OmniaScience

Journal of Industrial Engineering and Management
JIEM, 2023 – 16(2): 169-185 – Online ISSN: 2013-0953 – Print ISSN: 2013-8423
https://doi.org/10.3926/jiem.4916

Green Lean Six Sigma Model for Waste Reduction of Raw Material in a Nectar Manufacturing Company of Lima, Peru

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Received: November 2022
Accepted: February 2023

Abstract:

Purpose: Food waste is a latent problem for society, one of the main causes being poor management of the operating processes within the food industry, which is the main reason the present research aimed to reduce raw material waste in a nectar factory.

Design/methodology/approach: The methodology led to carrying out an experimental investigation where a Green Lean Six Sigma Model was applied, whose foundation was the use of tools such as Environmental Value Stream Mapping (E – VSM), DMAIC (Define - Measure - Analyze - Improve - Control), Poka Yoke and DOE (Design of Experiments), the data obtained were exposed to an inferential statistical analysis using tests such as Anderson - Darling and T-Student.

Findings: As a result, a waste reduction of 2.23% was obtained, which is equivalent to approximately 120 kg of useful raw material, in addition the environmental impact was reduced by 2.2% and produced an increase in global productivity by 2.4%.

Research limitations/implications: It is shown that the application of methodologies such as Green, Lean and Six Sigma in the food industry present benefits during and after the application of the model; such as preventive control of waste, standardization in processes; benefits that, in coordination with an organizational culture of continuous improvement, can significantly improve the current state of companies.

Practical implications: The positive obtained results support the methodology proposed by the authors to reduce the waste of agricultural raw material. It is expected to be a benchmark for other similar organizations that seek to generate greater productivity in line with the search for environmentally sustainable operations.

Originality/value: This is one of the first studies that aims to reduce the waste of raw materials in food processing companies, considering aspects of mitigating environmental impact.

Keywords: six sigma, lean, green, waste, food industry

To cite this article:

Ortiz-Porras, J.E., Bancovich-Erquínigo, A.M., Candia-Chávez, T.C., Huayanay-Palma, L.M., Moore-Torres, R.K., & Tinoco Gomez, O.R. (2023). Green Lean Six Sigma model for waste reduction of raw material in a nectar manufacturing company of Lima, Peru. *Journal of Industrial Engineering and Management*, 16(2), 169-185. https://doi.org/10.3926/jiem.4916

1. Introduction

Worldwide, food waste (FWP) has been recognized as a sustainability problem due to its negative impact on society at an economic, social and environmental level (Marques, Carvalho & Santos, 2022; Economic Commission for Latin America and the Caribbean - ECLAC, 2020) as in the world a average of 1,300 million tons of food is wasted (Kolawole, Mishra & Hussain, 2021) with 66% being the product of deterioration or decomposition (Wu, Mohammed & Harris, 2021). Peruvian food industry has not been exempted from this situation, since although favorable results in its growth are shown (from 9% in 2020 to 8.5% compared to 2019) (SNI, 2022: page 16) a solution to food waste has not been found yet (Vázquez-Rowe, Ziegler-Rodriguez, Margallo, Kahhat & Aldaco, 2021) generating the need of a proper management on its processes through continuous improvement (CI) projects to reduce waste, increase productivity and reduce environmental impact.

The purpose of this research is to design and implement a model based on the integration of Six Sigma, Lean and Green. The Six Sigma approach was responsible for reducing process variability and eliminating existing defects, while the Lean approach aimed to systematically minimize raw material waste in the company, by the other side the Green approach sought to reduce environmental impact. of the process and increase its sustainability. For this, tools such as Environmental Value Stream Mapping (E – VSM), DMAIC (Define - Measure - Analyze – Improve - Control), Poka Yoke, DOE (Design of Experiments), among others, were used. The objective of the study was to reduce the waste of raw material in a nectar factory in Lima (Peru), for which the following hypothesis was raised and contrasted: There is a significant difference in the reduction of waste of useful raw material before and after the implementation of the Green Six Sigma Lean (GLSS) model.

On the other hand, this article is formed by four sections. The first section is entitled Review of the literature, in which the main concepts related to research are addressed, such as the waste of raw materials in food production, sustainability and environmental impact in processes, as well as the integration of Six Sigma, Lean and Green. The second section approaches the Research Methodology, where the design, development and implementation of the model will be explained, it will focus especially on describing in detail how it was working with the E – VSM, Poka Yoke and DMAIC. In the third section entitled Results, the monitoring of the performance of the implemented model and the collection of data regarding the changes that occurred in the company are presented, to later carry out an inferential statistical treatment in order to reveal the impact of the changes. In the fourth section entitled Discussion, the data of the state of the company before and after the implementation will be compared with other investigations to highlight the impact of the improvement in the industrial process; likewise, on the fifth and last section the conclusions of the investigation are presented based on the results obtained.

2. Review of the Literature

2.1. Waste of Raw Material in Food Production

Food production causes 20% to 30% of the environmental impact related to man (Hartmann, Lazzarini, Funk & Siegrist, 2021), with a tendency to increase due to the growth of the population on the planet, making it necessary to seek solutions that reverse this panorama (Cortesi, Pénicaud, Saint-Eve, Soler & Souchon, 2022), likewise it generates a hidden environmental impact, understood as the one generated both by the creation and extraction of raw materials as well as by the final product after the production process (Skaf, Franzese, Capone & Buonocore, 2021). In the United Kingdom, the FW at the national level was responsible for THE generation of 3% of greenhouse gas emissions and 6% of the water footprint (Jeswani, Figueroa-Torres & Azapagic, 2021). Likewise, in the report on the Food Waste Index 2021, it indicates that in 2019, 931 million tons of FW were generated, representing 17% of the food produced, which ultimately ended up in the dump (UNEP, 2021). Due to this, companies that seek to increase their efficiency and ability to compete have been forced to consider the concept of managing waste, through the implementation of good operating practices that in some cases has led to savings of 150 million dollars. (Antony, Sunder, Laux & Cudney, 2020; Amani, Lindbom, Sundström & Östergren, 2015).

