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Green lean method to identify ecological waste in a nectar factory

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Abstract:

Nowadays, the waste of resources has become one of the biggest problems for industries, due to the serious environmental, social and economic consequences it generates. Therefore, to ensure a production based on sustainable processes, it's essential to have a responsible management of resources, being the first step one of the most important ones, the identification. Thus, the present research work aims to develop and implement a method based on the integration of Green and Lean methodologies to systematically identify ecological waste, taking as a case study a nectar factory in Lima - Peru. Through the implementation of tools such as Environmental Value Stream Mapping, Process Mapping or Failure Mode and Effects Analysis, it was found that the company generated a waste of 1584 litres of water and 38.5 kg of conditioned fruit every month. The identification of green waste is vital, as it is the first link in a long chain that contributes directly to improving the company's efficiency, profitability and reputation, as well as protecting the environment and promoting sustainable development.

Key words:

Green Lean, Food production, Waste identification, Sustainable process.

1. Introduction

Globally, 1.3×10^9 tonnes of food is wasted every year; it is also known that for every 344 million tonnes of food losses, 4×10^{18} J of energy and 82×10^9 m^3 of water are wasted (Coudard et al., 2021). Consequently, between 3300 and 5600 megatonnes of greenhouse gases are produced and 24% of all water is wasted (Schuster and Torero, 2016). According to the Food and Agriculture

Organization of the United Nations (FAO), it is estimated that approximately one third of all food produced in the world is lost during the production or consumption process (FAO, 2019). This is the case for the organic resource of fruits and vegetables, whose waste accounts for 45% of the entire supply chain, with the processing stage responsible for up to 18% of losses (Facchini et al., 2023). The case of water resources is no stranger to this problem, due to the global conception that water is an unlimited resource due to its renewable nature; however, the indiscriminate increase in its use in industry has led to an accelerated deterioration in its quality and quantity (López et al., 2016).

The problem lies in the fact that food production and processing requires large amounts of water, about two thirds of freshwater abstraction worldwide, and in some countries, up to 90% (Kirby et al., 2003). Considering that freshwater resources are already depleted in many areas of the world, there are some general guidelines for water management in the food industries, either elaborated by community authorities or published as manuals by authors (Garnier et al., 2023). However, in the case of Latin

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America, these guidelines are rarely reviewed and implemented. It is therefore a challenge to address the problem of water and ecological waste of different food groups, especially fruit and vegetables, to ensure their availability, access, utilisation, stability and sustainability through the implementation of techniques and tools (Muñiz-López et al., 2021).

2. Literature review

2.1. Ecological waste in processes

According to the Food and Agriculture Organization of the United Nations, about 70% of the world's freshwater is used for agriculture, and because of inefficient irrigation practices and inadequate crop management, 60% of that water ends up being wasted. In the case of the food industry, water use is intensive and often accompanied by inefficient management leading to pollution and waste (FAO, 2018). In the case of food waste, according to the Organization for Economic Cooperation and Development, around 20% of the food produced is wasted at every stage of the supply chain, from production to distribution (FAO, 2019). These losses result in damage to the environment, as food production causes 20% of the human related environmental impact (Hartmann et al., 2021) and also generates an extra impact when growing or extracting the raw materials needed to produce the final product (Skaf et al., 2021).

