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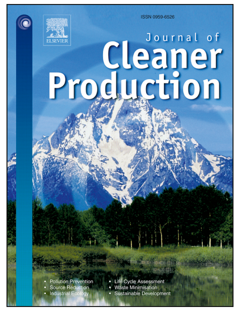

A framework for selecting lean practices in sustainable product development: The case study of a Brazilian agroindustry

Fernando Henrique Lermen, Márcia Elisa Echeveste, Carla Beatriz Peralta, Monique Sonego, Arthur Marcon

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Dear Editors,

We would like to submit the revised version of our paper JCLEPRO-D-17-08288R1 "A Framework for Selecting Lean Practices in Sustainable Product Development: the case study of a Brazilian Agroindustry" for publication in the Journal of Cleaner Production.
Our study proposes a framework with Lean tools and practices applied throughout the new product development and offers a customizable guide for the implementation of the Lean principles in the new product development. In addition, another important contribution of our paper resides in the empirical application of the framework to check for its robustness and real-world application.

Yours sincerely,

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A Framework for Selecting Lean Practices in Sustainable Product Development: the case study of a Brazilian Agroindustry

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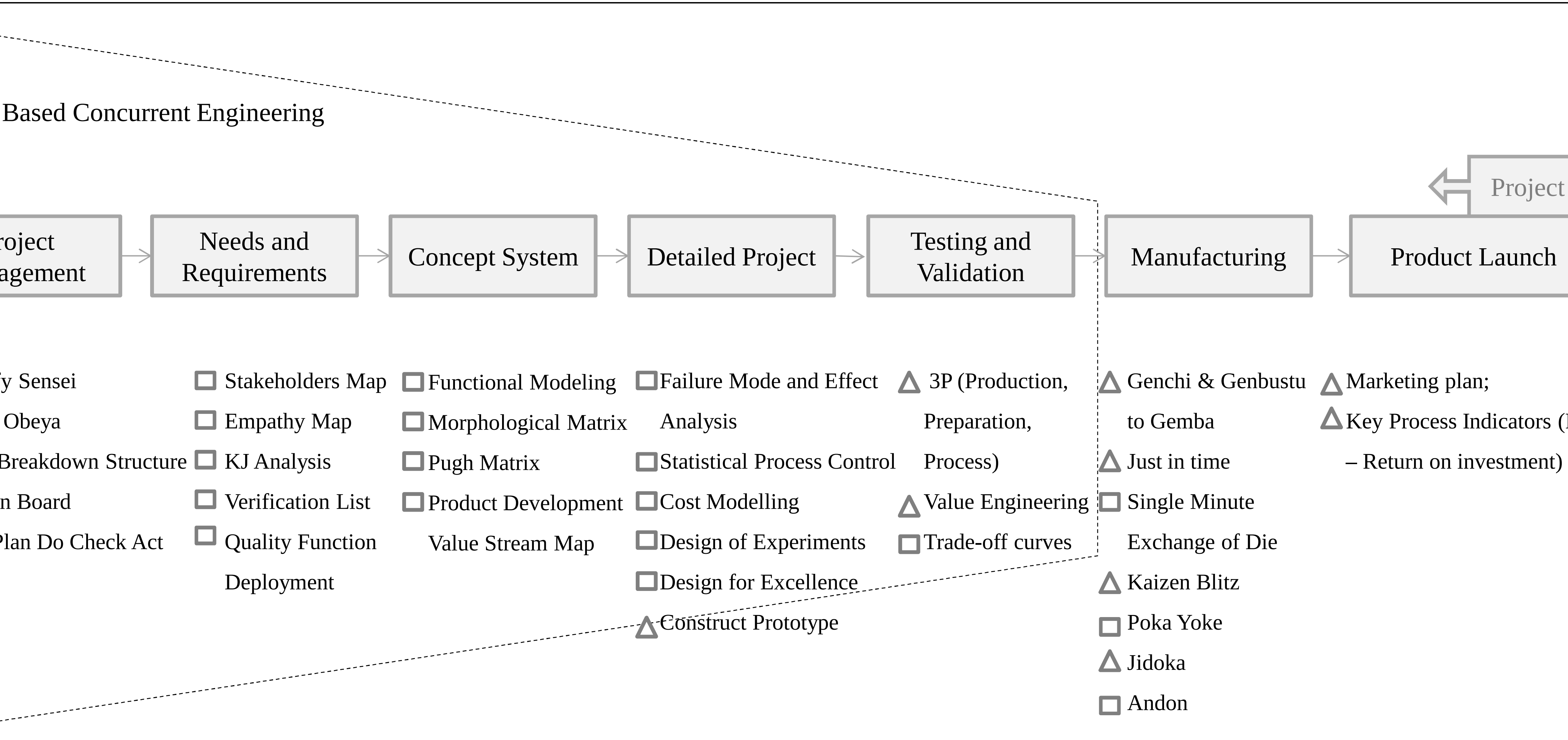

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Functional Modeling
Morphological Matrix
Pugh Matrix
Product Development Value Stream Map
Failure Mode and Effect Analysis
Statistical Process Control
Cost Modelling
Design of Experiments
Design for Excellence
Construct Prototype
3P (Production, Preparation, Process)
Value Engineering
Trade-off curves
Genchi & Genbustu to Gemba
Just in time
Single Minute Exchange of Die
Kaizen Blitz
Poka Yoke
Jidoka
Andon
Marketing plan;
Key Process Indicators (
– Return on investment)

Word count: 8.081

A Framework for Selecting Lean Practices in Sustainable Product Development: the case study of a Brazilian Agroindustry

ABSTRACT

Literature shows different forms of improving New Product Development performance for sustainable product innovation. To that end, Lean principles are widely disseminated as means for waste elimination, value proposition and continuous improvement in product development. Nevertheless, operationalizing the adoption of such principles requires knowledge regarding the adequate practices for each stage and the typology of the Lean Product Development. The available studies present practices focused on specific Lean practices in product development stages without a systemic vision of the process. This study's objective is to fill this gap by proposing a framework with tools and practices to be implemented throughout the Lean Product Development and by offering a customizable guide to implement the framework. The tools and practices addressing Lean Product Development were divided into phases, resulting in 17 studies and 42 tools/practices. We applied the proposed framework to the case of a fruit processing agroindustry to sustainably develop an innovative solution (Cationic, Anionic, Hydrophobic Modified Starch in Pre-Gel Form) for fruit preservation and to eliminate waste during the product development process. This study presents techniques and methodologies for the development of solutions for the agroindustrial sector. The development of this product was supported by Lean practices and tools, offering reusable knowledge, which preserved fruits for twice the shelf life. The proposed solution presented a 56-day preservation, which presents a 25% higher yield compared to the current best preserving solution (sulfur dioxide). In addition to eliminating the need to purchase a new equipment, since it comprises a similar process to the already existing ones in the fruit processing.

Keywords: New Product Development; Lean Product Development; Lean Practices; Sustainable Product; Agro-industrial.

1. Introduction

The success of organizations depends on the number of successful products they insert in the market (Hu et al., 2017). Seeking competitiveness, many companies have adopted innovation strategies focusing on innovative, highly qualified activities with great value (Marcon et al., 2017; Zhang et al., 2017). Product development (PD) is among these activities which provides products with resources, functions and technologies that contribute to satisfy customers' needs (Dobrotă and Dobrotă, 2018; Fraccascia et al., 2018). In this context, because they are characterized by pushed production, agricultural industries present innovation difficulties due to their products being derived from agriculture and livestock (Nagaratnam et al., 2016). These companies suffer a growing range of corporate pressures that directly impact their manufacturing operations (Bolaji et al., 2018).

The focus on value and waste elimination during the production processes proposed by the Lean Manufacturing principles is broadly known (Ward, 2007; Verrier et al., 2016; Kurilova-Palisaitiene et al., 2018). Fercoq et al. (2016) stated that Lean implementation is a natural process in the evolution of companies' maturity level since it aggregates benefits and eliminates wastes. However, Morgan and Liker (2006) reported that the Lean approach can be amplified beyond the focus on the improvement of processes and manufacturing operations by applying Lean principles, in areas such as Lean Innovation (Hoppmann et al., 2011; Welo et al., 2012), Lean Startup (Bajwa et al., 2016; Baldassare et al., 2017) and Lean Product Development (Gudem et al., 2014; Welo and Ringen, 2015).

Lean approach supporters have already emphasized the use of the methodology in distinct organizations, however companies still struggle to adapt the principles which were initially designed for manufacturing organizations to different contexts and objectives (Alhuraish et al., 2017). In this context, it is relevant to highlight the application of Lean in the New Product Development (NPD) as a new level of improvement in companies' process management which was named Lean Product Development (LPD). The main LPD topics approached by the authors identified in the literature were: wastes in PD processes (Nepal et al., 2011; Lidlöf et al., 2013), tools and techniques for LPD (Letens et al., 2011; Hoppmann et al., 2011; Tyagi et al., 2015) and LPD barriers (León and Farris, 2011).

In prior literature, few works have provided a more systemic approach by indicating Lean tools and practices in the NPD. The application of tools and practices is a way of implementing Lean principles and practices in the NPD. Such fact is supported by several authors (Haque and James-Moore, 2004; Cooper and Edgett, 2008; Letens et al., 2011). Thus, this study proposes a framework with tools and practices to be implemented throughout the LPD. Also, this study offers a customizable guide to the framework's application in different project typologies. The main contributions of this study are two-folded, namely: (i) to provide a guide to enable teams to select LPD practices for specific cases; and, (ii) the empirical application of the proposed framework in a real LPD case to provide evidence of its robustness and applicability in real settings.

Different from manufacturing companies, especially automotive industries, agroindustrial companies still perform some artisanal processes (Nuhoff-Isakhanyan et al., 2017). Research in this area still points to several sustainability-oriented opportunities, mainly in new versions of processes and product innovations with reduced use of natural resources (Skoronski et al., 2016; Souza and Alves, 2018). This case study brings the Lean perspective of waste elimination and the focus on value to the development of a solution that preserves fruit properties for longer periods of time avoiding fruit waste. The result from the LPD framework application in a fruit processing company led to the development of a modified starch which is an agroindustrial innovation with nontoxic and biodegradable characteristics by means of a chemical, physical modification grafted in the natural cassava starch (BeMiller and Whistler, 2009).

In sum, after this introduction, this study presents the LPD definition, practices and reference models from the literature review in Section 2. Afterwards, in Section 3, we discuss the methods used to the development of the LPD framework and explain the steps of the case study. Section 4 describes the application of the LPD framework to the development of an innovative solution to preserve fruits and eliminate wastes during the product development process of a fruit processing company. Finally, Section 5 explains the managerial implications of the LPD framework proposed by this study and, Section 6 concludes with a summary of the findings and presents the limitations and suggestions for future studies.