2.2. Sustainability and Environmental Impact in Processes

Sustainability consists of the prudent use of resources, that is, it transmits "resource awareness" (Agustiady & Badiru, 2012) being a long-term approach based on the improvement and reduction of raw material waste and solid waste whose objective is to reduce the environmental impact, especially regarding the reduction of CO2 emissions (Khodeir & Othman, 2018). Meanwhile, the environmental impact is the result of different green wastes, among which garbage, excessive use of resources and energy, etc. However, the consumption of resources becomes relevant because their excessive use triggers both environmental damages, as well as their depletion (Fercoq, Lamouri & Carbone, 2016).

One of the main indicators of environmental impact is the Carbon Footprint, considered as the total greenhouse gas (GHG) emissions expressed as CO2 equivalents in production processes (Iriarte, Yáñez, Villalobos, Huenchuleo & Rebolledo-Leiva, 2021), its consideration being necessary for decision-making on sustainable production and consumption, taking special relevance in the food industry, since it is an important source of GHG (Chen, Ma, Zhou, Liu, Huang, Wang et al., 2021; Naresh-Kumar & Chakabarti, 2019).

2.3. Six Sigma, Lean and Green Integration

Six Sigma stands out for solving complex problems with unknown solutions, focused on reducing variability and the percentage of defects in production, while Lean is responsible for reducing waste until it is eliminated and purifying activities that do not add value (Antony et al., 2020), its use in the food industry is still incipient, but it is highly effective because activities related only to hygiene and food safety predominate in the sector, but not in manufacturing processes (Costa, Godinhoo-Filho, Fredendall & Ganga, 2020). On the other hand, the Green approach minimizes the negative effects on the environment through the reduction/elimination of waste in processes, being of great relevance for industries, especially manufacturing, since it reduces adverse environmental effects and optimizes the use of available resources contributing positively to the company, people and the planet (Touriki, Benkhati, Kamble, Belhadi & El-Fezazi, 2021)

However, each of these methodologies has its own limitations. By implementing Six Sigma in isolation, it is likely that waste cannot be completely eliminated in the processes, and exhaustive data collection is also necessary. As for Lean, its isolated implementation is only successful when the team already knows the problem and the solution, so only a methodology and a set of tools are needed, presenting drawbacks when facing an unknown, complex problem that involves variable critical parameters and that also require statistical control (Antony et al., 2020). For this reason, the integration of Six Sigma and Lean overcomes the limitations that they have separately, increasing efficiency, effectiveness, performance and reducing implementation time. In addition, with the objective of maximizing the value of production, the companies adopted the tools and principles of both approaches, achieving an integration based on a collaborative effort to improve performance through improvement in customer satisfaction, cost-quality, the speed of the processes and reduction of the invested capital (Costa, Godinho-Filho, Fredendall & Ganga, 2021).

Regarding the Green approach by itself, it does not have the capacity to give true value to the processes, this is because the manufacturing performance is not only influenced by the environmental factor, which is why the Lean and Green integration appears as an extremely attractive option because the tools used in Lean practices, such as VSM, JIT, DOE, contribute directly and indirectly to the reduction of environmental impact, allowing simultaneously to increase both the sustainability and the economic performance of the organization (Singh, Kumar-Mangla, Bhatia & Luthra, 2022; Ahmad, Abdullah & Talib, 2021). However, Lean - Green integration has its own limitations and contingencies, the most notable being that it is not project-oriented, since it does not contribute to scrutiny or focus on the reduction of variations, showing long-term application drawbacks (Gholami, Jamil, Mat-Saman, Streimikiene, Sharif & Zakuan, 2021), they also highlight the high costs of improvement, the culture of support, the involvement of all employees and the lack of an adequate organizational structure (Bhattacharya, Nand & Castka, 2019).

A multi-focus vision that integrates the tools of Six Sigma, Lean and Green is required to not only have operational benefits, but also environmental ones (Antony et al., 2020), since the success of the integration is understood by the shared characteristics that the three approaches have for customer satisfaction, waste reduction, and value addition, each overcome the limitations of the other to deliver value by identifying and eliminating waste and debris, increasing sustainability, and reducing environmental impact (Farrukh, Mathrani & Taskin, 2020; Kaswan & Rathi, 2020).

2.4. Previous Studies of Green Lean Six Sigma Models

In the literature it is possible to find several studies on Green Lean Six Sigma because the combination of Green, an approach used in operations that considers the environmental impacts of production (Deif, 2011); with Lean, which maximizes the flow of the process and the delivery time since it reduces waste; and Six Sigma, since it recognizes and reduces existing variations in processes (Kazancoglu, Kazancoglu & Sagnak 2018); produces a powerful strategy that is capable of obtaining better results in environmental objectives (Garza-Reyes, Torres-Romero, Govindan, Cherrafi & Ramanathan, 2018). Researchers such as Kaswan and Rathi (2020), Gholami et al. (2021), Mohan, Rathi, Kaswan and Nain (2021), Yadav, Gahlot, Rathi, Yadav, Kumar and Kaswan (2021), Nagadi (2022), Gaikwad and Sunnapwar (2021), Rathi, Kaswan, Garza-Reyes, Antony and Cross (2022) and Sreedharan, Sandhya and Raju (2018) have developed GLSS models in different industries such as manufacturing, public sector, etc. However, the literature specifically on the food or agri-food industry is non-existent, because after a rigorous investigation, no work was compiled; therefore, the value of our article resides in this problem because it fills the academic gap.

