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Operational Model to Improve Productivity by Applying Lean Manufacturing and Circular Economy in an Agricultural SME

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Abstract—Agriculture is essential for sustainability and economic development due to growing demand for food and natural resources. In Peru, the industry has seen recent growth and is crucial for national advancement; however, it faces issues related with low productivity. Specifically, Peruvian agriculture SMEs have labor productivity lower than the average, significant food losses during storage and processing activities, as well as inefficient usage of irrigation water. A case study of a Peruvian company focused on agricultural exports, especially grape production, revealed a productivity rate of 0.77 kilograms of exportable grapes per kilogram of harvested grapes, below the industry standard of 0.85. The research aims to improve productivity of the exportable grapes processes by implementing an Operational Model that integrates lean principles, such as 5S, Standard Work, Kaizen, and Value Stream Mapping, with Circular Economy strategies including 3Rs and Life Cycle Assessment. To verify the effectiveness of the proposed model, the methodology included pilot tests implementations for lean tools and Montecarlo simulation for 3Rs, followed by an integrated simulation in Arena to obtain the final outputs. Results achieved expectations, achieving a 75.59% reduction in water footprint, reducing grape losses to 1.17% and improving the Food Loss Index by 58.31%. Additionally, labor productivity improved with a 38.50% reduction in average worker time for packing activities, resulting in an overall productivity increase to 0.85 kilograms of exportable grapes per kilogram harvested, meeting industry standards. Future research should address seasonal variability, consider reusing tools for irrigation, and conduct feasibility studies to improve storage technologies.

Keywords— Circular economy, food loss, lean agriculture, productivity, water efficiency

I. Introduction

The agricultural sector is crucial for global food security and economic growth, representing 4% of the global Gross Domestic Product (GDP), and over 25% in some developing countries [1]. In Peru, agriculture feeds 33 million people and has outpaced population growth and food imports. The industry has experienced a series of positive changes in recent years, with the sector growing 1.9% in 2022. This growth was driven by increased agricultural production, including a 0.4% growth in production for the domestic market, a 6.2% increase in agro-industrial production, and a 9.9% increase in export production [2]. Furthermore, agriculture contributed approximately 13.6% of total exports in 2023 [3]. However, due to its structural diversity and complexity, Peru's agriculture performance depends on various characteristics of the production areas and processes of value chains, including agroecological factors, climatic and water conditions, technological practices, logistics, and management models [4].

Based on the context and importance of the industry, an evaluation of the agricultural SME sector revealed recurring problems, primarily low productivity. Agriculture has the least productive workers in Peru with a labor productivity of 6500 USD per worker, a situation exacerbated by high food losses during storage and processing stages, as well as inefficient water resource usage [5]. These factors combined significantly impact the overall productivity of agricultural SMEs.

The selected case study is a company that focuses on agricultural exports, and it currently produces a wide variety of fruits and vegetables, including grapes, avocados, mandarins, peppers and onions. This study considers the production of grapes since it presents a low productivity, yielding only 0.77 kilograms of exportable grapes per kilogram of harvested grapes, below the industry standard of 0.85. Additionally, the company faces challenges in food loss management, with a significant 8.97% of Food Loss Index (FLI), exceeding the Agriculture Organization of the United Nations (FAO) standard of 3.75% [6]. These losses primarily occur during packaging and storage due to moisture issues. Furthermore, the labor productivity stands at 19,372 USD per worker, notably lower than the Peruvian standard of 22,700 USD per worker [5]. Lastly, the company's blue water footprint for grapes irrigation, which measures water efficiency, is 426 liters of water per kilogram of harvested grapes, high indicator compared to the standard of 97 liters per kilogram, showing an inefficient water resource usage [7]. Addressing these issues is crucial for enhancing efficiency in the company's operations. It is worth mentioning that recent research has primarily focused on isolated issues such as productivity improvements and food loss reduction in agriculture. A case study showed significant strides in reducing post-harvest losses using Standard Work, Autonomous Maintenance and 5S from 26% to 1% [8]. Additionally, another research applied 5S and lean green, demonstrating improvements in water efficiency by 47% and a reduction in water use by 45% [9]. Hence, integrating holistic solutions than combine lean methodologies with sustainable practices could offer substantial benefits in productivity.