2.2. Green and Lean Integration

Lean is a high impact management philosophy established in leading organisations around the world, this philosophy aims to achieve an improvement of the manufacturing system by eliminating waste (Carbajal, 2019). That is, it proposes a continuous and systematic process of identification and elimination of activities that do not contribute or add value to the product, but do add cost and labour (Torielli et al., 2011). On the other hand, Green manufacturing aims to minimise damage to the environment. To this end, a company can apply different types of environmental practices (Pampanelli et al., 2014). Green manufacturing has several tools that coincide with a company's efforts to reduce pollution and environmental emissions. Green industry offers a range of economic opportunities and environmental benefits at the same time. Making efficient use of resources helps its own conservation, reducing water pollution and CO_2 emissions (Carbajal, 2019). However, the Green approach alone does not have the ability to give true value to processes, because manufacturing performance is not only influenced by the environmental factor; also, the Lean approach alone does not claim to have the reduction of ecological waste as its main objective. Therefore, the integration of Lean and Green appears as an extremely attractive option that, through the Environmental Value Stream Mapping (E-VSM) tool, can directly contribute to the reduction and elimination of environmental waste, allowing to increase sustainability while maintaining the same level of productivity and economic performance of the organization (Singh et al., 2022).

3. Methods

3.1. Methodology

The purpose of the research is to show how, through the implementation of the developed method, ecological waste can be identified. For this reason, the work is governed by a case study methodology, as it offers great versatility in the design and application of both qualitative and quantitative analyses. This allows researchers to easily adapt to the specific needs of the organisation and the context in which they are located (Sanchez-Marquez et al., 2020). Furthermore, it is ideal for obtaining direct observational data in established and functioning environments, which facilitates the identification of critical success factors or areas for improvement. Furthermore, the comparison of different cases allows data to be compared and more robust and generalizable conclusions to be drawn (Sunder et al., 2019).

3.2. Development of the Green Lean method

The research aims to develop a method based on the integration of Green and Lean methodologies (Figure 1) in order to identify green waste in the food industry.

The overview of the most important tools used from the Green and Lean techniques are presented below.

3.2.1. Process map

According to Martin and Osterling (2014), the process map is the graphical representation of the structure of processes that make up a company's management system. Its importance lies in the fact that through it, key processes and critical success

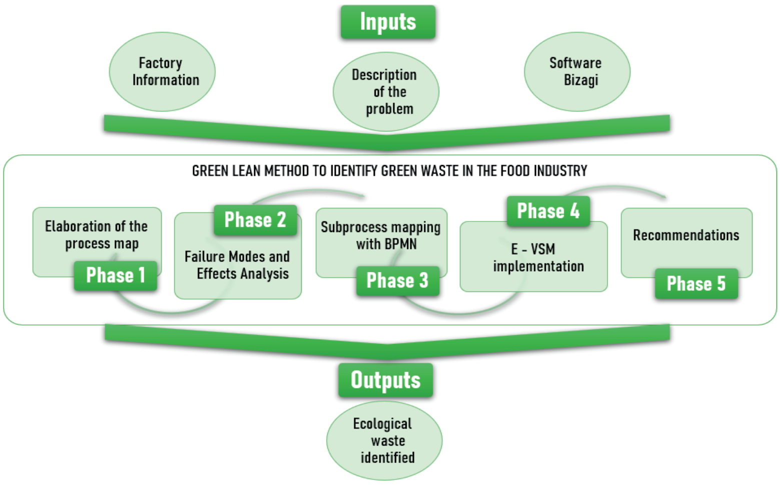

Figure 1. Green Lean Method.

factors can be identified, allowing the organisation to dedicate resources and efforts efficiently and effectively (Harmon, 2014).

3.2.2. Failure Modes and Effects Analysis (FMEA)

According to Bennett et al. (2017), Failure Mode and Effects Analysis is a quality tool mainly used to identify and evaluate possible failures and their incidence in a product or process, understanding Failure Mode as the different ways in which a process can fail; in addition to understanding Effects Analysis as the possible consequences of the identified failures. The main objective is to minimise or even eliminate errors, considering variables such as frequency and ease of detection (Alexander et al., 2019).

3.2.3. Business Process Model and Notation (BPMN)

BPMN is a process representation and analysis technique that has been mentioned in the literature as a useful tool that facilitates knowledge management, promoting the transfer of information in an agile and rapid manner in a variable context in which new competencies emerge (Salvadorinho and Teixeira, 2021). The success of BPMN comes from its versatility and ability to represent processes of different nature under a standardised structure by means of a standard (Corradini, et al., 2021).