2. Literature Review

The traditional NPD presents several types of wastes (Ulrich and Eppinger, 2015). In order to optimize the NPD, Lean principles can be used in the identification of value, value flow, elimination of wastes and continuous improvement. The solution that makes product development more sustainable was named LPD (Haque and James-Moore, 2004). LPD comprises a set of tools and practices that must be designed to consistently execute PD activities in an efficient and effective way through the creation of reusable knowledge (Hines et al., 2006; Ward, 2007). In this sense, LPD is a knowledge job shop and, as such, it can be continuously improved through the use of tools that are adaptable to the repetitive manufacturing processes in order to eliminate wastes and synchronize malfunctioning activities (Rauniar and Rawski, 2012).

Rossi et al. (2012) suggested a five-step methodology to improve an existing LPD process: (i) to identify and assess wastes, (ii) to prioritize wastes, (iii) analyze the current situation at subprocess level, (iv) to analyze the critical situation of the sub processes and (v) to implement corrective actions. Regarding the LPD structure, Womack et al. (1991) identified four main LPD characteristics, namely: leadership, team work, communication and simultaneous development. Similarly, Morgan and Liker (2006) described a systemic approach for LPD in which thirteen principles are distributed in three subsystems (processes, skilled personnel and, tools and technologies) which constantly interact with each other. According to the authors, the successful application of these principles enables meeting sustainable results that will support the company’s competitive advantage.

Several methods have been proposed to improve the conventional PD process, nevertheless, such methods do not match the innovative improvements observed in LPD (Morgan and Liker, 2006; Letens et al., 2011). The application of LPD focuses on suggesting solutions and countermeasures based on the analysis of wastes and losses in the current product development process (Hines et al., 2006; Johansson and Sundin, 2014). However, tools and techniques focused on the integration and coordination of the product development are essential to improving the company’s internal flow as a whole (Letens et al., 2011; Rauniar and Rawski, 2012).

As for the Lean practices, Ciccullo et al. (2018) reported that the literature is rich in notable contributions that define the pillars of Lean Manufacturing. Wang et al. (2012) stated that there are three main necessary aspects to establish the LPD: (i) experience for design collection and feedback tools/techniques, (ii) product design, development tools and techniques and (iii) chief engineer and organization tools/techniques. Womack et al. (1991) identified a set of the main LPD practices, namely, the existence of project managers, multifunctional teams, set-based concurrent engineering and decision-making involving all team members. Table 1 presents the frequency of LPD tools and practices addressed by 17 authors who proposed LPD structured frameworks, which were essential for the development of a new framework. In the last column on the right we report the number of times each tool is used in the articles selected.

Table 1: Lean Product Development practices

LPD Practices	Ward et al. (1995)	Sobek et al. (1998)	Sobek et al. (1999)	Kennedy (2003)	Oliver et al. (2004)	Haque and James-Moore (2004)	Kato (2005)	Morgan and Liker (2006)	Ward (2007)	Cooper and Edgett (2008)	Kennedy et al. (2008)	Oehmen and Rebentich (2010)	Bergmann (2010)	Oppenheim et al. (2011)	Letens et al. (2011)	Khan et al. (2011)	Wang et al. (2012)	**Total**
Chief Engineer (Shusa)	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X	15
Trade-off curves	X		X	X	X		X	X	X		X	X	X	X	X	X	X	14
Construct Prototype	X	X	X	X		X	X	X	X	X		X			X	X	X	13
Verification List	X	X	X	X		X		X	X		X		X	X		X		11
Report product performance	X	X	X	X					X	X		X	X	X	X		X	11
Portfolio Management		X		X	X	X			X	X	X	X			X	X		10

Set-Based Concurrent Engineer	X			X		X	X	X	X		X				X	X	X	10
Life cycle assessment		X						X	X	X		X	X		X	X	X	9
Work Breakdown Structure	X	X	X	X			X		X			X		X			X	9
A3-Plan-Do-Check-Act		X		X		X		X	X		X		X			X	X	9
Quality Function Deployment	X	X	X			X		X							X	X	X	8
DfX (Design for Excellence)					X	X	X	X	X					X		X	X	8
Stakeholder Map						X		X				X		X	X	X	X	7
A3 Report		X				X		X	X		X		X			X		7
Install Obeya				X				X	X		X		X			X		6
Kanban Board	X							X					X	X	X		X	6
Pugh Matrix			X		X			X			X					X	X	6
Key Process Indicators										X	X	X		X	X		X	6
Kaizen Blitz				X				X					X		X	X		5
Genchi and Genbustu to Gemba				X				X	X				X			X		5
Report Discontinuation Product	X									X			X	X	X			5
Nemawashi			X					X					X			X		4
Functional Modeling	X	X						X								X		4
Value Engineer	X		X					X									X	4
Hansei								X			X		X			X		4
Failure Mode and Effect Analysis								X				X		X		X		4
Jidoka								X					X			X		3
Just in time	X												X	X				3
Product Development Value Stream Map			X							X					X			3
SPC (Statistical Process Control)				X					X				X					3
DOE (Design of Experiments)						X				X				X				3
Poka Yoke												X	X				X	3
Identify Sensei	X								X									2
Morphological Matrix	X												X					2
Cost Modelling											X			X				2
Andon										X					X			2
Single Minute Exchange of die										X					X			2
BCG Matrix		X																1
Marketing Plan												X						1
Empathy Map	X																	1
KJ Analysis (Affinity Diagram)																X		1
3Ps (Preparation/Product/Process)								X										1

The chief engineer leadership is cited by 15 out of the 17 authors studied in Table 1. The chief engineer (*Shusa*) follows a shared view of the company and is responsible for the selection of projects to be developed and the products to be produced and marketed (Matsui et al., 2007). Deng et al. (2017) emphasized that the execution of trade-off curves enables sensitivity analysis to predict the system behavior under different configurations, as cited by 14 authors.

In the operations management field, frameworks are instruments used to discuss the methodology to be followed to reach the organization's objectives (Boone et al., 2017). In order to implement the LPD principles in an industry, several researchers, practitioners and consultants have proposed different structured frameworks to organize the LPD process. These frameworks provide support to reach organizational targets in the product development field and to meet consumer needs. Table 2 presents the LPD phases as cited by the authors that introduced such phases in the studies analyzed.

Table 2: Lean Product Development phases

LPD phases	Ward et al. (1995)	Sobek et al. (1998)	Sobek et al. (1999)	Kennedy (2003)	Oliver et al. (2004)	Haque and James-Moore (2004)	Kato (2005)	Morgan and Liker (2006)	Ward (2007)	Cooper and Edgett (2008)	Kennedy et al. (2008)	Oehmen and Rebentich (2010)	Bergmann (2010)	Oppenheim et al. (2011)	Letens et al. (2011)	Khan et al. (2011)	Wang et al. (2012)
Strategies and Portfolio	X		X					X	X	X		X	X	X	X	X	X
Project Management										X	X		X		X	X	X
Needs and Requirements	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Concept System	X	X	X	X	X		X		X	X	X		X		X	X	X
Detailed Project				X		X		X	X		X	X	X	X	X	X	X
Testing and Validation	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X
Manufacturing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Product Launch			X	X		X	X	X			X	X			X	X	X
Monitoring and Discontinuity						X		X		X		X			X	X	X

The Needs and Requirements and the Manufacturing phases were used by 17 authors, followed by the Testing and Validation phase (15 authors). The phases proposed in the LPD process models analyzed (Table 2) act as the basis to connect the practices and tools (Table 1) within the framework presented in this study.

3. Method

For the integration of practices and phases, we searched for the key activities in each tool. We also used the models of Morgan and Liker (2006) [LPD], Ward (2007) [LPD] and Ulrich and Eppinger (2015) [NPD] as the basis. For the selection of LPD practices, we used the Diamond framework of Shenhar and Dvir (2007), which, through the set of dimensions, assesses the complexity and uncertainty of targets, activities and the environment where the project is inserted and, thus, adapts it to the necessary typology. Figure 1 presents the methodological sequence followed by this study as well as the description of each step.

Based on the authors presented in Table 1, we developed a customizable LPD framework by grouping similar phases, tools and practices previously cited. The result comprises four macro phases and nine phases, namely: Front End (Strategies and Portfolio), Project (Project management, Needs and Requirements, Concept System, Detailed Project, Testing and Validation, Manufacturing and Product Launch) and Post Development (Monitoring and Discontinuity). As Figure 2 shows, the LPD framework presents customizable tools and practices based on product typology.

Phase 1
Selection of Lean Product Development models and the identification of practices, tools, and phases for the framework development

Phase 2
Integration practices and phases for the design of the Lean Product Development framework and selection of practices and phases for the design of the Lean Product Development framework

Phase 3
Testing and validation of the Lean Product Development framework proposed

To select the phases of the Lean Product Development base model, we used the models of Morgan and Liker (2006), Ward (2007) and Ulrich and Eppinger (2015) as reference.

Databases searched: Science Direct; Emerald, EBSCO, Springer, Taylor and Francis;
Keywords searched: lean product, new product development, lean product development, lean practices, framework;
Selected articles: 17;
Tools and practices identified: 42.

Key activities were searched in each tool and the models of Morgan and Liker (2006), Ward (2007), Ulrich and Eppinger (2015) were used to integrate practices and phases

Diamond framework of Shenhar and Dvir (2007) to assess the complexity and uncertainty of targets, activities, project's environment and the adaptations needed for typology

Lean Product Development Framework presents customizable tools and practices based on product typology

Application of the Lean Product Development framework in a fruit processing agroindustry for the sustainable development of a solution to reduce fruit waste.

The project was developed with direct contact with the Research & Development and Marketing managers of the fruit processing company through biweekly visits to the agro industrial company located in the state of Paraná – Brazil.