Therefore, this research study seeks to improve the productivity rate of the exportable grapes process by implementing an Operational Model at a Peruvian company. This will involve integrating Lean principles with tools such as 5S, Standard Work, Kaizen, and Value Stream Mapping, alongside Circular Economy strategies including 3Rs and Life Cycle Assessment. This research is crucial due to projected increases in food and water demand, with agriculture playing a pivotal role in global sustenance and economic growth. Despite successful implementations in other sectors, the study approach is underutilized in agriculture, presenting a significant research opportunity to enhance productivity, minimize food loss and using efficiently water resource.

This paper also includes additional sections that summarize the research conducted. For example, it will cover the State of the Art, detailing existing knowledge relevant to the study. The Contribution section will outline the approach of the study's design, variables, data collection procedures and measurement constructs. Results will present finding derived from implementing the Operational Model utilizing Lean principles and Circular Economy strategies. And the Discussion section will interpret these results to analyze their implications in relation to the objectives, thus providing a scope of our conclusions.

II. State of the Art

A. *Lean Manufacturing*

The philosophy of Lean Manufacturing encompasses the entire value chain, from raw material acquisition to the delivery of finished products, with the aim of reducing waste and maximizing the value added to the customer. The most significant benefits of this philosophy are related to cost reduction, lead time, improved quality, and the safety and health of workers [10]. Also, it is a set of tools, practices, and techniques designed to minimize waste and enhance the efficiency of a production system, utilizing the least possible resources [11]. This approach has effectively reduced losses and increased productivity. Tools like 5S, Value Stream Mapping, and Problem-Solving have been successfully implemented in agricultural operations, significantly reducing food losses and waste while increasing productivity, demonstrating lean's adaptability to this industry [12]. Furthermore, methodology of circular economy, Life Cycle Assessment (LCA), can be integrated with Value Stream Mapping (VSM) to evaluate the environmental impacts of products and services, reducing waste by 20% to 50% [13].

B. *The 5S*

The 5S is a methodology based on the workplace's order and cleanliness to standardize its processes. Also, increases the workflow by keeping the work area tidy, improving the workflow and product quality [14]. Its steps are Seiri (Sort), Seiton (Set in order), Seiso (Shine), Seiketsu (Set a standard), and Shitsuke (Sustain). Furthermore, it fosters a well-organized workstation, reducing the time needed to add value and enhancing system performance [15]. Proper application at all organizational levels can improve quality, productivity, efficient space utilization, cost optimization, and establish a safe work environment. For instance, productivity increased by 44% following the implementation of 5S in an agriculture company [16].

Moreover, research has demonstrated that implementing a combination of 5S and Kaizen can effectively reduce material search time by 50%, thereby enhancing labor productivity within a furniture factory [17]. Additionally, implementing 5S alongside Value Stream Mapping eliminated workflow obstacles, leading to a 15% production increase. [18]. This research demonstrates how 5S can address specific agricultural challenges, fostering a more efficient and productive work environment.

C. *Standard Work*

Standard Work is a lean tool, which proposes the best working method for the execution of a given task, avoiding performing random tasks [16]. In a Peruvian coffee farm, implementing Standard Work and Autonomous Maintenance under a lean approach with 5S resulted in a reduction of defective food losses from 16% to 1% and an increase in productivity by 17% [8].

In a Peruvian agro-export company, the utilization of Standard Work and 5S increased productivity from 51% to 74%, reduced waiting time from 79 to 24 minutes, and decreased the percentage of lost time from 53% to 2% [16]. These improvements underscore the efficacy of Standard Work in agriculture, providing optimal conditions for efficient production and significantly reducing waste and work time. Moreover, the combination of 5S and Kaizen with other lean tools, such as VSM, Standard Work, Spaghetti Diagram, and Flow Manufacturing, has enhanced productivity by organizing and cleaning the workplace, thus reducing annual work times by 29% [17].