3. Research Methodology

This research aims to develop a model based on the integration of Six Sigma, Lean and Green, (Figure 1) in order to reduce the waste of raw materials in the food industry. The model includes the Six Sigma approach, which, focused on customer satisfaction, brings with it the reduction of defects in the processes; to this is integrated the Lean approach that fully defends the systematic and progressive elimination of waste and activities that do not add value; and all under the Green approach, focused on increasing sustainability and reducing the environmental impact of processes.

For this, the method used in this paper is the case study. This research shows how the implementation of the developed model reduces the waste of useful raw material in a nectar factory in Lima (Peru). The case study was chosen because it offers versatility in design and flexibility in the application of qualitative and quantitative analysis, which are adequately adapted to the needs and context of the organization (Sánchez-Márquez, Guillem, Vicens-Salort & Vivas, 2020). In addition, it encourages direct observation, data collection in already established and operating environments, and comparison as a means of contrasting the derived data (Sunder, Ganesh & Marathé, 2019).

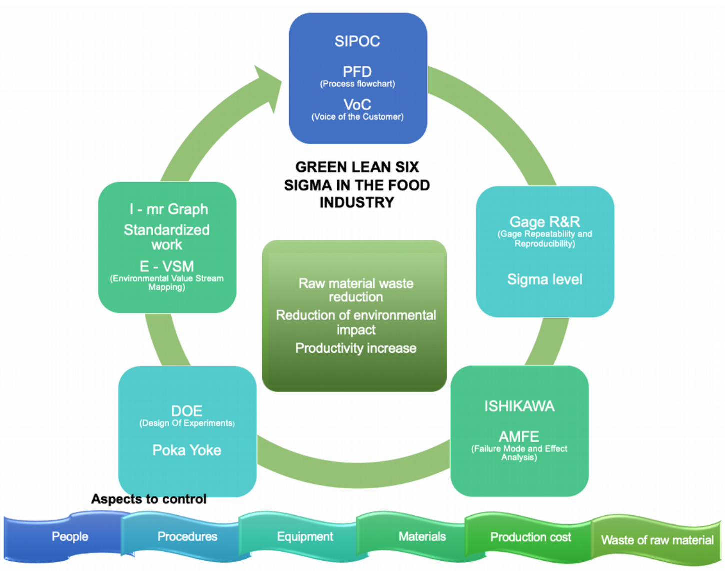

Figure 1. Green Lean Six Sigma model in food industry

In the present study, a real-time problem of food waste was considered. the data was based on the amount of input fruit, waste of useful raw material and amount of output useful raw material. As the main tool, the E – VSM was used to identify ecological waste and its consequent reduction / elimination, its choice is due to the ability to document, analyze and understand the flow of information and materials in production processes thanks to its simplicity in integration coupled with its high effectiveness (Ahmad et al., 2021; Gholami et al., 2021; Zhu, Zhang & Jiang, 2020). Also demonstrating its ease of adaptation with Green Lean and Six Sigma tools (Garza-Reyes et al., 2018). Also noteworthy is the application of Poka Yoke, a tool of Japanese origin, literally translated as "Error proof", because using the prevention and rectification of worker errors, it is intended to eliminate product defects; likewise, it prevents the operator of a machine from making errors by detecting and analyzing their main causes (Antony, Vinodh & Gijo, 2016). The general description of the most important tools used of the Green, Lean and Six Sigma techniques are presented below.

3.1. SIPOC Diagram

It is a tool that provides fundamental information, through a tabular format, about the inputs and outputs present in the different production processes. SIPOC is used in one of the DMAIC phases, specifically in the definition phase. Delivering a detailed description of the various processes and adapting the concept of a new process are some of the uses of this tool (Antony et al., 2016).

3.2. Gage R&R

Tool used to estimate the reproducibility (difference between readings from different operators) and repeatability (difference between readings when measurements are repeated under the same conditions) of the measurement system.

3.3. Failure Mode and Effect Analysis (FMEA)

Failure Modes are understood as the different ways in which something in the process can fail, likewise, Effects Analysis studies the consequences of the aforementioned failures. The objective of the FMEA is to minimize or suppress failures, taking into account the frequency of occurrence and their easy detection (Antony et al., 2016).

3.4. Design of Experiments (DOE)

The DOE is used for the optimization of the different production processes, in addition to making it possible to manipulate the various input factors, with the aim of obtaining a desired output effect. If the DOE is properly carried out, it will be possible to obtain the key factors and effects, variables and process inputs, in addition to looking for scenarios where the processes have a tolerable performance (Madariaga, 2013).

3.5. Poka Yoke

The Poka Yoke, a tool of Japanese origin, literally translates as "Fail-proof". Using the prevention and rectification of worker errors, it is intended to eliminate product defects; Likewise, it prevents the operator of a machine from making mistakes by detecting and analyzing their main causes (Madariaga, 2013).