3.2.4. Environmental Value Stream Mapping (BPMN)

Environmental Value Stream Mapping (E-VSM) is an effective tool for the identification and reduction of environmental waste in production processes. Its ability to document, analyse and understand the flow of information and materials in the supply chain minimises the identification of waste and its subsequent elimination or reduction (Ahmad et al., 2021; Gholami et al., 2021; Zhu et al., 2020).

The simplicity of its integration and high effectiveness makes E-VSM a valuable tool for organisations seeking to reduce their environmental impact and increase their sustainability. In fact, among the different lean applications, E-VSM has been considered the best ecological tool to reduce the environmental impact generated by waste, thanks to its efficiency and ease of application (Garza-Reyes et al., 2018)

3.3. Case study

The factory under study is located in the district of Ate, Lima - Peru, and its economic activity is the production of nectars of high nutritional value prepared from Andean cereals and fruit pulp. In the 2022 - III quarter, the production line of cat's claw with apple and maca with pineapple nectars reported unusually high water consumption, about 15% higher, equivalent to 8 m^3 of water; this, together with the sustained increase in waste, indicated a serious problem of waste of ecological resources. While this was not significant in terms of costs, it was a major

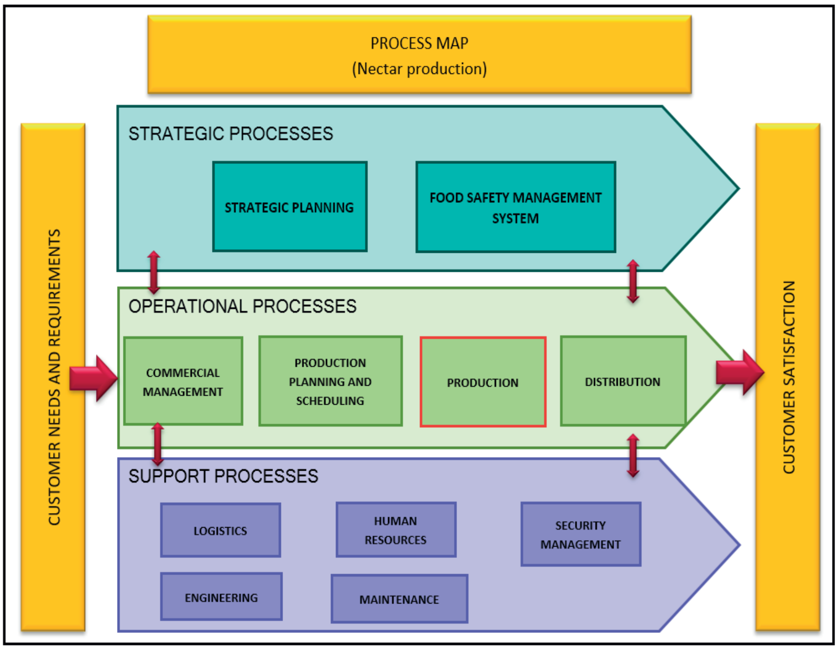

Figure 2. Process Map.

problem in terms of environmental responsibility. Therefore, faced with the need to increase the sustainability of its processes, the company opted to deploy an improvement project.

Thus, the method developed was deployed, using observation and questionnaire as techniques and the data recording sheet as the main instrument.

In this way, Phase 1 began, in which the process map shown in Figure 2 was drawn up in order to identify in which macroprocesses there is a greater probability of generating environmental waste.

This is how, through the analysis, the macroprocess of Production was chosen, where work would be carried out specifically on the manufacturing lines of cat's claw nectar with apple and maca with pineapple. This is mainly due to the fact that, being perishable and weak to the touch, there is a high probability of loss or waste.