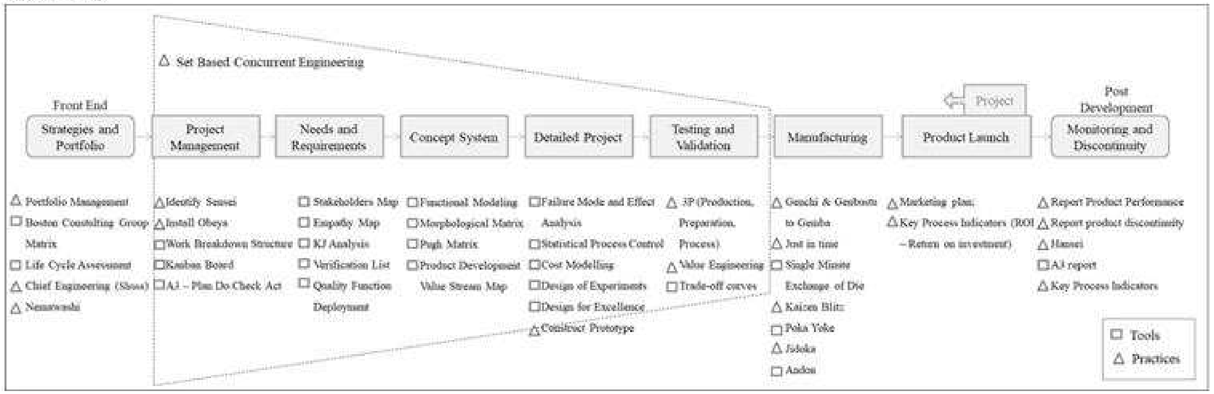


Figure 1: Research design and methodological steps

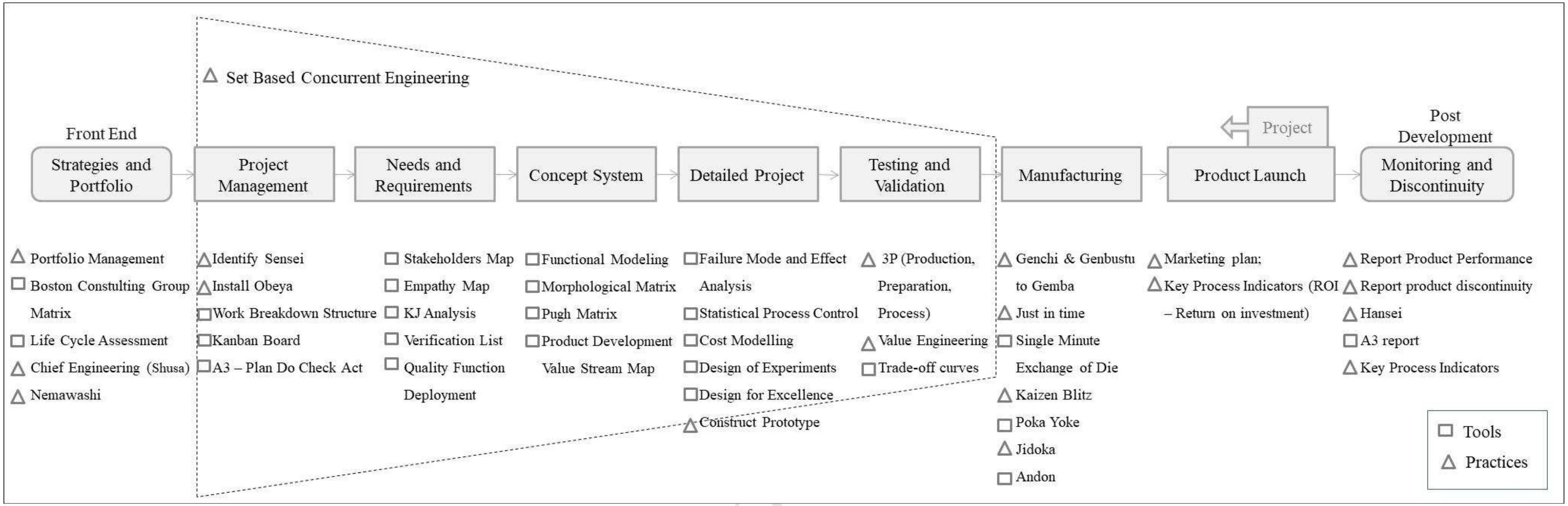


Figure 2: Lean Product Development Framework proposed

The detailed processes of the LPD framework along with the main activities are presented in Table 3.

Table 3**:** Association of the practices and tools to the LPD phases

Phase	**Main Activities**
Strategies and Portfolio	To select possible projects (Portfolio Management); to evaluate the projects to be developed (BCG Matrix); to quantify the product's environmental impacts (Life Cycle Assessment); to choose the best projects to be developed (Chief Engineering); to stablish the basis of the projects' propositions (Nemawashi)
Project Management	To identify the project leader (Identify sensei); To install a big project room (Install obeya); To subdivide the deliverables (Work Breakdown Structure); To optimize workflow (Kanban Board); To identify the premises and the solutions (A3-PDCA)
Needs and Requirements	To map the stakeholders involved (Stakeholder Map); To determine stakeholders' needs (Empathy Map); To group information based on affinity (KJ Analysis); To design a checklist for easy data collection (Verification list); To quantify the requirements that meet consumers' needs (Quality Function Deployment)
Concept System	To define the function of system's internal processes with the aid of data flow diagrams (Functional Modelling); To develop sets of concepts with alternatives (Morphological Matrix); To compare several concepts and choose the best one (Pugh Matrix); To assess product value stream and its takt time (Product Development Value Stream Mapping)
Detailed Project	To systematize a group of activities to detect possible failures and evaluate their effects on the project/process (Failure Mode and Effect Analysis); To monitor and control the projects in order to obtain a product in conformance (Statistical Process Control); To reduce costs and estimate elements with validated principles (Cost Modelling); To plan the experiments in order to define data to be collected in a given experiment enabling higher statistical precision and lower costs (Design of Experiments); To define the design for each sector of the project development (Design for Excellence); To develop the prototype in a practical and intelligent manner (Construct Prototype)
Testing and Validation	To design an experiment with the project team and to arrange the production process to assess the best project according to lead time, productivity, safety and cost aspects (3 P's – Presentation, Practice and Production); To apply value engineering concepts to attain the highest product value at the lowest cost (Value Engineering); To analyze interaction charts to evaluate the best project (Trade-off curves); The Shusa must choose the best project.
Manufacturing	Sensei and their team must tour the shop floor to identify problems in the source (Genchi and Genbutsu to Gemba); To determine what must be produced, transported and bought in the right time (Just in Time); To reduce equipment setup time, minimizing unproductive periods in the Gemba (Single Minute Exchange of Die); To gather employees of several sectors during a week in order to identify and improve processes (Kaizen Blitz); To implement foolproof mechanisms to avoid errors and defects in the production process and in the execution of activities (Poka Yoke); Process autonomation where the operator controls the gemba (Jidoka); Signs of process productivity and process failures (Andon)
Product Launch	To develop the sales, distribution and market launch plan (Marketing plan); Assess return on Investment (Key Process Indicators – Return of Investiment); Product Launch
Monitoring and Discontinuity	To describe the product's market performance (Report Product Performance); To register the product life plan for discontinuity (Report Product Discontinuity); To reflect on the project to admit errors (Hansei); To fill in the A3 report based on the hansei and to propose solutions to the problems and the key results (A3-Report); To measure the LPD performance indicators (Key Process Indicators)

Analyzing Table 3, we observe that the main activities depend on the project/product type, where the activities to be performed in each phase of the LPD framework are presented. The framework application deliverables are the following: the product to be developed, product launch and product discontinuity. Projects that use the Set-based Concurrent Engineering approach must develop for each project from the Project Management to the Testing and Validation phases.

There are project typologies to evaluate which practices and tools should be used in the projects to be developed. The Diamond Framework of Shenhar and Dvir (2007) is a framework composed of four axis/dimensions which comprise three or four project types, namely: Novelty (derivate, platform or assembly), Technology (low-tech, medium-tech, high-tech or superhigh-tech), Complexity (assembly, system, or array) and Place (regular, fast/competitive, time-critical or blitz). Project types are marked on the semi-axles of a Cartesian plane, where each project type refers to a dimension, thus forming a diamond.

Several characteristics define the project type. This study will consider the Diamond Framework variables proposed by Shenhar and Dvir (2007), where the authors propose a multidimensional view to adapt the reference model to the singularities of each project. The dimension set assesses the complexity and uncertainty of the targets, activities and the environment where the project is inserted.

For the validation of the framework, we looked for an agroindustry interested in developing products in a sustainable way. A fruit processing company with fruit waste issues was selected. We directly contacted the company's CEO, who showed interest in implementing Lean aspects in the product development process. We conducted an unstructured interview to map the current process, to identify the problems and to propose countermeasures for the project.

4. Results

4.1. Introduction to the case study and the proposed LPD framework

The case of this study is derived from a project to test the LPD framework in a fruit processing company in the state of Paraná - Brazil. The company is responsible for processing approximately 200 thousand tons of food per year, where 155 thousand tons are of fruit and 45 thousand tons are vegetables.

The company's portfolio is composed of projects of fruit and vegetable production and transport. This agroindustry has sought to implement the Lean philosophy in its manufacturing processes and in its product development processes in a sustainable manner.

Currently, fruit preservation in the company follows a sanitization process with Sodium Hypochlorite ($NaClO$) and the application of a natural cassava starch, both cooked at a 10% solution in water. Nevertheless, this is an inefficient process since the company has a 31% product waste rate. The demand for a product that eliminates fruit waste is justified since Brazil is the third greatest fruit producer in the world, with an estimated production of 44 million tons in 2017. In addition, it is estimated that 40% of the fruit production will deteriorate before consumption (IBGE, 2017).

4.2. Strategies and Portfolio

This phase aims to describe the company's product portfolio and the demand for new products, in addition to studying the strategies for successful products (Kirilova and Vaklieva-Bancheva, 2017). Since the company's project is characterized by a Platform novelty project type, the BCG Matrix is of extreme importance since it positions products that already exist in the market in quarters and, thus, maps opportunities to save money considering the best alternative (Sobek et al., 1998; Letens et al., 2011).

Table 4 presents the BCG Matrix of the projects that can be developed by the company and the respective fruit preservation time proposed by the marketing department, evaluating the alternative with the best performance.

Table 4: BCG Matrix of the existing products

		Relative Market Share	
		High	Low
Market Growth	High	Cationic, Anionic, Hydrophobic Modified Starch in Pre-Gel Form (CAHMSPGF) – **56 days**	Ionic Radiation – **35 days**
		Sulfur Dioxide – **42 days**	Carnauba starch biofilm – **35 days**
		Wax coupled with carbenzadin (0,1%) – **30/48 days**	
	Low	Pinion starch biofilm – **28 days**	Lobo fruit starch biofilm – **21 days**

Based on Table 4, the strategic planning team of the agroindustrial company performed the portfolio management (Oehmen and Rebentich, 2010; Letens et al., 2011), where they selected the Cationic, Anionic, Hydrophobic Modified Starch in Pre-Gel Form (CAHMSPGF) method due to its highest relative market share and considering that in previous experiments the method preserved the fruit for the longest period of time (56 days). The draft of this study defined this type of preservation method because it presents financial feasibility and due to its similarity to the current fruit biofilm application method used by the company. The other preservation methods were not chosen because the film application processes were different from the current processes in the fruit processing company.

4.3. Project Management

This step refers to the application of knowledge, skills, tools and techniques to project activities to meet the project requirements (Marcelino-Sabada et al., 2015). After the choice of the product to be developed, we applied the Diamond Framework to identify the project typology under study, which represents the project category under development by the fruit processing company (Shenhar and Dvir, 2007).

To choose the product to be manufactured, this case study applied a simplified version of the LPD framework as presented in Figure 3, where practices and tools of the Front End and Project macro phases were selected. To illustrate the use of the framework, some tools will be discussed in this study. We chose the Front End and some phases of the Project macro phase to analyze the solution to be manufactured.