3.6. Environmental Value Stream Mapping (E – VSM)

Environmental Value Stream Mapping minimizes the tasks of identifying ecological waste and its consequent reduction/elimination, thanks to the ability to document, analyze and understand the flow of information and materials in production processes. Its simplicity in integration with its high effectiveness make it a really useful tool when seeking to reduce environmental impact and increase sustainability in organizations. (Gholami et al., 2021). According to (Garza-Reyes et al., 2018) from the set of Lean applications, the Environmental Value Stream Map (E – VSM) has been considered the best ecological tool to reduce the environmental impact generated by waste due to its efficiency and ease of application.

4. Study Case

The company under study is located in the district of Lurín, Lima (Peru), and specializes in the production of nectars made from fruits and cereals; focused on a high nutritional value, its main objective is to provide the market with a healthy and nutritious supplement. The production line under study is that of cat's claw and maca nectars, where nine processes are developed to include: 1. Selection and weighing of the fruit, 2. Washing, disinfection and rinsing of the fruits, 3. Extraction of the juices from maca and cat's claw, 4. Conditioning of the fruits through peeling and extraction of the core, it is the main source of waste, 5. Blanching of the fruit, 6. Industrial processing, 7. Refining, 8. Homogenized raw material and inputs and finally 9. Pasteurized.

During the study, the waste of useful raw material (peeled and cored fruit) reached around 7% of the total available raw material (unpeeled and uncored fruit) in the conditioning process, which not only decreases productivity, but also directly affects the environmental impact of the company through the increase in the carbon footprint (Table 1).

Months	Waste of useful raw material (kg)	Wasted useful raw material / Available raw material	Carbon footprint generated by waste (kg CO2eq)
January	83.09	6.20%	240.961
February	81.95	6.12%	237.655
March	73.42	6.08%	236.118
April	99.34	7.41%	288.086
June	99.04	7.39%	287.216
July	97.88	7.30%	283.852

Table 1. Waste of useful raw material in the organization

In the study, the Six Sigma and Lean methodology were integrated under the Green approach, by using of the DMAIC phases (Figure 2). The research had a study period of 8 months leading to the collection of data and their analysis to answer research questions and hypotheses through descriptive and inferential statistical treatment, in addition, one or more independent variables were manipulated with the purpose of analyze the influence and magnitude of the impact they have on the dependent variables, Design by Experiments (DOE) is the most convenient methodology, since it is used for the optimization of the different production processes, in addition to making it possible to manipulate the results. various input factors, with the aim of obtaining a desired output effect (Antony et al., 2016).

The first step led to the development of the Define phase, which had the objective of delimiting the goals of the improvement project and establishing the schedule of activities, for which an E – VSM was prepared with special emphasis on the waste of useful raw material, and to complement the mapping of the process, a SIPOC diagram was prepared in order to analyze the most affected production area; also, a Process Diagram was developed that helped to identify critical, non-critical, controllable and non-controllable processes. In this same phase, the Voice of the Customer (VoC) program was also applied in the blanching area to define the most urgent needs of the internal customer regarding the conditioning process. In the Measure phase, the measurement system (the precision of the data) was validated using the Gage R&R study, in addition, a measurement of the process capacity was made through the calculation of the sigma level, using the analysis of defects per million opportunities (DPMO). On the other hand, in the Analyze phase, a Brainstorming program was developed to make an Ishikawa Diagram, with the objective of finding the possible causes of the waste of useful raw material in the conditioning area, later, a Modal Analysis of Failures and Effects (AMFE) in order to determine the root causes.

Regarding the Improve phase, the DOE was carried out to optimize the quality requirement limits in the process, then the Poka Yoke method was used to propose and implement solutions for the root causes, which were generated by inadvertent human errors. After the improvements, the measurement of the process capacity and the sigma level was repeated to identify its impact on the main indicator, the waste of useful raw material. To validate the model, which revolves around the question: Is the Six Sigma Lean Green model capable of reducing the waste of useful raw material in the nectars factory?, the Anderson-Darling data normality test was performed after of the improvements, verifying the normal distribution of the collected data. Subsequently, to accept or reject the proposed hypotheses, the T-Student test was carried out and finally the future E – VSM was developed in order to encourage the improvements to last over time. Finally, in the Control phase, an I – mr graph was made to verify that the waste of useful raw material is kept within the control limits, as well as a Control Plan in which the instructions for those in charge of control were specifically detailed for the people in charge of the evaluation of the conditioning area in order to standardize the improvements applied.