4. Results

4.1. Identifying waste generating subprocesses

We continued with phase 2 of the method, which consists of implementing the FMEA to identify which of the subprocesses generates the most waste. To do this, initially the questions that would facilitate the assignment of Severity (S), Likelihood of Occurrence (O) and Likelihood of Detection (D) for the calculation of the Risk Profile Number (RPN) were defined.

4.1.1. Severity

Assigned question: How much environmental waste do you think the failure may generate within the subprocess?

Criteria:

- 1 – Very low: It is not reasonable to expect this minor failure to cause any real environmental waste in the subprocess.
- 2 to 3 - Low: The type of failure generates a slight amount of ecological waste in the subprocess. However, it is controlled.
- 4 to 6 - Moderate: Failure results in environmental waste, however, it can be remedied.
- 7 to 8 - High: Failure may generate large amounts of environmental waste.
- 9 to 10 - Very high: Very critical and high quantity of waste generation potential failure mode that seriously involves noncompliance with environmental regulatory standards.

4.1.2. Likelihood of Occurrence

Assigned question: How often does the failure recur?

Criteria:

- 1 - Very low: No failure is associated with the subprocess, nor has it ever occurred in the past, but it is conceivable.
- 2 to 3 - Low: Subprocess failures. Expected in the life of the system, but unlikely to happen.
- 4 to 6 - Moderate: The defect appears occasionally in the thread. It will probably appear a few times.
- 7 to 8 - High: The defect appears occasionally in the thread. It will probably appear a few times.
- 9 to 10 - Very high: The failure has occurred with some frequency in the subprocess.

4.1.3. Likelihood of Detection

Assigned question: How easily can the fault be detected?

Criteria:

- 1 – Very low: The defect is very noticeable. It is unlikely to go undetected.
- 2 to 3 – Low: The defect, although obvious and easily detectable, could on occasion escape a first check, although it would certainly be detected afterwards.
- 4 to 6 – Moderate: The defect is detectable, possibly detected in the last steps of production.
- 7 to 8 – High: The defect is of such a nature that it is difficult to detect using established procedures.
- 9 to 10 – Very high: The defect cannot be detected. It will almost certainly pass undetected.

Following the definition of criteria, the Modal Failure and Effects Analysis Matrix was developed and is shown in Figure 3.

Thus, the highest RPN was obtained by the Washing, disinfection and rinsing and Conditioning subprocesses, as, although the severity of the failure is not alarming, the occurrence and ease of detection is.

MACROPROCESS	Manufacture of cat's claw nectar with apple and maca with pineapple.						
SUBPROCESS	**SUBPROCESS DESCRIPTION**	**FAILURE MODE**	**EFFECT**	**S**	**O**	**D**	**RPN**
Sorting and weighing	The fruit in the best condition is selected and weighed to identify the input kilogram	Discard fruit in good condition	Fruit waste	5	4	2	40
Washing, disinfection and rinsing	Sodium hypochlorite is used as a disinfectant for fruits and cereals, then rinsed with plenty of water.	Excessive use of water	Water waste	4	7	8	**224**
Conditioning	The fruits are peeled and cored	Excessive peeling	Waste of conditioned fruit	6	8	6	**288**
		Excessive discouragement	Waste of conditioned fruit	6	8	6	**288**
Blanching	Enzymes are removed from pineapple and apple, both fruits are peeled and cored, placed in industrial pots and boiled until the last bacteria are eliminated	Over-boil conditioned fruit	Fuel waste	8	2	7	112
Processing	The product is liquefied using industrial processor	Overprocessing blanched fruit	Fuel waste	6	4	3	72
Homogenizing	It is mixed in the industrial kettle with the pulp obtained in a tank with agitator, where medicinal plants, natural sweeteners and additives are added.	Overmixing of components	Fuel waste	5	4	3	60
Pasteurizing	The aim is to reduce the bacterial load, so the temperature is raised to 80°C for 20 minutes and then cooled rapidly.	Heating for longer than required	Fuel waste	9	2	7	126

Figure 3. Failure Modes and Effects Analysis (FMEA).