D. *Kaizen*

Kaizen, which means continuous improvement, derives from the Japanese terms kai (change) and zen (improvement). It is based on Deming's PDCA cycle, comprising the phases plan, do, check, and act. This approach is oriented towards identifying the root causes of problems and introduces corrective measures as well as control procedures [19]. Kaizen employs critical and analytical thinking to find solutions, for that an organization, succeed in applying this methodology, must understand its current state, identify its ideal state, and be determined to bridge the gap between the two. Kaizen focuses on making small, incremental improvements that collectively lead to significant change in a more efficient, lean manner [20]. For instance, implementing Kaizen and 5S reduced defective products by 3.13% and increased productivity by 38% in a Peruvian footwear company [21].

Moreover, the application of 5S, Kaizen, and Autonomous Maintenance to reorganize workstations and improve process flow resulted in a 40% reduction in rejected products [22]. Kaizen has also been proven effective in reducing cycle and lead times. The integration of VSM, 5S, and Kaizen reduced cycle time from 1484.87 minutes to 1480.50 minutes and lead time from 2954.11 minutes to 2947.01 minutes, thereby enhancing operational efficiency [20].

E. Circular Economy

The Circular Economy is a sustainable management tool aimed at reducing waste generation and mitigating global warming. It seeks to retain used materials in the economy for as long as possible, ensuring that waste from one process is not discarded but restored or regenerated as resources for other applications [23].

This tool involves six actions in the water and wastewater: reducing water usage and contamination, removing contaminants with effective technologies, reusing wastewater as a non-potable source, recycling wastewater for potable use, recovering resources like nutrients and energy, and rethinking resource use to create a sustainable, waste-free, and emission-free economy [24].

In the other hand, Circular Economy can be implemented alongside with Lean Manufacturing, as shown in recent research, which has demonstrated potential increases in water efficiency by 47%, reductions in water use by 45%, and simultaneous enhancements in labor productivity by 20% [9].

III. CONTRIBUTION

A. Model Basis

For the development of the productivity improvement model, various proposals analyzed in the literature were taken as references, focusing on the reduction of food losses, unproductive times, and the improvement of water use efficiency. However, many of these studies exclusively focus on Lean Manufacturing to increase productivity without addressing the water resource issue.

Consequently, an integrated model is sought to address both operational problems and water use inefficiency, as both aspects affect the company's productivity and generate unnecessary expenses due to the misuse of resources.

Unlike other models applied in the agricultural sector, the proposed model integrates Lean Manufacturing tools with Circular Economy principles, as seen in Table I. This integration aims not only at optimizing operations but also at promoting sustainability and resource conservation.

B. Proposed Model

The proposed model design is structured into three components aimed at transforming inputs into positive impacts or outputs for the agriculture company, like it is showed in Fig. 1. After reviewing literature, it was decided that the model integrates Lean Manufacturing and Circular Economy tools to enhance productivity and achieve set objectives. The first component involves initial data collection for analysis and diagnosis using engineering tools to define productivity metrics and identify root causes.

TABLE I
COMPARATIVE MATRIX OF SELECTED LITERATURE

Causes Scientific Papers	**Food loss**	**Labor productivity**	**Water inefficiency**
J. Bobadilla-Calderón, C. Martinez-Flores and C. León-Chavarri [8]	Standard Work- 5S	Standard Work- 5S	
A. Sartal, N. Ozcelik and M. Á. Rodríguez [9]			5S - 3R
I. E. Estrada-González, P. Taboada-González, H. R. Guerrero-García-Rojas and L. Márquez-Benavides [13]			VSM-ACV
H. Ramos-Leon, G. Montoya-Valdiviezo, J. Castillo and L. Cardenas [16]	Standard Work - 5S	Standard Work - 5S	
D. Guzel and A. S. Asiabi [17]		VSM-Kaizen-5S - Standard Work	
A. P. Proenca, P. D. Gaspar and T. M. Lima [20]	VSM - Kaizen- 5S		
Proposed tools	**VSM-Kaizen-5s**	**VSM-Standard Work-5S**	**LCA-5S-3R**

The second component focuses on a systematic review of Lean Manufacturing and Circular Economy tools to address identified issues. Solutions include Kaizen and 5S for food loss reduction, Standard Work and 5S to improve labor productivity in grape packing and utilize workspace efficiently. Additionally, 5S initiatives and Circular Economy tools are applied to reduce water consumption, targeting water efficiency challenges. Finally, the third component entails implementing the solution proposal through pilot testing, Monte Carlo simulation, and Arena simulation to assess the impact on predefined study case indicators.

