really in line with the needs of the end customer, small producers in the region were consulted and interviewed. In addition, a small craft chocolate business was visited in the city of Salvador, Bahia. The enterprise is known nationally for its chocolates, as well as for being the only company in the municipality that extracts and sells cocoa butter.

	Basic Product Attributes							
Life Cycle	**Operation**	**Ergonomics**	**Aesthetics**	**Economic**	**Safety**	**Normalization**	**Environmental Impact**	**Oil Quality**
Manufacture		Have easy welding.		Be painted without waste; Have minimum production cost.				
Assembly		Have easy assembly (do not require specialized knowledge).			Have safe assembly (avoid exposed parts that may hurt).			
Transportation								
Storage				Have economical storage.	Have safe and practical storage.		Have storage that does not imply risks for the environment.	
Function		Have wheels to prevent loading.	Have nice color. Have nice geometry.	Have no heavy structure; Have low energy consumption.				
Use	Have continuous extraction; Have easy use.	Be ergonomic; Have an operation that does not require high physical effort.		Have low waste during the extraction process.	Have safe use and do not require many safety requirements.		Have an extraction mechanism that does not harm the environment.	Be developed to extract quality oil (for food purposes).
Maintenance				Have cheap maintenance and simple spare parts.		Have standardized joints.		
Discard							Have disposal that does not harm the environment.	

Figure 1. Customer needs matrix

Informational design: At this stage, the informational design phase of the development of a technological solution for the extraction of cocoa oil to obtain butter was detailed. The design problem consists ofa lack of technology for primary processing which is economically accessible to the small cocoa producer. With such a technology, the user can move forward within the cocoa supply chain and add value to his/her product. In the informational phase, in possession of important information such as what the design problem is and who the product users are, technologies and methods for extracting oils were studied and presented. User needs and user requirements, in turn, were identified. Then, the method that best fits the scope of this work was presented. Finally, the project specifications were detailed.

Method definition: There are basically four fundamental methods for extracting oils: chemical extraction, supercritical fluid extraction (SFE), mechanical extraction and steam distillation (Mariana et al., 2013).In order to compare the methods and define the most suitable for the scope of this work, two aspects were taken into account: (1) the socioeconomic reality of the small producer in southern

The producer was interviewed, gave a tour of the facilities, and reported the problems existing in his/her production, mainly with regard to the extraction of cocoa butter. The user's needs (the most fundamental) were compared with the technical characteristics of each vegetable oil extraction technologyto define which extraction method is the best for the scope of the project. Chemical extraction was the first method to be disregarded. The essential oil produced by this technology contains a small amount of solvent (or enzyme) as a residue and, therefore, its use in food applications is not possible, unless a specific solvent is used (Stratakos & Koidis, 2016). This extraction method is not in line with a fundamentally important user requirement i.e. to extract quality oil (for food purposes). In addition, this method presents environmental problems due to the higher energy consumption required and higher emissions of volatile organic materials, as well as complications for human health due to working conditions and the use of flammable chemicals (Bhuiya et al., 2020). The extraction of oils by supercritical fluid was also inappropriate here given the industrial scale envisaged, it is not viable when it comes to a low cost solution for the small producer.Research done by Johner and Meireles (2016) showed that a homemade oil extraction unit using supercritical fluid has an approximate cost of US$ 16,000. Despite being considered an ecological extraction method (that is, it does not use solvents or uses small amounts of organic solvents, besides having low energy consumption), its use is incompatible with the socioeconomic reality of the small producer. In addition to the high cost of installation, this technology requires specialized technical knowledge for its operation (Khaw et al., 2017).