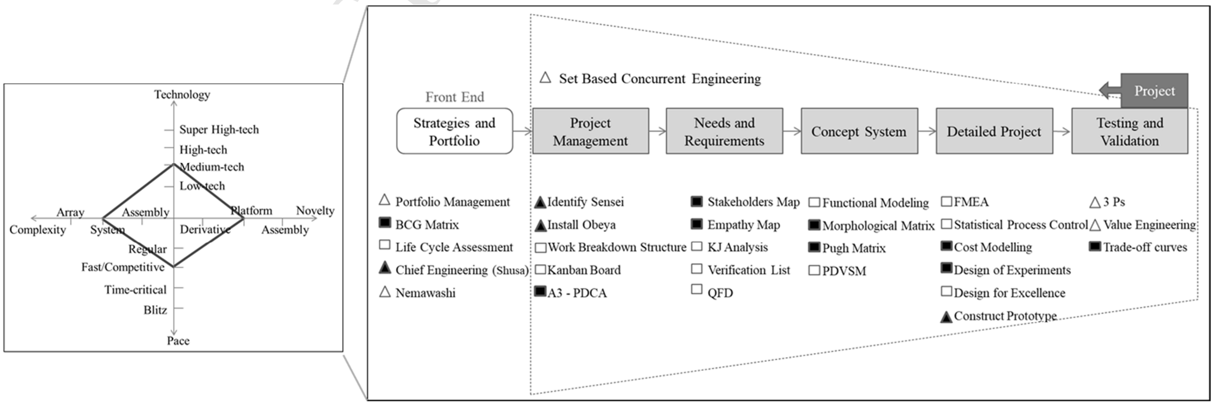


Figure 3: Diamond Framework and illustrative LPD framework

The product development project is classified as mild in novelty and complexity for the agroindustry, project developing time is fast (seasonal crops) and the product has intermediary level of technology, since it is similar to the current process of the company (sanitized fruit and cooked starch biofilm), according to the project team. Figure 3 presents the tools and practices to be applied to the fruit processing company's project. The company's marketing manager was chosen as the sensei due to the project's system complexity (Ward et al., 1995; Ward, 2007).

The obeya room is the place where the team members shared project information aiming to assist the team to identify multifunctional teams and issues (Kennedy, 2003; Morgan and Liker, 2006; Bergmann, 2010; Khan et al., 2011). Since the project's novelty was defined as Platform, it is essential to apply the A3-PDCA tool (Figure 4), which is composed of seven elements oriented by the continuous improvement learning cycle (Kennedy et al., 2008; Khan et al., 2011; Wang et al., 2012).

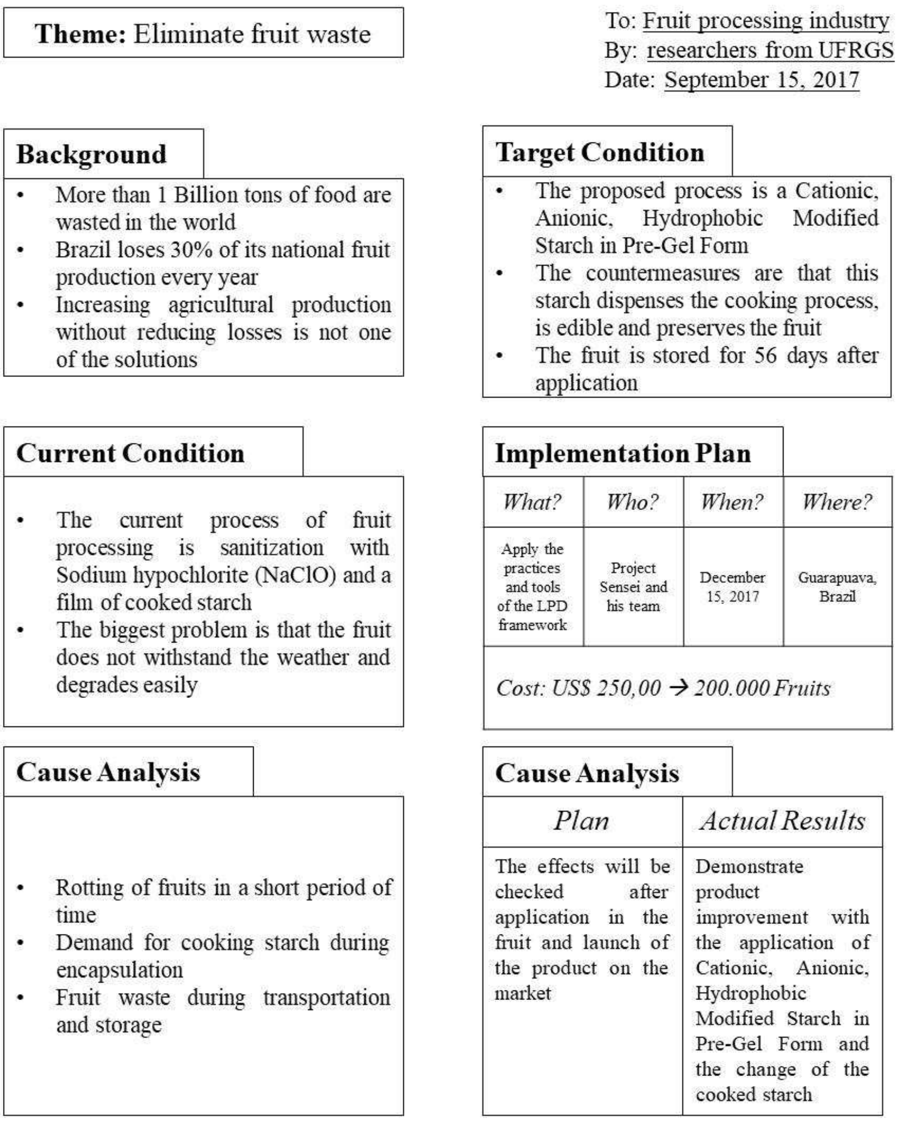


Figure 4: A3-PDCA of the case study

The A3-PDCA assessed the fruit waste issue in Brazil and in the world and the current situation of the fruit processing company, as well as the causes of the problems. Besides, we proposed a CAHMSPGF biofilm for fruit preservation and planned its implementation.

4.4. Needs and Requirements

Needs and Requirements is a phase that aims at the understanding of consumers' needs in technical requirements, which demands dialogue between the different teams involved (Majava et al., 2014). Since this is a platform novelty project, it is necessary to develop the stakeholders map to identify the main parties involved in the project (Haque and James-Moore, 2004; Oehmen and Rebentich, 2010) and the empathy map to identify what the user is feeling (Ward et al., 1995; Moul et al., 2012).The tools are shown in Figure 5 and Figure 6 respectively.

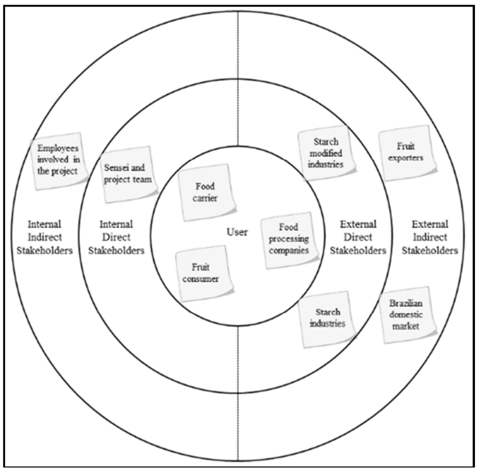


Figure 5: Stakeholders Map

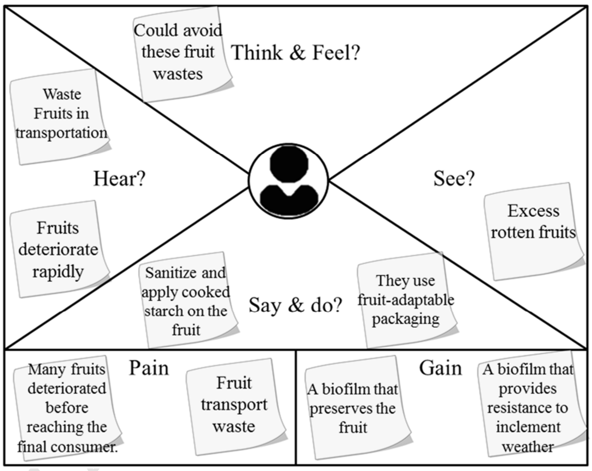


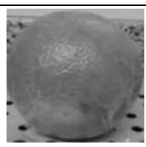
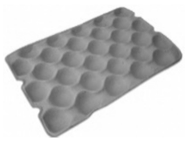
Figure 6: Empathy Map

The stakeholder map suggests that the product users are: fruit processing companies, shipping companies and fruit's final consumers. After the users have been recognized, the empathy map identified what the consumers demand from a biofilm that preserves fruit and provides resistance to weathering.

4.5. Concept System

Concept System assesses the needs and the requirements demanded by consumers with the aim to market the product in time, within budget and according to the required specifications (Bhuiyan, 2011). Since the project presents a System complexity level, it is important to develop the morphological matrix as presented in Table 5 (Bergmann, 2010; Álvarez and Ritchey, 2015).

Table 5: Morphological Matrix

	Main solution 1	Main solution 2	Main solution 3
To preserve the fruit			
To adapt to the fruit type			
To pack the fruit			

The morphological matrix identified users' demand for preserving, packaging and adapting to the type of fruit. Therefore, since the project presents an intermediate technology level, the Pugh matrix was applied (Table 6) which is formed by the scale of importance weighting (from 1 to 5, being 5 very fundamental and 1 little fundamental) to evaluate product requirements established by the consumer (Ulrich and Eppinger, 2015).

Table 6: Pugh Matrix

Criteria	Requirements	Importance Weight	Concept 1 (Biofilm/ Fruit without pit/ Cardboard sheets)	Concept 2 (Vacuum/ Fruit with pit/ Wrapped in paper)	Concept 3 (Preserve/ Sensitive fruit/ In boxes)
Demand from the external client	Reduced expenses with energy for refrigeration	2	1	0	1
	Ease of unpacking/unwrapping	3	1	0	-1
	Increase in the selling price	5	1	1	0
	Maintain flavor	4	1	1	0
	Fruit suitable for consumption	5	1	1	-1
Demand from the internal client	Supplier's availability of raw material	4	1	0	0
	Compatibility with existing processes	3	1	0	0
	Existence of a national supplier	3	1	0	0
	Small number of new items	2	1	0	-1
Demands from the intermediate client	Ease of transportation	3	1	1	0
	Ease of storage	3	1	1	0
	Adaptability to the current situations	4	1	0	-1
Costs	Comparison with the target cost	3	1	1	0
	Norm/legislation compliance	2	1	1	0
		Sum	46	25	-12

Through the Pugh Matrix, concept 1 was chosen (Fruit without pit with biofilm and packaged with cardboard sheets) for it presented the best evaluation and it is similar to the existing one in the fruit processing company.

4.6. Detailed Project

The Detailed Project phase investigates the financial feasibility and evaluates the physical-chemical properties of the products under development (Bhuiyan, 2011). Cost modelling, where the price and quantity to develop a new product/service are assessed is necessary due to the project's fast and competitive rhythm (Oppenheim et al., 2011; Al-Roomi et al., 2013). Table 7 presents cost modelling to produce a ton of CAHMSPGF, presenting the necessary material, the quantities and prices.