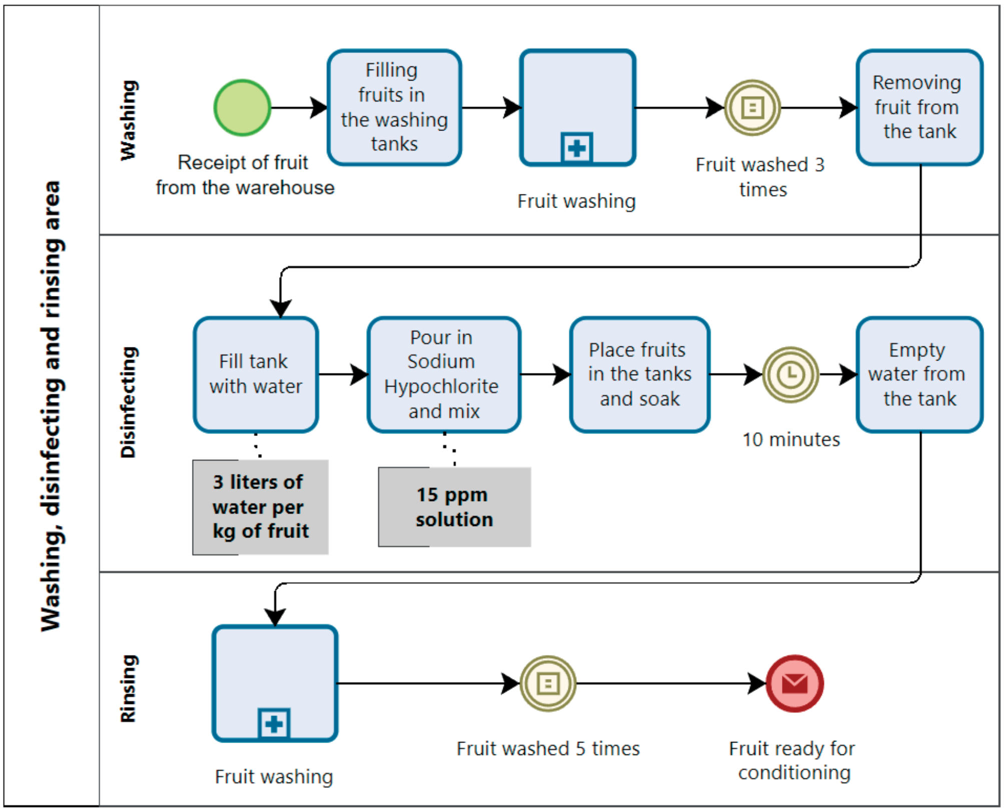

Figure 4. Flow chart of Washing, Disinfection and Rinsing area.

It should be emphasized that, although fuel wastage has a higher environmental impact, the subprocesses that generate it are very well controlled. For example, in the blanching or pasteurizing process, overboiling or heating for longer than required could change the properties of the mixture, directly affecting the taste, preservation and nutritional value; therefore, they have very strict controls.

4.2. Mapping of critical subprocesses

For the mapping of critical subprocesses, phase 2 of the method was continued with the use of the process modelling software Bizagi.

Figure 4 shows the flow charts of the Washing, Disinfection and Rinsing area. The reusable process of Fruit Washing was defined and is shown expanded in Figure 5.

Likewise, Figure 6 shows the flow diagram of the conditioning area.

After the elaboration of the flowcharts, phase 4 of the method continued, which consists of the implementation of the E - VSM. For this, some criteria were initially defined.

4.2.1. Washing, disinfection and rinsing area

- Number of operators: 2, 3 and 2 operators for washing, disinfecting and rinsing respectively.

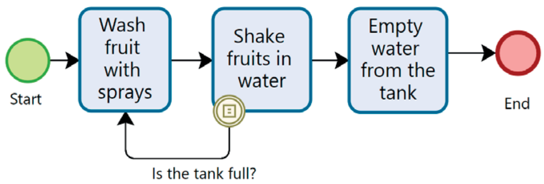

Figure 5. Reusable Fruit Washing Process.