The technology of steam distillation is also not suitable, as it is a method used to extract essential oils from plants, and here we are dealing with beans (Sari, 2006). Essential oils represent a small fraction of the composition of a plant, and confer characteristic properties that justify their use in the pharmaceutical, food and fragrance industries (Stratakos & Koidis, 2016). Finally, mechanical extraction seems a viable method. It is a technique widely used due to its ease of operation and maintenance and it does not require a high level of technical knowledge (Pradhan et al., 2011). The extracted oil is of good quality and the extraction rate is high (screw presses can extract up to 80% of the seed oil). After purchasing the machine, the running costs are very low. Seeds or whole grains can be processed, including cocoa, which eliminates previous steps and makes the process shorter. There is no significant environmental concern with the use of mechanical extraction machines, especially when compared to other existing techniques (Bhuiya et al., 2020). In addition to these points, mechanical extraction is a relatively inexpensive technology,a Brazilian company in the industry sells a model to small producers (processing up to 50 kg/h) for approximately US$ 6,900 (which is still not viable for the small producer). These observations indicate that mechanical extraction is the most suitable method for the project.

unidirectional compression and, for these reasons, are often used on a laboratory scale and pilot (Çakaloğlu et al., 2018). Owolarafe et al. (2002) compared the two mechanical extraction techniques in relation to yield, oil quality and costs for the palm oil extraction process. No differences were observed in the chemical quality of the oil. The screw press was more advantageous because it requires less labor, processing time and cost during the process, in addition to guaranteeing a higher yield and is thus the faster and more economical technique. This directed the present work towards the adoption of the screw press as the chosen mechanical extraction technique.

Engineering specifications: In the previous item, customer requirements were defined, as shown in Figure1. However, these requirements are still in the form of needs, without being associated with the measurable characteristics of the product. It is necessary therefore to convert this information into engineering parameters, expressing it through design specifications, which have technical and quantitative characteristics. The specifications of the screw press under development are detailed in Figure2, and were based on studies and market research.

As illustrated, for each engineering parameter, there is an associated engineering specification. A sensor, here, can be understood as a method or an instrument used to assess whether a specification has been met. The undesirable outputs represent exactly what you want to avoid when adding the associated specification. Finally, the priority level column establishes a criterion: (A) for specifications that relate to user safety and/or product ergonomics, (B) whether the specification is directly related to customer needs (Figure1) and (C) for the other specifications. This criterion defines a hierarchy between specifications, and can serve as a prioritization tool during the product development.

Parameter	Specification	Priority level	Sensor	Undesirable output	Comments
Weight	140 kg	B	Weight scale	Difficulty in transportation and handling	Have wheels to prevent loading
Sharp edges	Absence	A	Visual inspection	Possible accidents	User has physical contact with the machine
Production capacity	50 kg/h	B	Stopwatch	Process inefficiency	The machine must be able to process up to 50 kg of cocoa beans in one hour
Rated power	1.5 kW	B	Dynamometer	Possible changes in power consumption and machine performance	
Operating voltage	220 V or 380 V three-phase	B	Voltmeter	Possible changes in power consumption and machine performance	
Dimensions (length x width x height)	1250 mm x 550 mm x 750 mm	A	Measuring tape	Storage and/or ergonomic problems	
Type of painting	Epoxy paint	C	Visual inspection	Exposed metal parts	

Figure 2. Engineering specifications

Studies show that the extraction of oil by screw press has advantages over hydraulic pressing. The screw press has a higher extraction yield and is a continuous process (Martínez et al., 2017), a great advantage(Sari, 2006). On the other hand hydraulic presses provide discontinuous and

Conceptual design: The development of the product design was the focus of the second major stage of this work. To achieve this, the functional structure of the product was developed, by defining the global function to be performed, as well as its sub-functions. After this activity, alternative functional structures were analyzed. Regarding the selected functional structure, alternative concepts were evaluated. Finally, a comparative analysis between the alternatives was carried out, in order to select the most adequate concept.

Technical system global function formulation: In possession of the engineering specifications for the problem detailed in the informational design, the next step was to generate alternative solutions. For this, the method of functional synthesis was used, which is one of the most referenced in the literature (Back et al., 2008). The first step of the method is the definition of the global function of the problem for which a solution is sought, as well as the interfaces with other technical systems and the environment, as shown in Figure 3.