Table 7: Cost Modeling

Product	Quantity (S.I)	Price (US$)
Cassava Starch	869 Kg	630,85
AKD (Alkyl ketene dimmer)	100 Kg	132,20
Monochloroacetic acid	30 Kg	204,77
3-chloro 2-hydroxypropyl trimethylammonium chloride	1 L	117,94
Total	1 Ton	1,085.76

The cost to produce a ton of CAHMSPGF is US$ 1,085.76. This starch undergoes a pregelatinization process, exempting the cooking process, requiring a H_2O solution of 10% to 100 m³. This solution can preserve up to 2 million fruits.

The Design of Experiments technique is important for projects of intermediary technology levels, comprising an efficient approach to optimizing chemical processes (Cooper and Edgett, 2008; Weissman and Anderson, 2015). The objective of this tool is to assess whether the viscosity of the starch is related to the modification of the starch type (Factor A) and to the starch's pH-value (Factor B). The response variable of the experiment is the starch's viscosity in seconds (s).

This variable presents the characteristics of the type: the more stable, the better. These characteristics arise from starch applications in industries that demand a smaller variability rate (absolute difference between the maximum and the minimum rates) in the raw material's viscosity. The control factors are the type of starch (A) at two levels and the starch's pH (b) at 12 levels.

Viscosity data was retrieved with the help of a 5 mm Ford viscosity measuring cup and two burettes (HCl and NaOH 2%), both placed on a tripod for the addition of the solution rates. The control of pH variation occurred by adding ± 2 mL rates of HCl to reduce pH and ± 2 mL of NaOH 2% to increase pH. The experiment was carried out twice and the results of the viscosity tests versus pH are presented in Table 8.

Table 8: Viscosity versus pH test of Natural Starch and CAHMSPGF

		Natural Starch's Viscosity (s)		CAHMSPGF's Viscosity (s)	
pH type	pH	Exp. 1	Exp. 2	Exp. 1	Exp. 2
Basic	11.25	58.46	57.52	5.30	5.29
	11	61.32	60.24	5.37	5.34
	10	69.54	68.48	5.52	5.48
	9	74.61	73.54	5.88	5.83
	8	89.43	88.75	6.45	6.37
Neutral	7	102.27	101.58	6.58	6.53
Acid	6	122.49	121.35	6.74	6.72
	5	147.32	146.52	7.34	7.31
	4	162.46	158.14	7.40	7.41
	3	80.61	82.52	7.87	7.82
	2	63.12	65.78	8.02	7.98
	1	39.27	41.95	8.71	8.68

Table 9 presents the experiment's two-way ANOVA.

Table 9: Two-way ANOVA of the experiments

Variance Source	Sum of Squares	Degrees of freedom	Mean Square	F value	p-value
Type of starch	81286.89	1	81286.89	89109.80	0.000
pH	15218.17	11	1383.47	1516.61	0.000
Interactions	14947.79	11	1358.89	1489.67	0.000
Error	21.89	24	0.91		
Total	111474.74	47			

Data from Table 9 show that the main effects and the interaction between type of starch and pH factors is significant regarding the viscosity response variable (p value = 0.000), that is, the types of starch are distinct. The chart in Figure 7 presents the average viscosity rates of each pH level for both types of starch. The scale in the horizontal axis is inverted to portray pH evolution from basic (11,25) to acid (1). Due to the type of the current study and to the "the more stable, the better" characteristic of the response variable, the multiple comparison of means was essential. This is due to the fact that a direct amplitude analysis between the minimum and the maximum starch viscosity rates was necessary. In addition, the chart shows that CAHMSPGF is indicated to be used in industries. Due to the "the more stable, the better" factor of the starch's viscosity, the simple linear model of low angular coefficient (a slight inclination of the line) explains the viscosity behavior of CAHMSPGF in relation to the pH variation and is the desired model, since it is the best fit for this end.

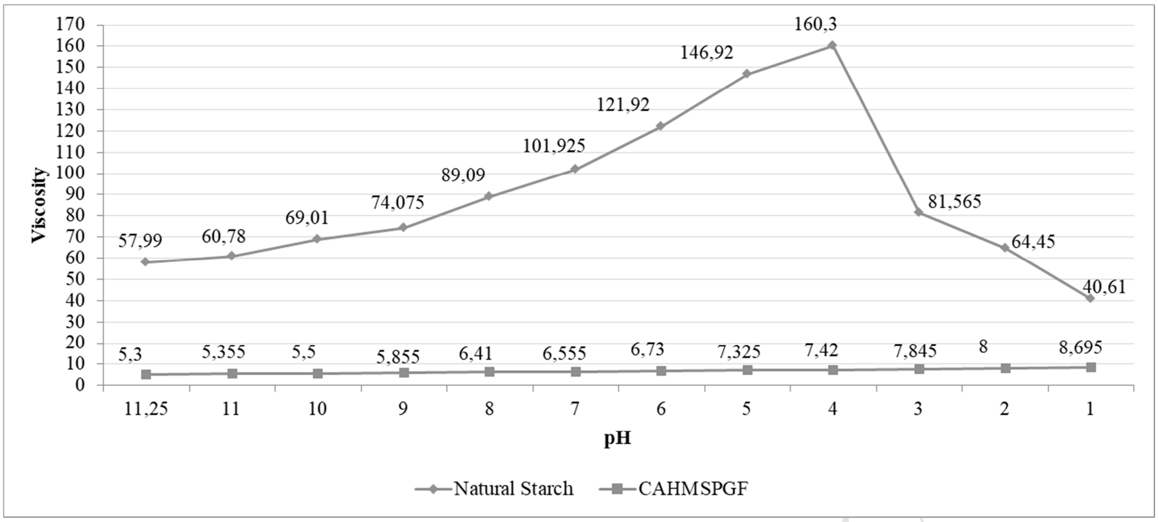


Figure 7: The average viscosity rates of each pH level for Natural Starch and CAHMSPGF

Developing the product prototype is very important since the project is the Platform novelty type, where a prototype is a way of presenting the product under development in the best possible manner (Letens et al., 2011; Wang et al., 2012). Two cases were performed to assess the duration of fruit preservation (sanitized fruit and sanitized fruit with CAHMSPGF biofilm). To that end, fruits were sanitized with 2 mL of chlorine to 1000 mL of water and they were left to rest for 10 minutes to dry. Afterwards, the mixture of CAHMSPGF with water (composed of 100g of starch to every 1000 mL of water) was carried out.

Next, the fruit was brushed with the mixture. The mixture coating was approximately 0,1mm thick and the fruits were stored at room temperature (25ºC). The experiment was observed daily throughout 56 days by means of pictures and notes. The experiment was performed three times and it is presented in Table 10.

Table 10: Fruit condition of freshly harvested fruit and the fruit after 56 days

Sanitized fruit		Sanitized fruit with CAHMSPGF biofilm	
Freshly harvested	After 56 days	Freshly harvested	After 56 days
			

There was no considerable change between the freshly harvested fruit with the CAHMSPGF biofilm and the fruit after 56 days, because the protective layer assured fruit impermeability thus freeing it from the contact with moisture and other contaminants. Nevertheless, the fruit that was only sanitized presented changes, completely rotting and eliminating the presence of the fruit liquid.

4.7. Testing and Validation

The Testing and Validation phase investigates whether the project under development will or will not take the product to the manufacturing phase (Ulrich and Eppinger, 2015). Trade-off curves are important tools for this project since it present intermediary technology, facilitating the decision of whether the product will join the process manufacturing (Morgan and Liker, 2006; Ward, 2007). The physical-chemical analysis was carried out three times with the sanitized fruit (freshly harvested and after 56 days) and with the sanitized fruit with CAHMSPGF biofilm (freshly harvested and after 56 days) as displayed in Table 10, where the brix concentration, the density, the mass, the diameter and pH were identified. This experiment is presented in Table 11.

Table 11: Experiment with sanitized fruit and with sanitized fruit with CAHMSPGF biofilm

		Sanitized fruit		Sanitized fruit with CAHMSPGF	
Material used	Type of Analysis	Freshly harvested	After 56 days	Freshly harvested	After 56 days
Refractometer	Brix concentration (g/mL)	10.7	*	10.18	9.32
Densitometer	Density (kg/m^3)	9.4	*	9.38	8.85
Pachymeter	Diameter (cm)	14.12	8.52	13.74	13.68
pH meter	pH (mol/L)	3.59	*	3.63	4.19
Analytical Balance	Mass (g)	192.8	38.6	187.9	182.6

* Not measured since the sanitized fruit did not present any liquid after 56 days.

These results show that the sanitized fruit lost 80% of its initial mass, whereas the sanitized fruit with the CAHMSPGF biofilm reduced only 2,82% of the initial mass. Afterwards, the trade-off curves were executed to identify the variations of the physical-chemical analysis of the product. Figure 8 presents the trade-off curves.

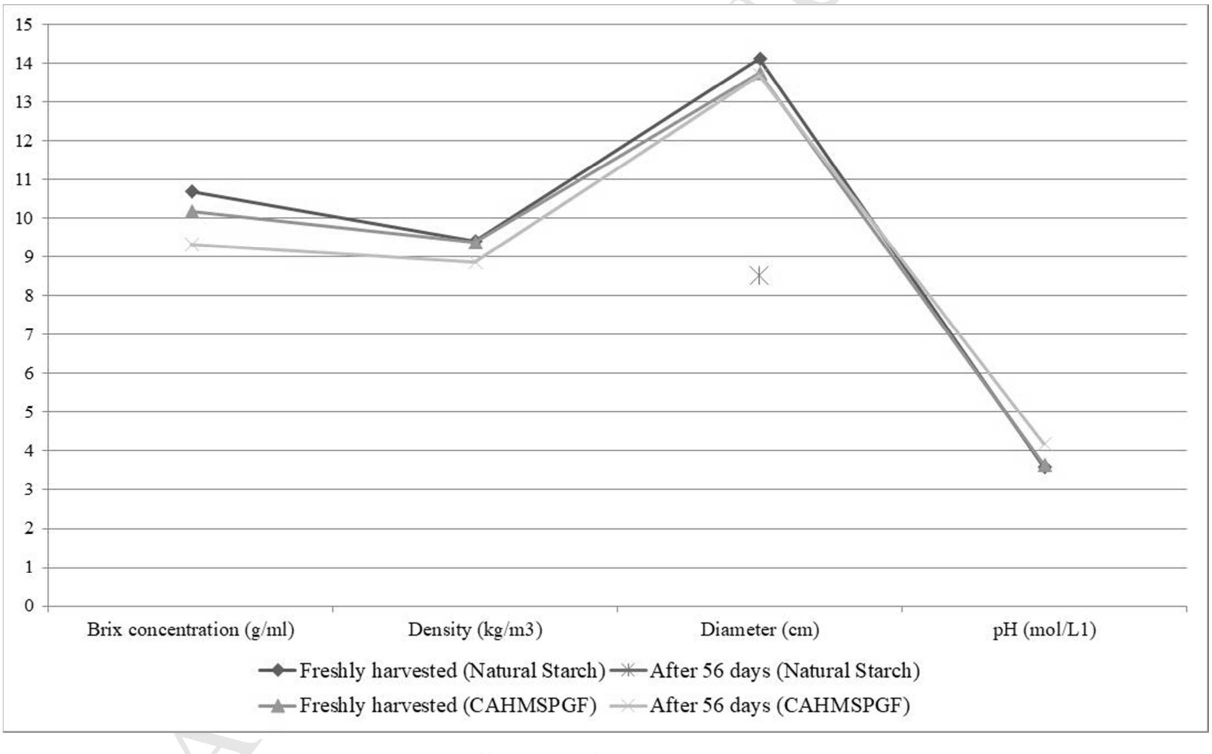


Figure 8: Trade-off curves of the physical-chemical analysis

The sanitized fruit with the CAHMSPGF biofilm presented stability in the physical-chemical analyses, yet the sanitized fruit after 56 days did not allow measuring pH, density and brix concentration since the fruit did not present any juice (liquid). Thus, the managers decided to choose the CAHMSPGF to proceed to the manufacturing phase.