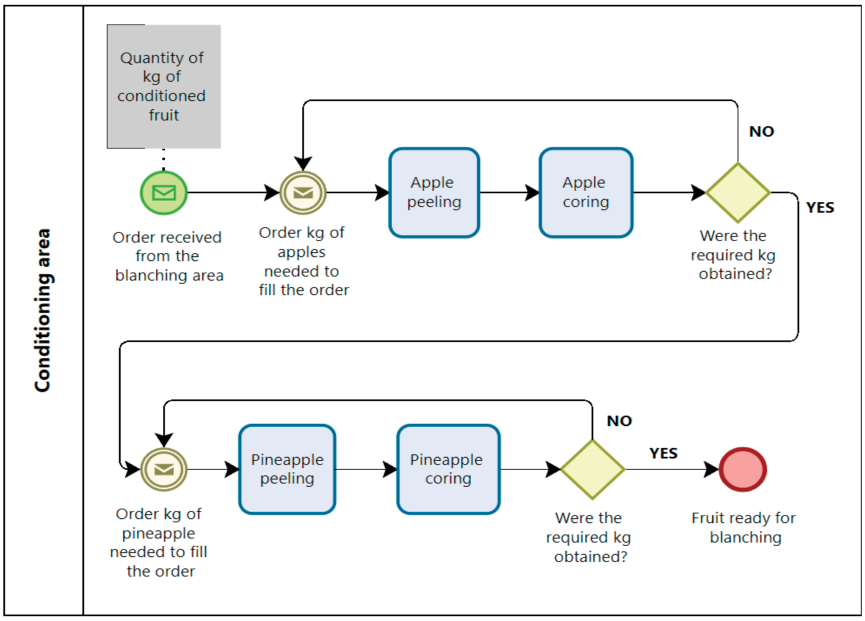

Figure 6. Flow chart of Conditioning area.

- Cycle time: 15, 12 and 25 minutes washing, disinfecting and rinsing respectively.
- Time available: The company has 1 shift from 8:00 am to 5:00 pm, with 30 minutes for lunch and two 15 minute supplements. Thus, following formula (1), the time available was found to be 28800 seconds.

Time available = (Workday – supplements) (1)

- Ecological waste: Water waste was calculated with the meter by the difference of how much water can be wasted under ideal conditions, trying to waste as little as possible, but without affecting the process flow; and how much water is wasted under normal conditions.
- Output: Output is variable, averaging 11.55 kg per day between the two fruits.
- Takt time: The requirement is 70 kg/day, taking into account that the time available is 28800 seconds, we proceeded to calculate the takt time with formula (2), with a result of 411.42 seconds/kg.

Takt time = Time available / Requirement (2)

With the criteria defined, the development of the E-VSM continued, which is shown in Figure 7.

4.2.2. Conditioning area

- Number of operators: 3 operators in charge of all subprocesses.
- Cycle time: 5 and 10 minutes for apple peeling and coring, respectively; and 5 and 15 minutes for pineapple peeling and coring.
- Time available: The company has 1 shift from 8:00 am to 5:00 pm, with 30 minutes for lunch and two 15 minute supplements. Therefore, using formula (1), the time available is 28800 seconds.
- Ecological waste: Fruit waste was calculated by inspecting the waste from the subprocesses checking if there was pulp in the peel that could be used, as well as the waste from the core of the fruit.
- Output: Output is variable, averaging 7.62 kg per day between the two fruits
- Takt time: The requirement is 45.72 kg/day, considering that the time available is 28800 seconds, through the formula of 2, the takt time of the area is 629.92 seconds/kg.