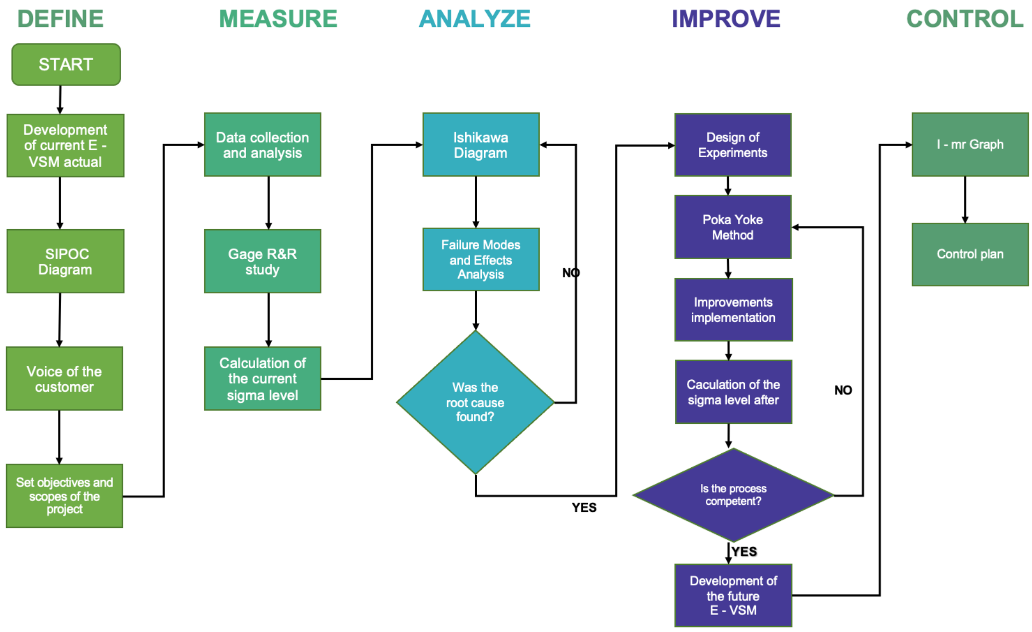

Figure 2. Flowchart of the methodology applied in the organization

4.1. Production Requirements before the Improvements

Within the company, the conditioning area is recognized as the main source of waste due to the direct treatment that it has with the raw material, for which it was necessary to map the conditioning process through a Process Diagram (Figure 3).

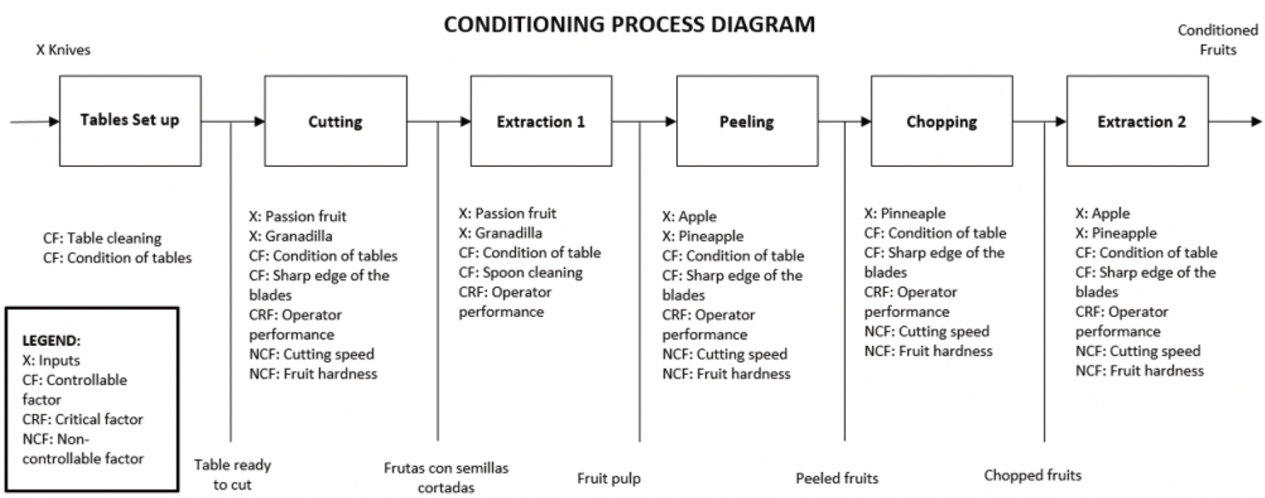

Figure 3. Diagram – Conditioning Area

The monthly requirements are 902.4 kg of peeled and cored fruit and considering 20 working days a month, 45.8 kg/day is obtained; likewise, 6 production cycles per day are considered, therefore, a daily demand of 7.52 kg/cycle is obtained.