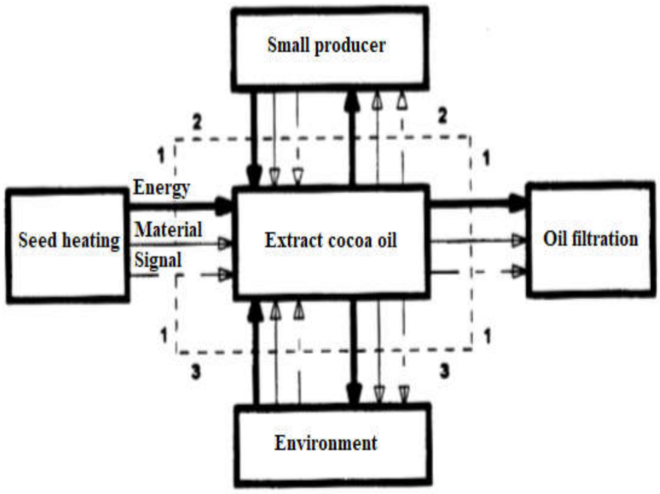

Figure 3. System global function

The global function of the system is located in the central block of Figure 3, in a condensed and abstract way. Interfaces 1 represent interfaces with peripheral technical systems, which are systems that directly relate to the central technical system. Interface 2 is the control that the user wants over the system, such as commands and input and output information for actuation and identification of the operating state. Finally, interface 3 encourages the identification of possible influences from the environment (Back et al., 2008).

Technical system functional structure development: The second step of the method consists of finding solutions for the global function that transforms inputs into outputs, considering the limitations imposed by the auxiliary interfaces. The global function is broken down into its partial or elementary functions, following the flows of energy, material and/or information (or signal)(Back et al., 2008). Figure 4 represents the functional structure of the mechanical extraction system using a cocoa oil screw press to obtain butter.

Morphological matrix: Once the task of developing the functional structure of the technical system is complete, the next step is to generate alternative solutions. For this, first the morphological matrix method was used, which consists of conducting a systematic search of different combinations of elements or parameters, in view of the functional structure of the system developed, so as to find a new solution for the problem (Back et al., 2008).

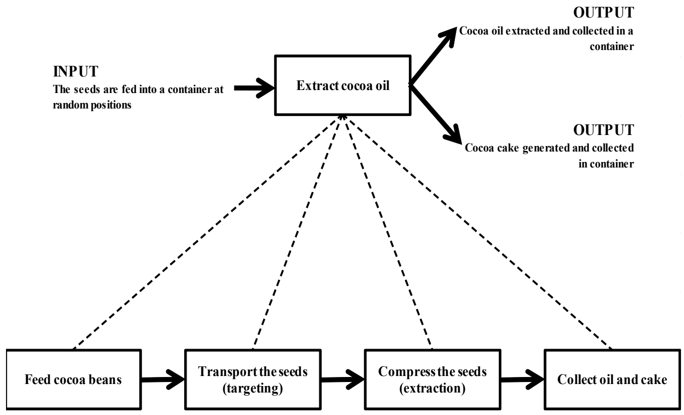

Figure 4. System functional structure from the global function

The first step of the method is to determine the sequence of process functions. When examining the functional structure of the mechanical extraction system using a cocoa oil screw press, it is observed that the sequence of functions (or operations) is: (1) feeding the cocoa seeds into the machine, (2) directing the seeds inside the machine, (3) compressing the seeds and extracting the oil and (4) collecting and removing the extracted oil and the cake generated. The second step is to fill in the first column of the morphological matrix. Figure 5 shows the matrix with the first column filled in by the functions, as well as the respective discussion parameters for each of the functions. The third step is based on the search for alternative solution principles for each function of the process. The idea is to look for ways or principles for each operation, independently, without worrying about the others. Each literal description and/or graphic representation inFigure 5, distributed along the columns, represents a solution. The solutions, in turn, were raised from the works and references cited and used throughout this study, as well as from research and understanding of the state of the art regarding the screw press method of mechanical extraction.

Solution principle variants proposition: The next step in the development process is the search for alternative solutions or concepts for the global problem formulated. For this, different combinations of the morphological matrix adopting a one-line solution principle with the principles of the other lines were examined. Many alternative concepts can be generated. This assembly process is an empirical activity; combinations are being formed and analyzed, some solutions are selected, and many others are discarded due to technological incompatibility. However, this empiricism is driven by the designer's understanding of the state of the art regarding the problem. Figures 14, 15 and 16 represent three possible solutions for the screw press in development. These three solutions are some of the thousands that can be generated from the morphological matrix for the concept of the screw press.