5. Implications

The case study enabled the use and application of the framework in agroindustries, as demonstrated by the adoption of the fruit processing company. Especially, the framework has the potential of developing products along with the Lean methodology, contributing to the increase of fruit processing company's economic benefits and to increasing the environmental impact of the product's full life cycle.

Next, we present the implications to assist industry managers to make more effective decisions about product life cycle. Initially, we found that the LPD framework proposed is adaptable to the type of project to be developed. Companies that intend to develop products can employ the Set Based Concurrent Engineering practice by developing various products in parallel, thus, at times, avoiding rework. Therefore, the framework proposed can be implemented in several industrial sectors, supporting a sustainable inclination to the product life cycle.

After a deeper investigation, the fruit processing company's case study enables concluding that the current application of the framework can be extended to benefit other companies. According to the LPD framework proposed, processes can be executed more efficiently in manufacturing organizations. Lastly, the Shusas of other manufacturing companies can use hansei in the projects to diagnose the company's current wastes and to propose countermeasures. The proposed framework predicts the possibility of developing optimized products and to eliminate waste in manufacturing companies. The application of Lean practices makes processes more experimental and serves as an example to the transformation of agroindustrial processes toward more sustainable operations.

6. Conclusions

In view of the objectives proposed, we designed a framework with tools and practices throughout the LPD, along with a customizable guideline for the implementation of the Lean principles in the NPD. These guidelines empower the team to select practices according to the project typology based on the Diamond framework. To test the framework, we applied it to a fruit processing company to the development of CAHMSPGF for fruit preservation and waste elimination.

The application of this case demonstrated the application of Lean principles in the PD process. The framework contributed to the application of this improvement project by developing a new product that is similar to the existing one. The physical-chemical and the economic feasibility of the new product were also assessed.

This study contributes to the development of a didactic perspective to the process, assisting in the implementation of the LPD, leveling Lean knowledge and facilitating the learning and the systemic implementation of the Lean tools and practices applicable to the PD process of agroindustries and other fields of the manufacturing industry. In future studies, we intend to disseminate and replicate the knowledge both in agroindustries and in the teaching of Lean practices.

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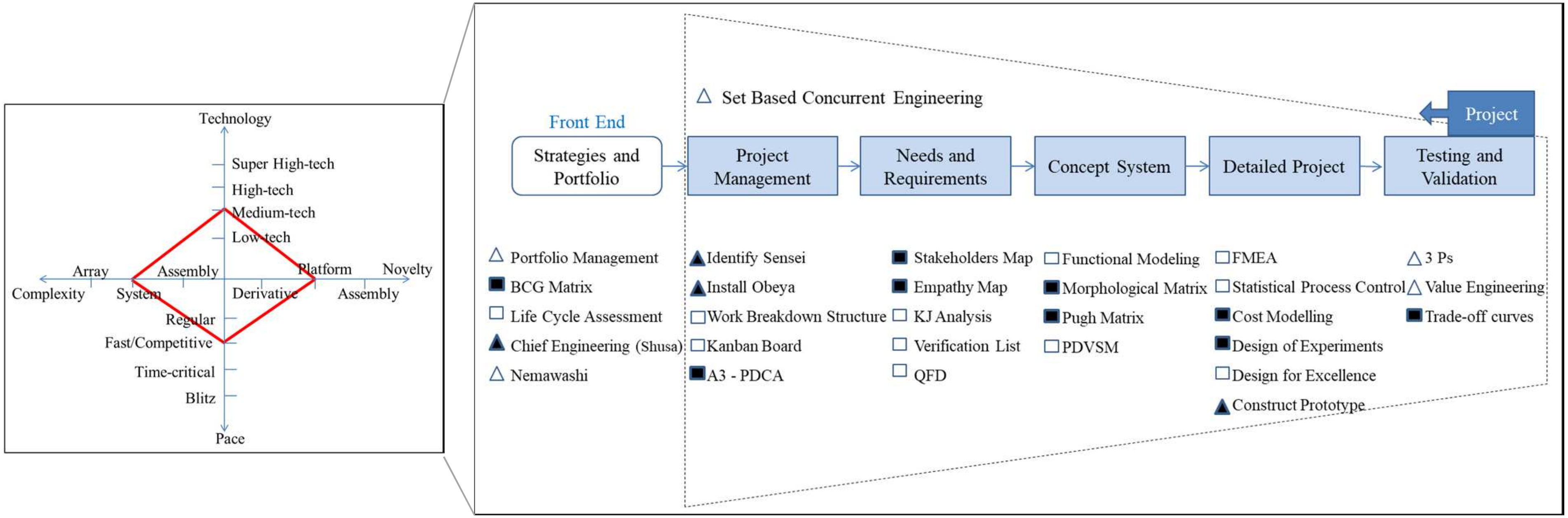
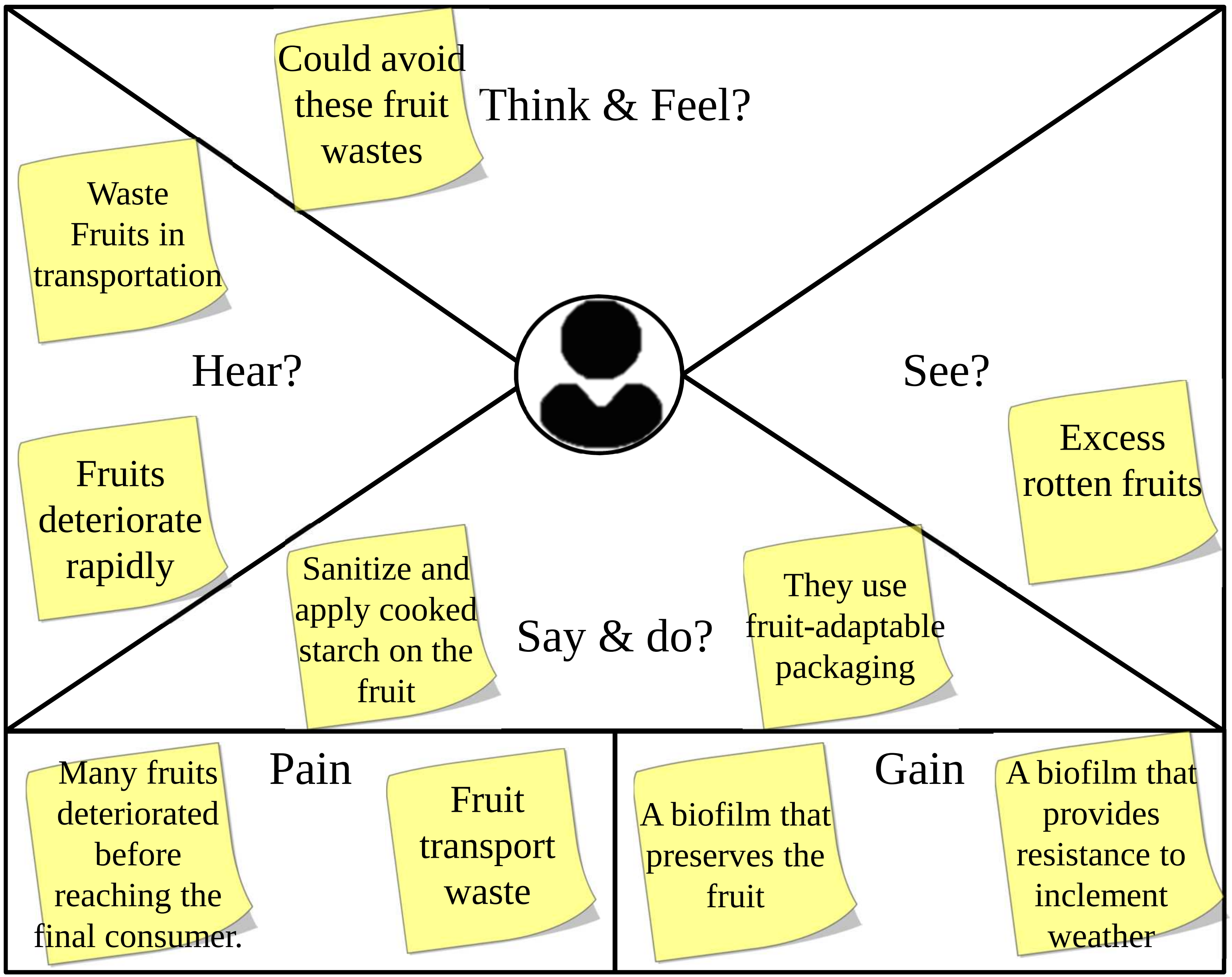
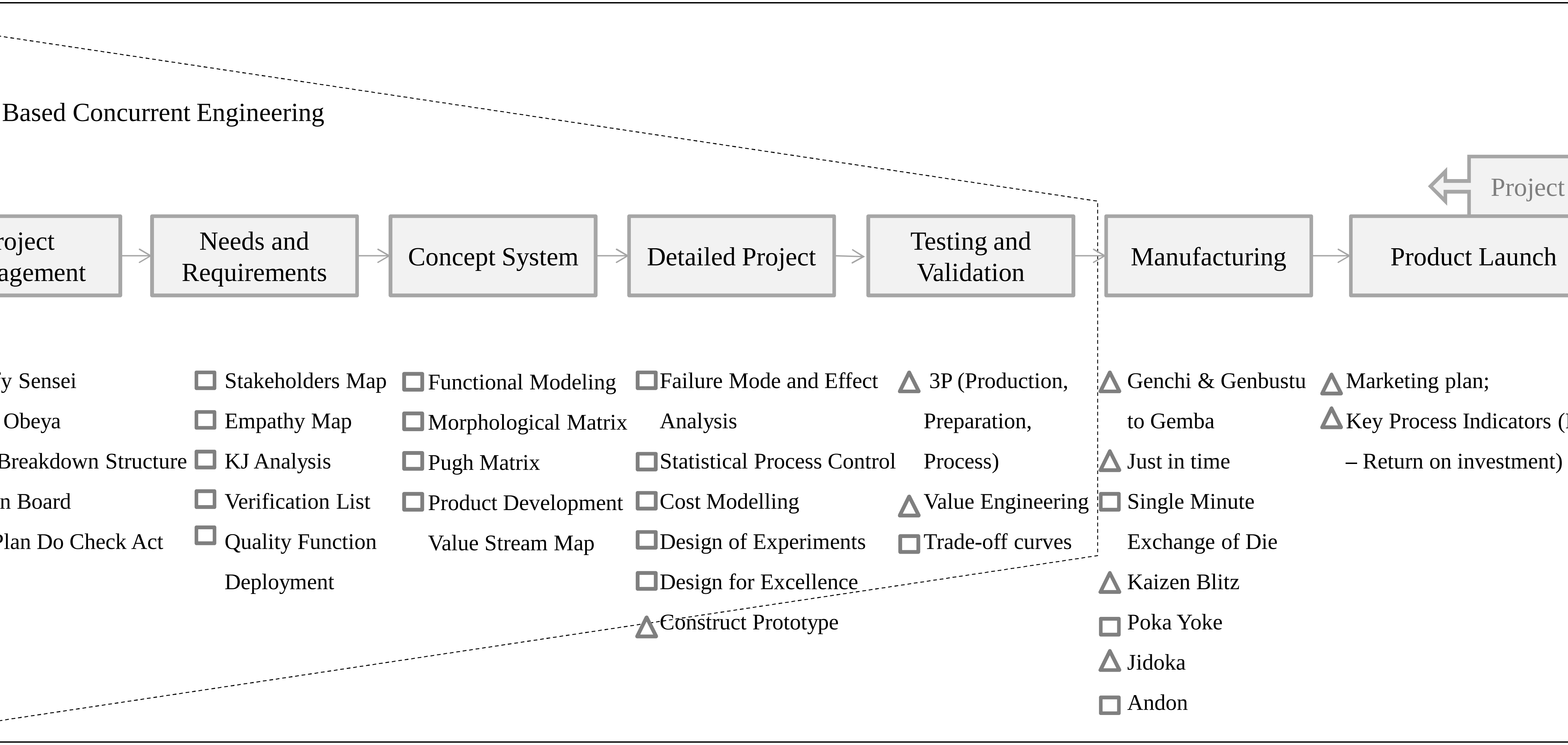