4.1.1. Environmental Value Stream Mapping (E – VSM)

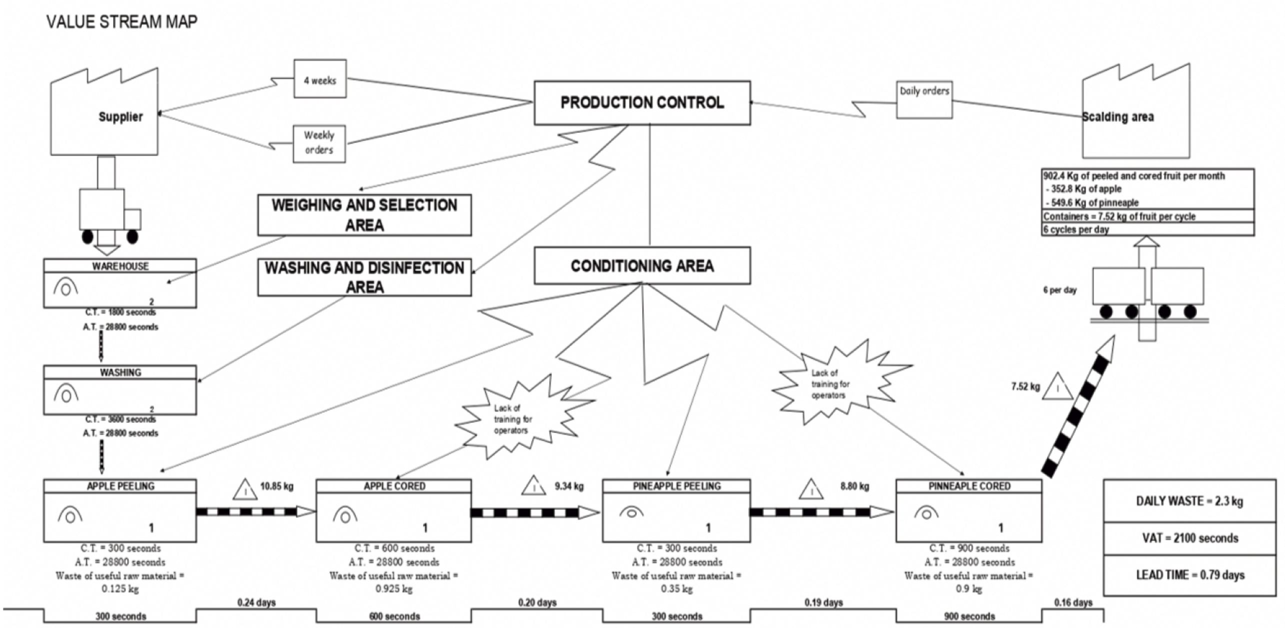

Figure 4. E – VSM before the improvements

4.1.2. Calculation of the Current Sigma Level

To calculate the sigma level, the analysis of defects per million opportunities (DPMO) was used, which was obtained using the following formula: (Siegel, Antony, Garza-Reyes, Cherrafi & Lameijer, 2019).

$$DPMO = Defects * 10^6 \,/\, Units * Opportunities \qquad (1)$$

Each cycle in the conditioning area was considered as a unit, in this way, after analyzing 60 cycles, a sample size of 60 units was considered. The duration of the cycle, the final weight of the product and the percentage of wasted useful raw material were considered as opportunities for the appearance of defects (Table 2). After applying equation 1, a DPMO of 572,222.00 was obtained, approximately a sigma level of 1.3.

Subprocess	Defects	Opportunities
Apple conditioning	106	3
Pineapple conditioning	97	3
Total	203	6

Table 2. Calculation of the current DPMO in the conditioning process

5. Results

5.1. Identification of Root Causes

5.1.1. Failure Mode and Effect Analysis (FMEA)

After the Brainstorming and the Ishikawa Diagram, a FMEA was carried out to determine which of all the possible root causes thrown by the Ishikawa were the most critical, detecting three (03) critical factors (Table 3), the first two related to the waste of peeled and cored apple and pineapple, both due to the deficient coring technique of the workers; the third related to the non-optimal conditions of the tools used for the process.

Fmea of the conditioning area									
		Failure				Indicators			
Process	Requirements	Mode	Effect	Cause	Current controls	G	O	D	IPR
Manufacture of nectars (fruit conditioning)	Peeled apples	Inefficient cutting method	Waste of useful raw material	Lack of training	Minimal training	3	8	10	240
		Worn edge Knives	Time increase	Lack of preventative maintenance	None	8	8	4	256
	Cored apples	Poor extraction method	Waste of useful raw material	There is no control of requirements	None	10	8	5	400
				Lack of training	Minimal training				
		Worn edge Knives	Wear of useful raw material	Lack of preventative maintenance	None	5	4	10	200
			Wrong filtering	There is no control of requirements	None	9	4	7	252
			Time increase	Lack of preventative maintenance	None	8	6	3	144
	Peeled pineapples	Poor extraction method	Waste of useful raw material	Lack of training	Minimal training	3	8	10	240
		Worn edge Knives	Time increase	Lack of preventative maintenance	None	9	8	4	288
	Cored pineaples	Poor extraction method	Waste of useful raw material	There is no control of requirements	None	10	9	5	450
		Worn edge Knives	Wear of useful raw material	Lack of preventative maintenance	None	4	2	10	80
			Wrong filtering	There is no control of requirements	None	6	4	8	192
			Time increase	Lack of preventative maintenance	None	10	6	2	120

Tabla 3. Failure Mode and Effects Analysis of the conditioning process

5.2. Process improvements and standardization

The DOE provided a coefficient of determination of 89.71% and the equation Y: 3.9856 + 0.2844*A + 0.4831*B, which was optimized by obtaining the minimum permissible useful raw material waste value of 2.01 kg in the case of apple and 1.12 kg in the case of pineapple for each cycle.

5.2.1. Poka Yoke

Taking into account what the minimum permissible values were, the Poka Yoke method was used to prevent and control inadvertent critical factors. Thus, 3 Poka Yoke charts were proposed to directly influence the root causes, the process that demonstrated substantial improvement was the coring of pineapple (Figure 5).

Poka Yoke N°1 Proposal					
Process:	Pinneaple core removal	**Error prevention:**	X	**Stop:**	-
Problem:	Suboptimal technique, knife usage generates a considerable percentage of waste				
Solution:	To replace the knife with a better tool for the subprocess and to train operators on its use.	**Error detection:**		**Control:**	X
Key improvement:	To provide the tool for core removal			**Alarm:**	
Description of the process:	Operators receive the peeled pineapple, they are in charge of the core. Nevertheless, when they use the knife to chop the pineapple and the core it, a considerable amount of useful raw material is wasted.				

Before the improvement:	**After the improvement:**
Operators receive the peeled pineapple, take the knife and chop it into several pieces, then remove the core of each piece. Nevertheless, this technique is not efficient of pineapple, because pineapple is bigger than apple, so they cut around eight pieces, and to remove the core of each piece represent a waste of several pulp fruit and time.	Operators receive the peeled pineapple, they hold it tight and then insert the core remover from above, turning it slowly. This tool removes the fruit pulp and cuts it as a spiral, leaving the core as a stem. This is not viable on apple, because of the size of the apple the core remover wastes much more fruit pulp.

Figure 5. Poka Yoke Chart N°1

5.2.2. Calculation of the Sigma Level After Improvements

The sigma level was measured under exactly the same conditions, with 3 critical characteristics and a sample size of 60 cycles (Table 4). After applying equation 1, a DPMO of 311,111.11 was obtained, approximately a sigma level of 2.0, being higher than the initial level 1.3.