Solution selection: The next step is to select the most appropriate solution for the product development. For this, the alternative concepts were evaluated using the Pugh method. This is a conceptual evaluation technique that uses the most fundamental client needs (Figure 1) as a basis in the process of valuation, comparison and decision-making. The essence of the method is to measure the capacity of each concept to meet the user needs(Back et al., 2008). Figure 9 represents the evaluation matrix for the developing screw press.

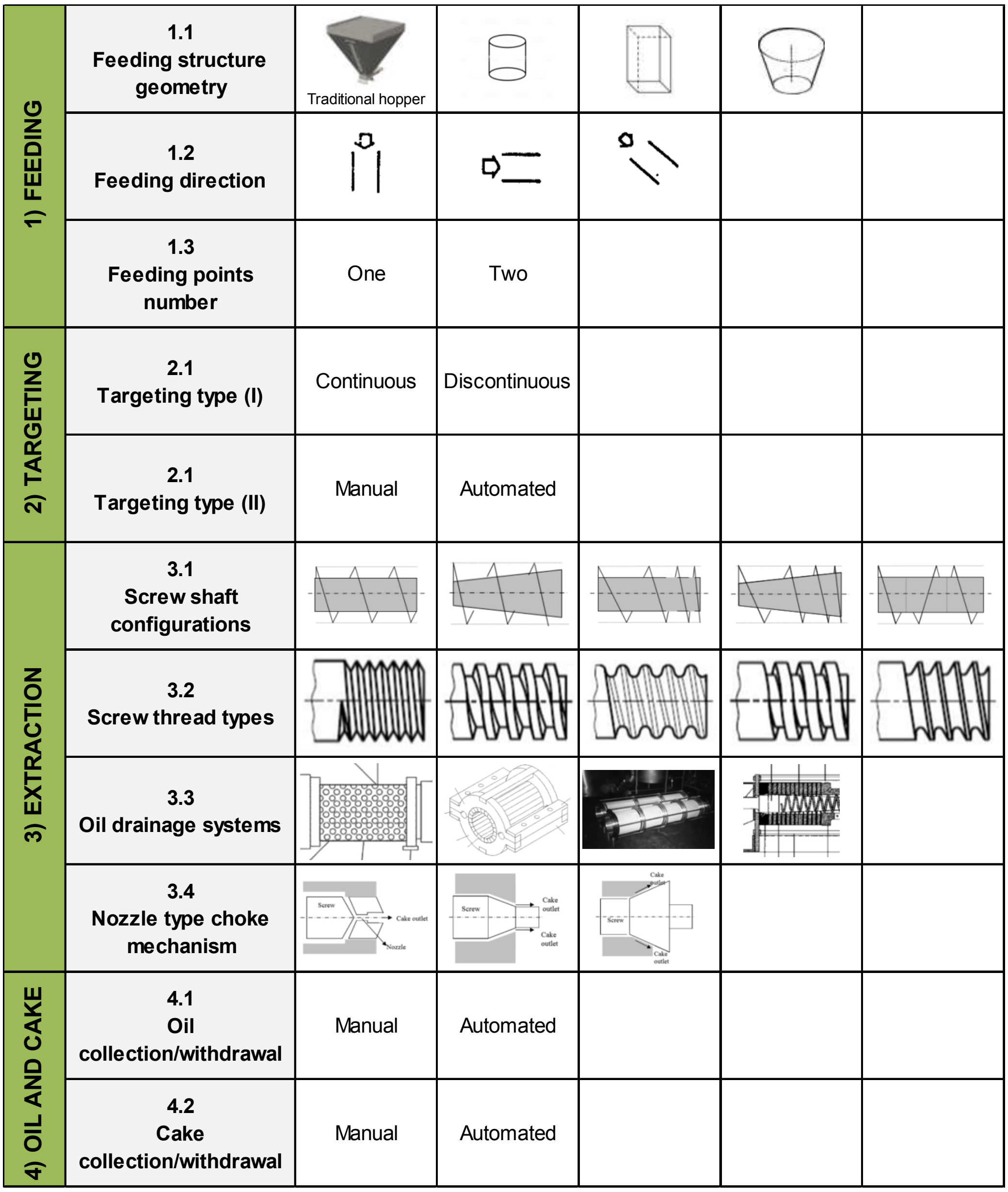

Figure 5. Morphological matrix for the screw press design

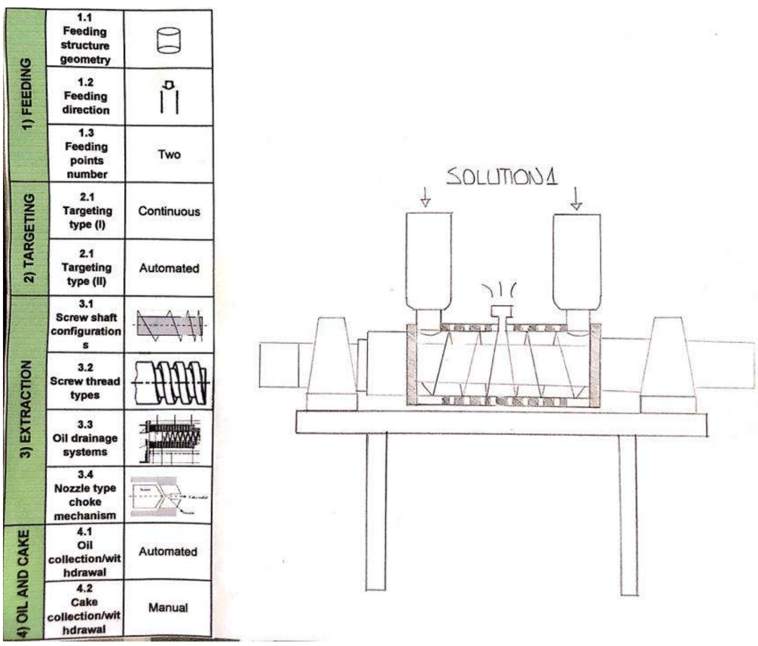

Figure 6. Solution 1 (S1) for the screw press under development

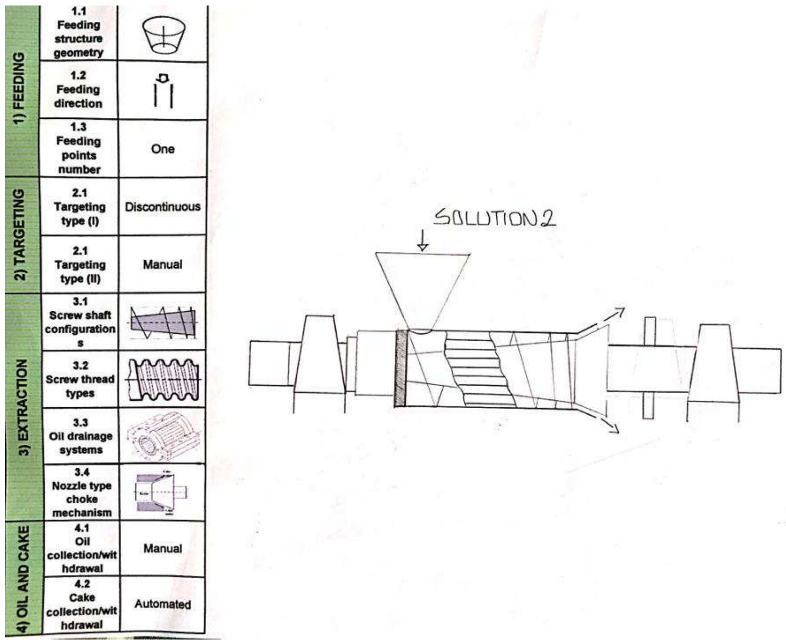

Figure 7. Solution 2 (S2) for the screw pressunder development

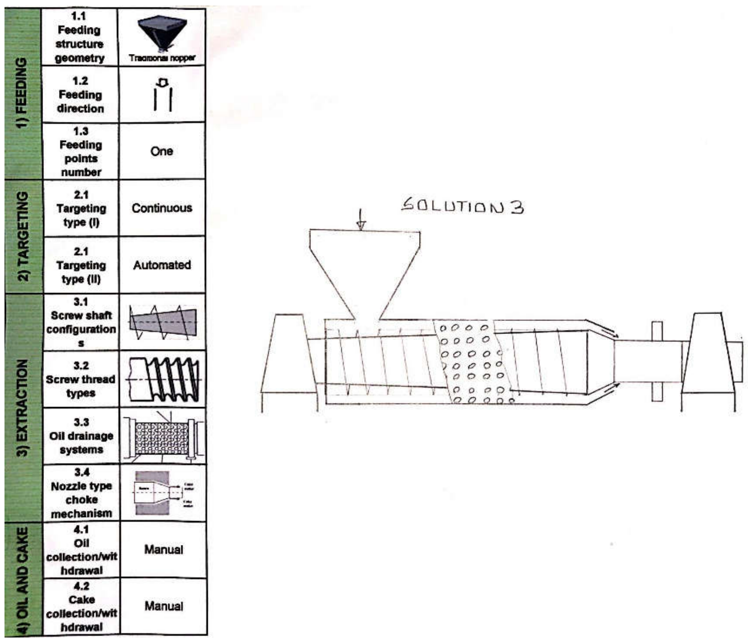

Figure 8. Solution 3 (S3) for the screw pressunder development

Solution 3 (S3) was taken as the reference solution for comparison with the other two. For each comparison regarding needs, the concept being evaluated is judged as better than (receives a "+"), similar (receives an "M") or worse than the reference (receives a "-"). As S3 is the reference, it received a "0" for all criteria. Note that S3 obtained the best total score, and some technical aspects can explain this. S1 and S2 have higher investment and maintenance costs than S3 because they have a screw with variable pitch.This type of configuration can only be machined with a five-axis CNC