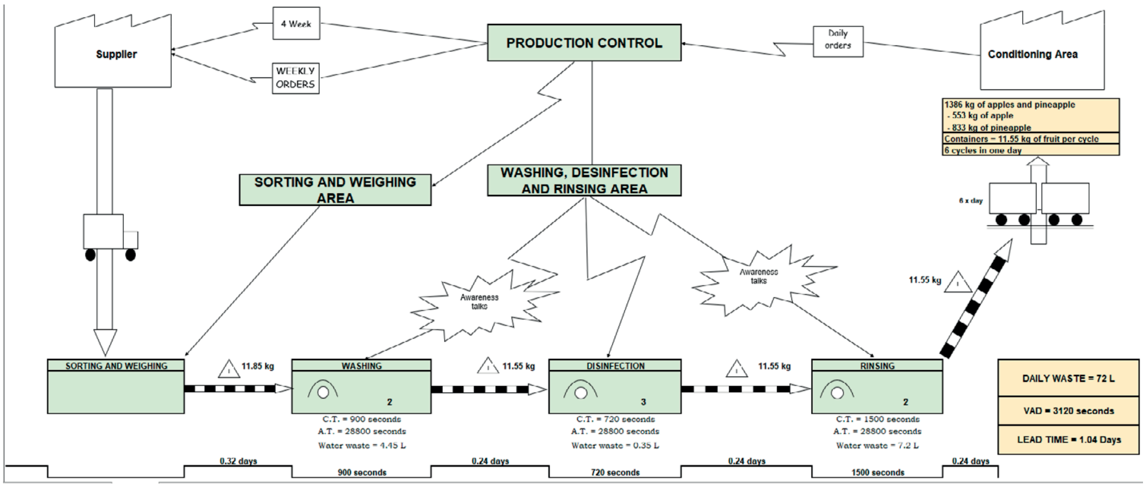

Figure 7. E – VSM of Washing, disinfection and rinsing area.

With the criteria defined, the development of the E - VSM continued, which is shown in Figure 8.

After the implementation of the E-VSM, it was identified that the Washing, disinfection and rinsing area generated a water waste of around 1584 litres of water per month; similarly, it was identified that the Conditioning area generated a waste of 38.5 kg of conditioned fruit per month, which is alarming considering that the environmental impact of conditioned fruit is much greater than that of conventional fruit, since the former went through other subprocesses that increased its ecological footprint.

Finally, we conclude with phase 5 of the method, which refers to the recommendations: The main cause of water wastage in the factory lies in the fact that the operators have no commitment to saving water, sometimes even leaving the pipes open while removing the fruit from the tanks, which aggravates the water wastage.

As can be seen from the Environmental Value Stream Mapping, there is an imminent need to schedule awareness talks to increase operator commitment to water saving and thus reduce environmental impact. In addition, a recirculation system could be implemented, so that instead of discharging process water to the drain after each use, it could be collected and recirculated, for example, for cleaning the facilities, which would significantly reduce consumption in the plant.