Subprocess	Defects	Opportunities
Apple conditioning	58	3
Pineapple conditioning	54	3
Total	112	6

Table 4. Calculation of the DPMO after the improvements

5.2.3. Environmental Value Stream Map (E – VSM) After the Improvements

Following the improvements implemented in the process and the optimized production requirements, the future E – VSM was developed (Figure 6).

5.2.4. Control Plan

To ensure that the improvements are maintained over time to the point of standardization, a control plan was made for all those in charge of supervising the conditioning process (Figure 7).

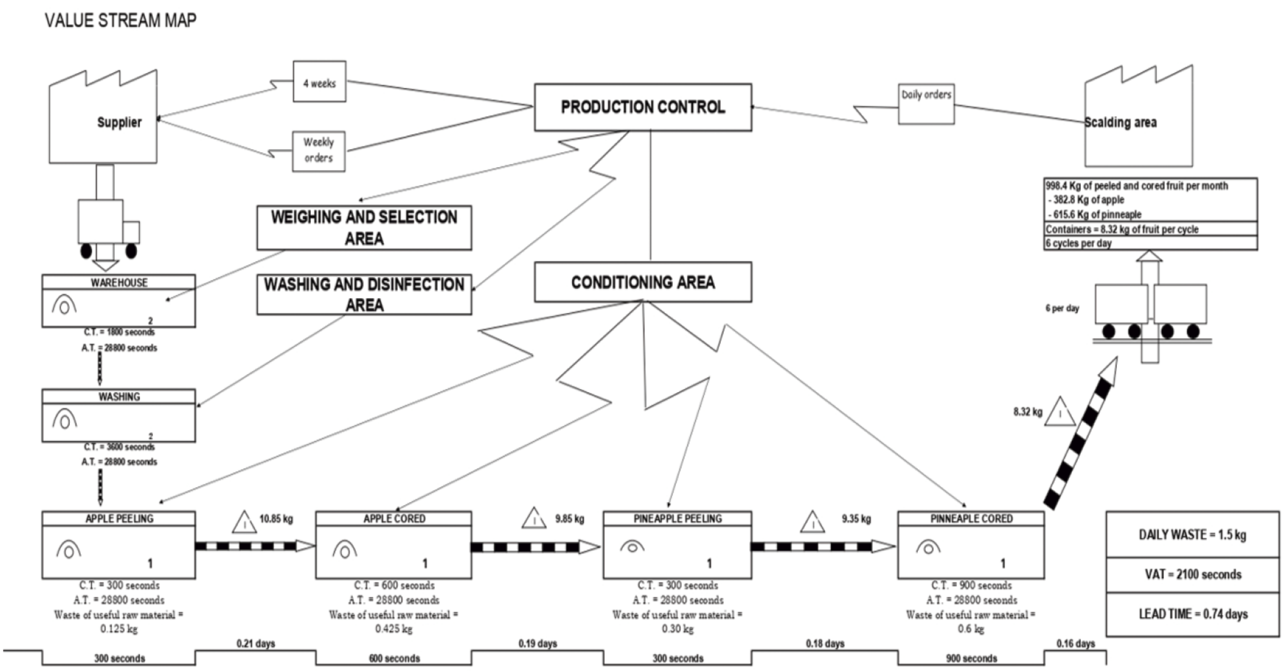

Figure 6. Future E -VSM

CONTROL PLAN

Number: X			by: Administration and Logistics					
Sector:			Area: Conditioned				Date:	
Parameter	**Features**	**Requirements**	**Instrument**	**Evaluation**	**Sample size**	**Frequency**	**In charge**	**Decision rules/**
Waste of apple pulp	Amount of wasted apple pulp	Less than 33 kg a week	I - mr control graph	Kilograms	8	Bimonthly	Department of administration and logistics	Increased control and inspection, verification that the proposed technique is being used
Waste of pineapple pulp	Amount of wasted pineapple pulp	Less than 34 kg a week	I - mr control graph	Kilograms	8	Bimonthly	Department of administration and logistics	Increased control and inspection, verification that the provided tool is being used correctly
Tools in adequate or optimal condition	Number of operators who approved the checklist	Checklist approved by all operators	Checklist	N° of operators	6	Weekly	Manager of the conditioning area	Inspect the preventive maintenance plan, redesign it if necessary and increase the rigor of the evaluation with the checklist

Figure 7. Control Plan for the conditioning area

5.3. Descriptive and Inferential Results

5.3.1. Descriptive Results

The main objective of the implementation of the model was to reduce the waste of useful raw material in the conditioning process of the production line of cat's claw and maca nectar. As can be seen in Table 5, the waste was reduced by 2.24%, which translates into almost 120 kg.

8+Period	Month	Waste (kg)			Total raw material (kg)	Waste of raw material regarding the total
		Apple	Pineapple	Total		
Period 2021	March	39.99	41.43	377.68	5360	7.05%
	April	49.16	50.18			
	May	49.68	49.36			
	June	49.74	48.14			
Period 2022	March	31.99	33.64	257.96	5360	4.81%
	April	32.13	31.77			
	May	30.28	32.79			
	June	33.13	32.22			

Table 5. Waste of useful raw material after improvements

Likewise, as shown in Table 6, the environmental impact measured through the carbon footprint generated by waste was reduced at 347,217 kg CO2 eq.