machine, which makes manufacturing more specific and therefore more expensive(Sari, 2006). Furthermore, S3 is easier to assemble because it has a single-piece oil drainage system, while solutions 1 and 2 have systems that need adjustment when assembling, i.e. the distance between the discs, in the case of S1, and the spacing between the rulers, for S2.

Solution 2, in turn, was designed considering discontinuous targeting of the seeds and, for this reason, presented a score lower than S3 in relation to this criterion. Finally, the first solution has two seed feeding systems, which makes electricity consumption higher. Thus, it was concluded that, of the alternative conceptions generated, solution 3 was the best to suit the present work. Then, the third solution was again evaluated by the Pugh method, however, this time, the comparison made was between S3 and the machines already available in the market. There are only two companies in Brazil, A and B, which sell screw presses to obtain cocoa butter from the oilseed extraction. Solution 3 developed in the present work was compared with the M1 and M2 models of A and B companies, respectively, and the technical characteristics of these models were verified in the market research carried out. M1 and M2 are models aimed at the small cocoa producer, with production capacities of 40 kg/h (M1) and 50 kg/h (M2). Again, solution 3 (S3) was taken as the reference solution for comparison with the models, and Figure 10 represents the second evaluation matrix for the developing screw press.

	Solutions		
Customer needs	S1	S2	S3
Must have minimum production cost (investment cost).	-	-	0
Must have easy assembly (do not require specialized knowledge).	-	-	0
Must have safe and practical storage; Must have storage that does not imply risks for the environment.	M	M	0
Must have low energy consumption.	-	M	0
Must have continuous extraction.	M	-	0
Must have easy use.	M	M	0
Must be ergonomic; Must have an operation that does not require high physical effort.	M	M	0
Must have safe use and do not require many safety requirements.	M	M	0
Must have an extraction mechanism that does not harm the environment.	M	M	0
Must be developed to extract quality oil (for food purposes).	M	M	0
Must have cheap maintenance and simple spare parts.	-	-	0
Must have disposal that does not harm the environment.	M	M	0
Total +	0	0	0
Total -	4	4	0
Global total	-4	-4	0

Figure 9. Evaluation matrix for the screw press

The second evaluation shows that solution 3 (S3) is the one that best meets the needs of users. M1 and M2 models have a higher electricity consumption as both rated operating powersare higher than S3 (4.6 kW and 2.2 kW, respectively). M1 was inferior to S3 in three needs. M1 required a higher investment and higher maintenance costs as it works with an auger with variable pitch and diameter. In addition, it is more difficult to assemble than S3 because it has an oil drainage system with a compression basket containing 12 discs spaced by adjustable openings. Thus, S3 was deemed to be a solution with competitive potential within this market.