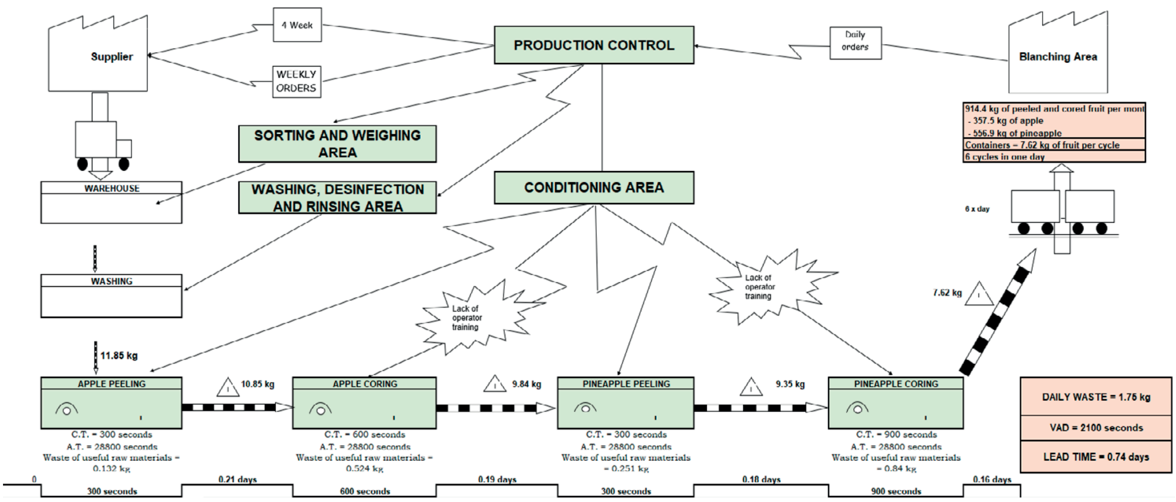

Figure 8. E – VSM of Conditioning area.

In the other subprocess, the main cause of wastage of conditioned fruit is the lack of skill of the operators, who use a very inefficient technique for cutting and coring, which increases wastage. It is recommended to invest in training to improve the working method, and it is also suggested to provide better implements, such as knives in optimum condition and coring machines.

5. Discussion

The situation of food and water waste in the region is alarming and the numbers support the urgency of conducting research and taking concrete action. According to data from the Peruvian Ministry of Environment, it is estimated that approximately 40% of the food produced in the country ends up being wasted at various stages of the supply chain, from production to final consumption. In terms of water, the region faces a critical water scarcity situation. According to the Lima Water and Sewerage Service (SEDAPAL), the demand for water in the city far exceeds the available supply, and it is estimated that more than one million people do not have regular access to safe drinking water. It is therefore essential to carry out research that focuses on increasing sustainability in industries belonging to the food sector.

According to the Peruvian Ministry of the Environment, for a process to be considered sustainable, among other things, its water waste must be less than 5%. Considering that the company wastes 1584 litres of water per month in the washing process, around 7.5%, it is concluded that it must continue to make efforts to reduce it. On the other hand, according to the Food and Agriculture Organisation of the United Nations (FAO), there should be a maximum of 10% food waste per process. In the case of the company, 38.5 kg is wasted per month, which is equivalent to 8%, demonstrating that in this parameter the company is sustainable.

The present research demonstrates the practical usefulness of the developed method, since the main purpose of the method is to identify ecological waste in food industries.

The results obtained are in line with research such as that of Saetta and Caldarelli (2023), in which through Green and Lean integration they manage to reduce waste and environmental impact. Likewise, this research is complemented by the studies of Garza-Reyes et al. (2018), Rodríguez et al. (2019), Giles et al. (2022) or Ortiz et al. (2023) which establish the theoretical importance of the integration of Lean and Green materialised through the E - VSM tool and its implementation in different industries.

This research addressed the question: How can green waste be identified in a nectar factory? The difficulty of working in the food industry lies in the short concept of quality, a term that is limited to food safety, leaving aside the search for excellence and sustainability of processes. However, the literature shows that methodologies such as Green and Lean can expand the concept of quality to reduce waste and environmental impact. Therefore, a Green Lean method was developed with tools such as process mapping, BPMN, E - VSM, among others; and to answer the question, the method was implemented as a case study in a nectar factory in Lima - Peru.

The objective of the research was to identify ecological waste and offer recommendations to reduce the environmental impact and increase the sustainability of the processes. As a final result, it was found that the company in question wastes 1584 litres of water per month and 38.5 kg of conditioned fruit per month.

As a final learning, the results obtained demonstrate the feasibility and profitability of the application of methodologies such as Lean and Green in the food industry, and their application in companies in the same sector is also recommended. However, the method was implemented specifically in the context described in the research, as an opportunity for future research, the possibility of extending the method by identifying the environmental impact generated by green waste through the calculation of the ecological and water footprint is highlighted in order to enhance the results and show the urgency of its treatment.

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