Technology
Super High-tech
High-tech
Medium-tech
Low-tech
Array
Assembly
Platform
Novelty
Complexity
System
Derivative
Assembly
Regular
Fast/Competitive
Time-critical
Blitz
Pace
Set Based Concurrent Engineering
Project
Front End
Strategies and Portfolio
Project Management
Needs and Requirements
Concept System
Detailed Project
Testing and Validation
Portfolio Management
BCG Matrix
Life Cycle Assessment
Chief Engineering (Shusa)
Nemawashi
Identify Sensei
Install Obeya
Work Breakdown Structure
Kanban Board
A3 - PDCA
Stakeholders Map
Empathy Map
KJ Analysis
Verification List
QFD
Functional Modeling
Morphological Matrix
Pugh Matrix
PDVSM
FMEA
Statistical Process Control
Cost Modelling
Design of Experiments
Design for Excellence
Construct Prototype
3 Ps
Value Engineering
Trade-off curves


Could avoid these fruit wastes
Think & Feel?
Waste Fruits in transportation
Hear?
See?
Fruits deteriorate rapidly
Excess rotten fruits
Sanitize and apply cooked starch on the fruit
Say & do?
They use fruit-adaptable packaging
Pain
Many fruits deteriorated before reaching the final consumer.
Fruit transport waste
Gain
A biofilm that preserves the fruit
A biofilm that provides resistance to inclement weather



Based Concurrent Engineering
Project
roject
agement
Needs and Requirements
Concept System
Detailed Project
Testing and Validation
Manufacturing
Product Launch
y Sensei
Obeya
Breakdown Structure
n Board
Plan Do Check Act
Stakeholders Map
Empathy Map
KJ Analysis
Verification List
Quality Function Deployment
Functional Modeling
Morphological Matrix
Pugh Matrix
Product Development Value Stream Map
Failure Mode and Effect Analysis
Statistical Process Control
Cost Modelling
Design of Experiments
Design for Excellence
Construct Prototype
3P (Production, Preparation, Process)
Value Engineering
Trade-off curves
Genchi & Genbustu to Gemba
Just in time
Single Minute Exchange of Die
Kaizen Blitz
Poka Yoke
Jidoka
Andon
Marketing plan;
Key Process Indicators (
– Return on investment)

Phase 1
Selection of Lean Product Development models and the identification of practices, tools, and phases for the framework development

Phase 2
Integration practices and phases for the design of the Lean Product Development framework and selection of practices and phases for the design of the Lean Product Development framework

Phase 3
Testing and validation of the Lean Product Development framework proposed

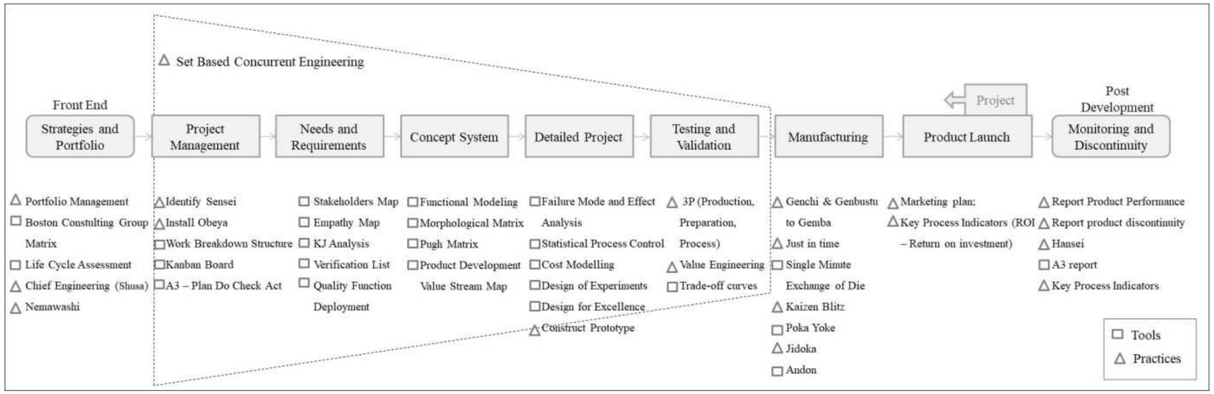
To select the phases of the Lean Product Development base model, we used the models of Morgan and Liker (2006), Ward (2007) and Ulrich and Eppinger (2015) as reference.

Databases searched: Science Direct; Emerald, EBSCO, Springer, Taylor and Francis;
Keywords searched: lean product, new product development, lean product development, lean practices, framework;
Selected articles: 17;
Tools and practices identified: 42.

Key activities were searched in each tool and the models of Morgan and Liker (2006), Ward (2007), Ulrich and Eppinger (2015) were used to integrate practices and phases

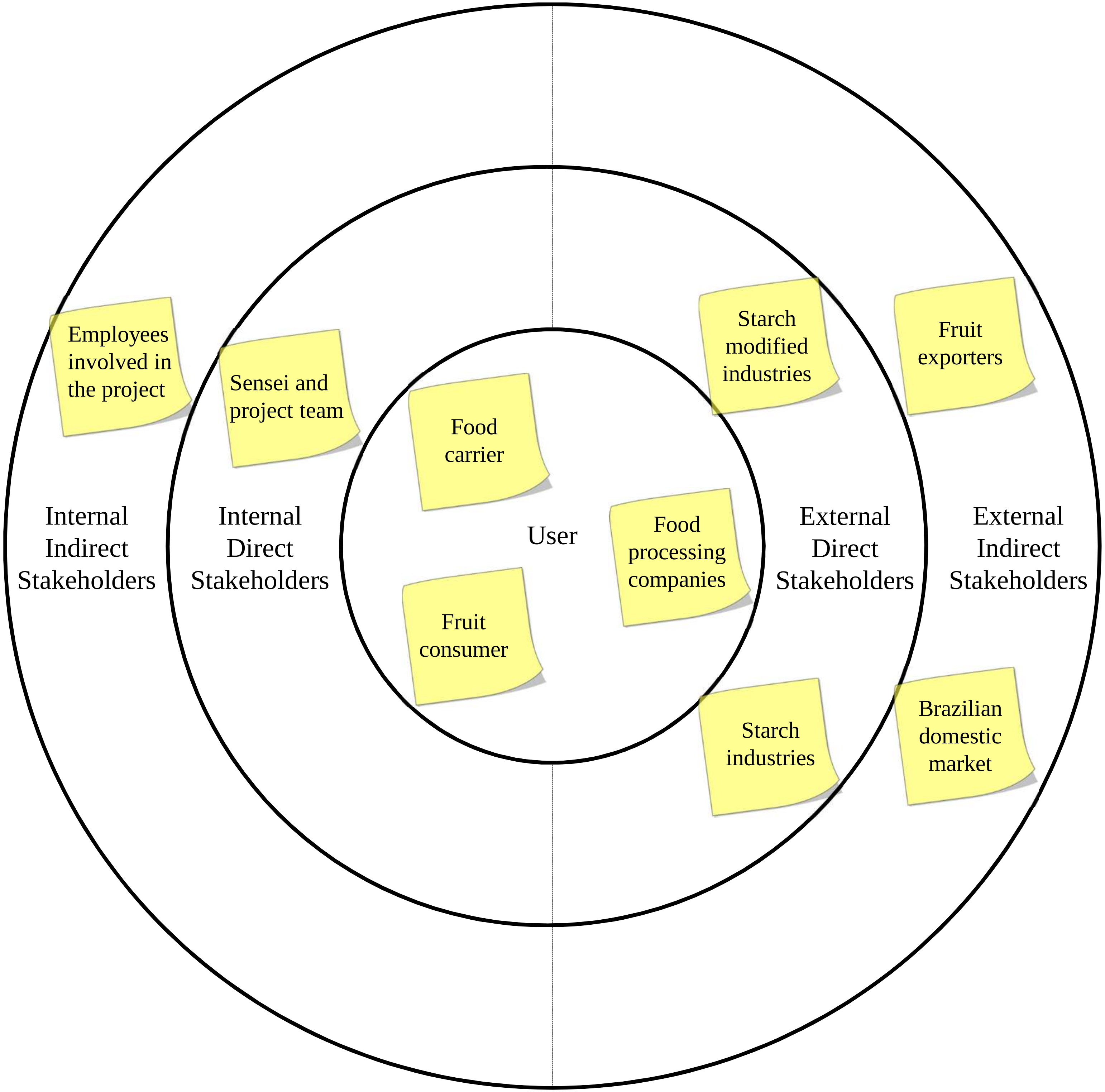
Diamond framework of Shenhar and Dvir (2007) to assess the complexity and uncertainty of targets, activities, project's environment and the adaptations needed for typology

Lean Product Development Framework presents customizable tools and practices based on product typology



Application of the Lean Product Development framework in a fruit processing agroindustry for the sustainable development of a solution to reduce fruit waste.