	Solutions		
Customer needs	M1	M2	S3
Must have minimum production cost (investment cost).	-	M	0
Must have easy assembly (do not require specialized knowledge).	-	M	0
Must have safe and practical storage; Must have storage that does not imply risks for the environment.	M	M	0
Must have low energy consumption.	-	-	0
Must have continuous extraction.	M	M	0
Must have easy use.	M	M	0
Must be ergonomic; Must have an operation that does not require high physical effort.	M	M	0
Must have safe use and do not require many safety requirements.	M	M	0
Must have an extraction mechanism that does not harm the environment.	M	M	0
Must be developed to extract quality oil (for food purposes).	M	M	0
Must have cheap maintenance and simple spare parts.	-	M	0
Must have disposal that does not harm the environment.	M	M	0
Total +	0	0	0
Total -	4	1	0
Global total	-4	-1	0

Figure 10. Second evaluation matrix for the screw press

Final considerations: In general, the small cocoa producer is in a position in the production chain that is not sustainable nor self-sufficient. Therefore, alternatives need to be developed for such users to move forward within the chain and add value to their product. The extraction of cocoa oil is an alternative that can contribute effectively to supplement the income of the small producer. As detailed during the study, vegetable oils can be extracted using different methods. Considering the socioeconomic reality of the small producer and the characteristics of the cocoa seed, it was concluded that mechanical extraction by screw press is the technique that best suits these people. In addition, market research and related patent research have shown that available technologies are scarce and economically out of reach for such producers. In Brazil, for example, the largest cocoa producer in the American continent and the seventh largest in the world, only two companies offer this type of equipment in the country. Therefore, the development of cheaper solution meets a national and even an international need, considering the possible use of this technology in other South American, African countries and also in other continents. Regarding the development of the product itself, the exercise of generating ideas provided by the Integrated Product Development Process (PRODIP) proved to be effective in dividing and organizing the activities that product design involves, as well as making the process of idealization limitless,and alternative solutions possible. Of the three alternative concepts described, using the Pugh method, it was concluded that solution 3 (S3) is the one that best suits the present study. S3 stood out as it required lower investment and lower maintenance costs.It consists of a screw with a constant pitch making manufacturing simple and cheap using conventional lathes. Considering that the oil drainage system of S3 consists of a single piece, also meant that it proved to be superior in terms of assembly. Finally, solution 3 has a lower energy consumption than S1, as well as superiority in relation to solution 2 with regard to being continuous.

In a second evaluation carried out, this time between solution 3 (S3) and machines already available in the market (M1 and M2), the solution of the present work was potentially competitive. S3 costsless and has lower maintenance costs than M1 because it has a screw configuration with a constant pitch and is easier to assemble due to its oil drainage system being a single piece. In addition, S3 has the lowest electricity consumption, as it has a lower rated operating power than M1 and M2. In the next stages of the work, the objective is to focus on preliminary and detailed product development projects. The final machine will be modeled in CAD software, simulations will be carried out (of movement, stress and strains and fluid flow), the components will be sized and specified, and one or more prototypes will be manufactured for evaluation and validation. In parallel, these future activities should serve as opportunities for improving solution 3, in order to make it even more competitive in the market. Finally, we intend to develop a functional prototype for mechanical extraction of cocoa oil, which is of low cost, small size, with a productive capacity appropriatefor small producers, and easy to maintain and operate. The resulting device for the small producer should enable them to advance within the cocoa chain. After harvesting and processing the beans in a primary way, they can add value to their product, fostering entrepreneurship and the self-sufficiency of rural workers.

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