Period	Month	CF of waste (kg CO2 eq)			CF of total raw material (kg CO2 eq)	CF of waste regarding total CF
		Apple	Pineapple	Total		
Period 2021	March	115.971	120.147	1095.272	15544	7.05%
	April	142.564	145.522			
	May	144.072	143.144			
	June	144.246	139.606			
Period 2022	March	92.771	97.556	748.055	15544	4.81%
	April	93.177	92.133			
	May	87.812	95.091			
	June	96.077	93.438			

Note: kg CO2 eq alludes to kilograms of carbon dioxide equivalent

Table 6. Carbon footprint after improvements

5.3.2. Inferential Results

Under the research question, Is the GLSS model capable of reducing the waste of useful raw material in the nectar factory? The following general hypothesis was raised:

Ho (null hypothesis) = There is no significant difference in the reduction of useful raw material waste before and after the implementation of the GLSS model

Ha (Alternate hypothesis) = There is a significant difference in the reduction of useful raw material waste before and after the implementation of the GLSS model

After implementing the improvements and collecting the data, it was confirmed that they followed a normal distribution through the Anderson - Darling test, under a significance level of 5% with the use of the MINITAB 2018 statistical software, since a p value equal to at 0.878. Subsequently, the T-Student test was carried out for the acceptance or rejection of the proposed hypothesis, because a P value equal to 0.000 was obtained, which is much lower than the T value, therefore, Ho is rejected and Ha is accepted, that is, it can be affirmed that there is a significant difference in the reduction of waste of useful raw material before and after the implementation of the GLSS model (Table 7) in the nectar factory.

Null hypothesis	Ho: μ = 1
Alternate hypothesis	Ha: μ ≠ 1
T value	P value
12.99	0.0000

Table 7. T-Student test of two samples for the acceptance or rejection of hypotheses about the GLSS model

6. Discussion of Results

The Six Sigma Lean Green model considerably reduced the waste of useful raw material in the company, reducing the environmental impact; likewise, the efficiency of the raw material was improved, which led to an increased productivity in the company's conditioning area. This agrees with Touriki et al. (2021), who through a survey of more than 100 companies belonging to the food industry concluded that the implementation of Six Sigma and LSS was transcendental for the sector, reducing waste, improving performance and increasing the productivity of companies.

The descriptive results obtained through the application of the GLSS model indicate a reduction of useful raw material waste of 2.23%, since before the improvements the sum of the first months was 377.68 kg compared to the 257.96 kg produced after the improvements. recommendations. These numbers agree with Amani et al. (2015) who, after implementing LSS in one of their mass-based production lines, reduced their waste by 50%. In the same way, there is Ibarra, Robles, Montemayor, Iñiguez, Blanco and Torrecillas (2019) who used DMAIC in a lollipop factory, achieving a 36.51% reduction in waste, highly exceeding the estimated percentage.

Within this framework, the work in question considers the term environmental impact, since it is highly linked to waste, because the excessive use of resources generates environmental damage and scarcity. In addition to indicating that food production related to man causes 20% to 30% of the environmental impact. This concept is determined in this research by the Carbon Footprint, and consistent with the variation in waste, it went from 1095.272 kg CO2eq to 748.84 kg CO2eq, representing a reduction of 2.23%. What was obtained agrees with (Marrucci, Marchi & Daddi, 2020), since in his article he indicates that through LSS - DMAIC the waste before the improvements generated a carbon footprint of 5101.36 Kg CO2eq, but when measured after the recommendations the value was reduced to 3471.29 Kg CO2eq, which is equivalent to a decrease of 1630.08 Kg CO2eq.

Regarding productivity, in the research work this concept is obtained through efficiency, which is represented by the quotient of the produced quantity of nectar bottles between the raw material available to be used in the conditioning area. Productivity is achieved when your waste is minimized, making better use of your resources. In the results obtained, the average productivity went from 7,822 to 8,010, which is equivalent to an increase of 2.40%, since the number of bottles produced increased despite using the same amount of available raw material. These results coincide with what was obtained by Dora and Gellynck (2015) who argue that the reduction of waste in the filling area in a confectionery through the LSS methodology managed to improve productivity from 0.79 to 1.12.

7. Conclusions

This research addressed the question: How can raw material waste be reduced in a nectar factory? The food industry is presented as a labyrinthine scenario due to its own characteristics, the limited concept of quality and the way in which the human factor develops in it. Despite this, the application of methodologies such as Lean and Six Sigma continues to be profitable, either to improve performance, reduce variability, reduce defects, reduce costs and increase productivity; several studies supporting the aforementioned. Therefore, in response to the question raised and as an innovative factor, a model based on Green, Lean and Six Sigma integration was developed using tools such as E – VSM, SIPOC, Flow Diagrams, Design of Experiments, FMEA, Poka Yoke and statistical analysis tools.

The objective of the research was mainly to reduce raw material waste, although increasing productivity, reducing environmental impact, and reducing costs generated by waste were raised as secondary objectives. As a final result, a waste reduction of 2.23% was obtained, which is approximately equivalent to 120 kg of useful raw material, in addition, the environmental impact was reduced by 2.2% and there was an increase in global productivity by 2.4%.

As final learning, the results obtained demonstrate the feasibility and profitability of the application of methodologies such as Green, Lean and Six Sigma in the food industry, also suggest the need for its application in companies in the same sector, not only for the results obtained, but also for the benefits that are obtained post application of the model; for example, reliable sources of data collection, preventive control of waste, standardization in their processes; benefits that, in coordination with an organizational culture of continuous improvement, can significantly improve the current state of companies.

However, the model was specifically implemented in the context described in the research, as an opportunity for future research is highlighted the possibility of integrating the proposed GLSS model with moderately modern tools such as Industry 4.0, Circular Economy, Sustainable Manufacturing, among others.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

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