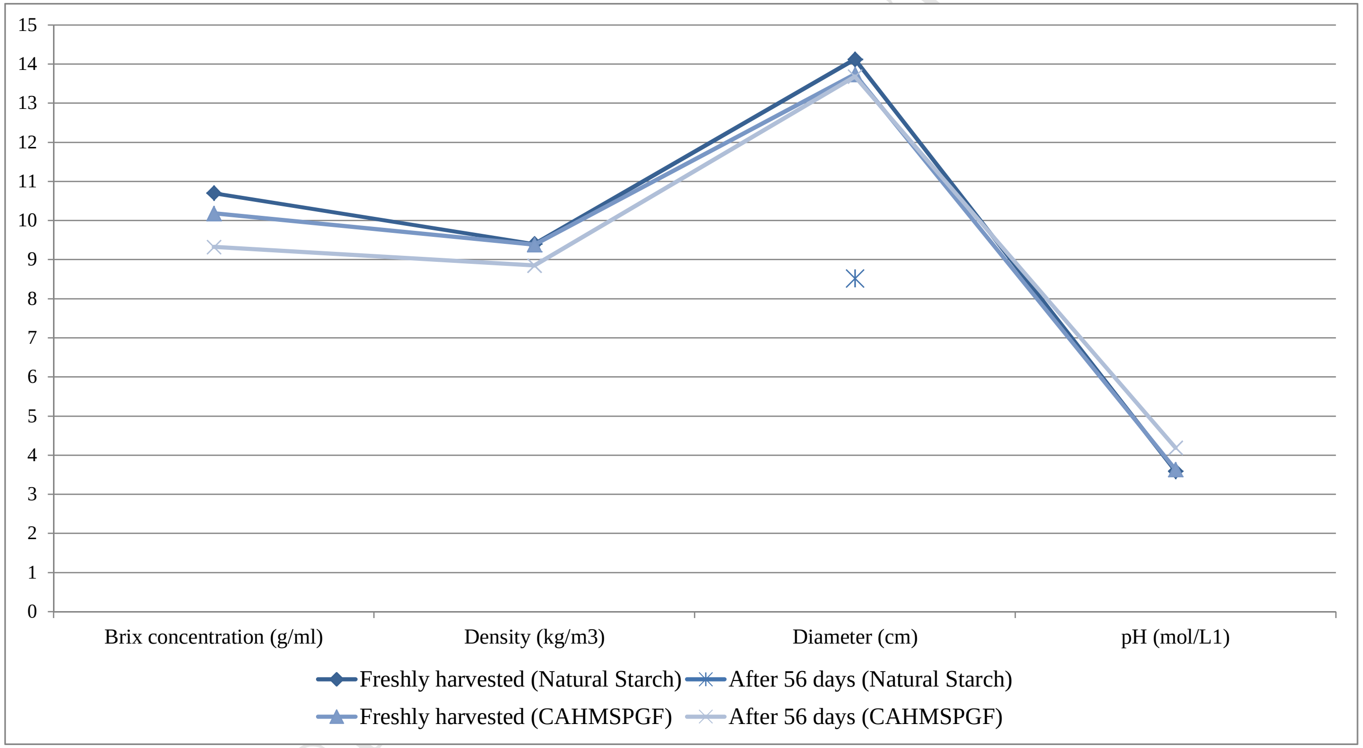
The project was developed with direct contact with the Research & Development and Marketing managers of the fruit processing company through biweekly visits to the agro industrial company located in the state of Paraná – Brazil.


Employees involved in the project
Sensei and project team
Food carrier
Starch modified industries
Fruit exporters
Internal Indirect Stakeholders
Internal Direct Stakeholders
User
Food processing companies
External Direct Stakeholders
External Indirect Stakeholders
Fruit consumer
Starch industries
Brazilian domestic market

Material Utilizado	Índices	Tipo de Fruta	Fruta Sanitizada	Fruta com capa protetora
Balança Análitica	Densidade	Fruta Recém-Colhida	9,40 kg/m³	9,38 kg/m³
		Fruta com oito semanas	*	8,85 kg/m³
Refratômero	Grau Brix	Fruta Recém-Colhida	10,70 g/ml	10,18 g/ml
		Fruta com oito semanas	*	9,32 g/ml
Paquímetro	Diâmetro	Fruta Recém-Colhida	14,12 cm	13,74 cm
		Fruta com oito semanas	8,52 cm	13,68 cm
Balança	Massa	Fruta Recém-Colhida	192,8 g	187,9 g
		Fruta com oito semanas	38,6 g	182,6 g
Peagômetro	Ph	Fruta Recém-Colhida	3,59 mol/L¹	3,63 mol/L¹
		Fruta com oito semanas	*	4,19 mol/L¹

	Freshly harvested (Natural Starch)	After 56 days (Natural Starch)	Freshly harvested (CAHMSPGF)	After 56 days (CAHMSPGF)
Brix concentration (g/ml)	10.7		10.18	9.32
Density (kg/m3)	9.4		9.38	8.85
Diameter (cm)	14.12	8.52	13.74	13.68
pH (mol/L1)	3.59		3.63	4.19

Massa (g)	192.8	38.6	187.9	182.6



		Fruta Sanitizada		Fruta sanitizada com AMCAHPG	
Material utilizado	Tipo de Análise	Recém colhida	Após 56 dias	Recém colhida	Após 56 dias
Refratômero	Grau Brix (g/ml)	10.7	*	10.18	9.32
Densímetro	Densidade (kg/m3)	9.4	*	9.38	8.85
Paquímetro	Diâmetro (cm)	14.12	8.52	13.74	13.68
Peagômetro	pH (mol/L1)	3.59	*	3.63	4.19
Balança Analítica	Massa (g)	192.8	38.6	187.9	182.6

Theme: Eliminate fruit waste

To: Fruit processing industry
By: researchers from UFRGS
Date: September 15, 2017

Background

- More than 1 Billion tons of food are wasted in the world
- Brazil loses 30% of its national fruit production every year
- Increasing agricultural production without reducing losses is not one of the solutions

Current Condition

- The current process of fruit processing is sanitization with Sodium hypochlorite (NaClO) and a film of cooked starch
- The biggest problem is that the fruit does not withstand the weather and degrades easily

Cause Analysis

- Rotting of fruits in a short period of time
- Demand for cooking starch during encapsulation
- Fruit waste during transportation and storage

Target Condition

- The proposed process is a Cationic, Anionic, Hydrophobic Modified Starch in Pre-Gel Form
- The countermeasures are that this starch dispenses the cooking process, is edible and preserves the fruit
- The fruit is stored for 56 days after application

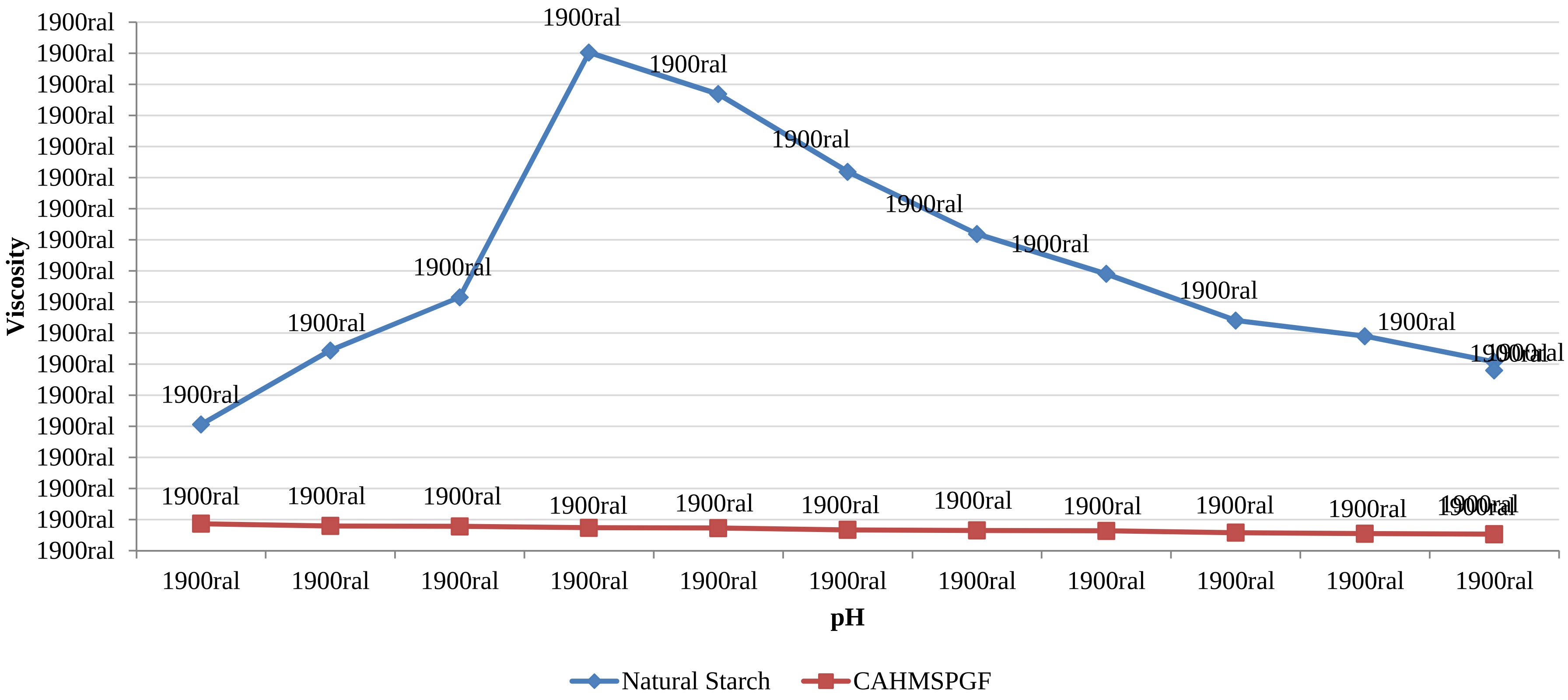
Implementation Plan

What?	*Who?*	*When?*	*Where?*
Apply the practices and tools of the LPD framework	Project Sensei and his team	December 15, 2017	Guarapuava, Brazil

Cost: US$ 250,00 → 200.000 Fruits

Cause Analysis

Plan	*Actual Results*
The effects will be checked after application in the fruit and launch of the product on the market	Demonstrate product improvement with the application of Cationic, Anionic, Hydrophobic Modified Starch in Pre-Gel Form and



Viscosity
pH
1900ral
Natural Starch
CAHMSPGF

HIGHLIGHTS

Lean principles are used for waste elimination and continuous improvement in NPD.

A LPD framework was proposed to offer customizable tools and practices for NPD.

Practices and tools are selected according to product typology.

The proposed framework was validated in a fruit processing industry.

Application of LPD in the push industry is favored.