C. Model Components

To develop the proposed model, three components have been used as indicated in Fig. 1. Therefore, each component of the model will be explained in detail.

1) Component 1: Data collection

The first component begins with data collection which was conducted using Value Stream Mapping (VSM), a Problem Tree, and Life Cycle Assessment (LCA) to identify the underlying reasons and root causes of the primary issue, and to propose the most appropriate tools.

2) Component 2: Engineering tools

A systematic literature review was conducted to investigate the application of tools addressing identified root causes and issues, as well as case studies similar to the current project. These findings were used as a basis for the model's development.

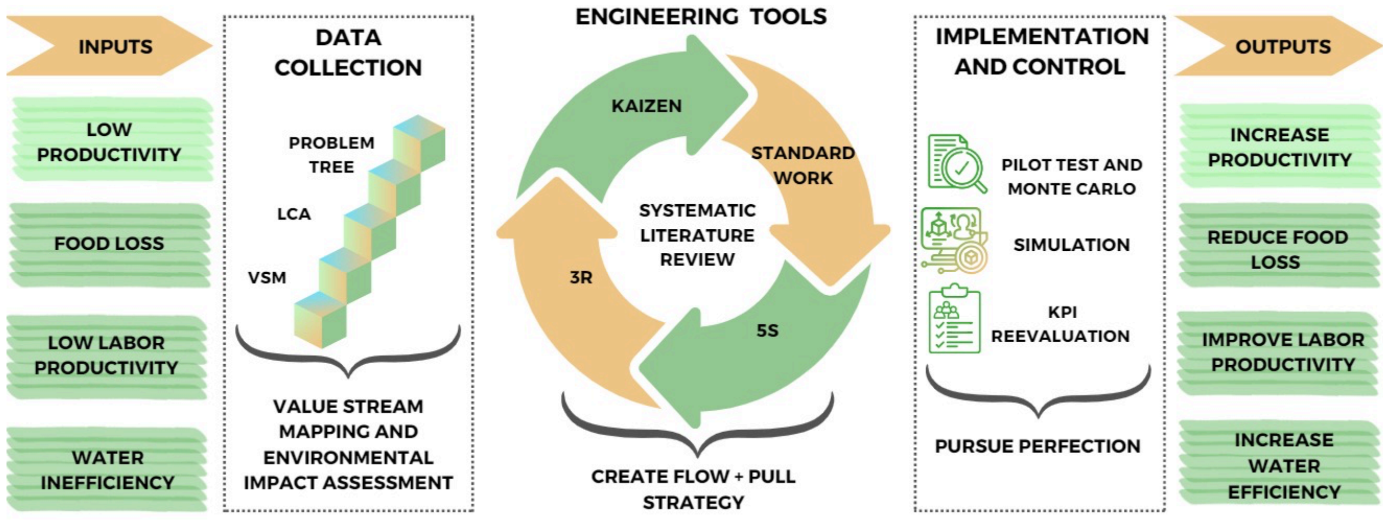

Figure 1. Proposed improvement model

a) Water inefficiency: 5S and 3R

The implementation of 5S aims to reduce water usage through two possible approaches, namely the "direct path" and the "indirect path". Choosing the direct path involves reusing irrigation water, while the indirect path focuses on reducing overall water consumption. Both options contribute to improving water efficiency, a critical factor affecting productivity. Additionally, soil moisture analysis using a tensiometer was conducted on a crop. Moisture levels were measured at a depth of 40 cm for five consecutive days, both before and after irrigation. The results of this experiment demonstrated a reduction in the amount of irrigation water used, and a percentage reduction in water usage was calculated by applying the 3R reduction strategy.

b) Food Loss: 5S and Kaizen

The methodology was implemented in five stages. In the first stage, Sort, unnecessary items were removed from the workstation, retaining only those essential for the activity. The second stage, Arrange, focused on organizing the workspace based on usage frequency and implementing labeling and space delineation for workstation items. In the third stage, Clean, work areas were cleaned, and a waste bin was added for discarded grapes. The fourth stage, Set a Standard, involved creating a board with quality specifications for each target market: American, European, and Asian. These served as visual references to ensure that the kilograms of grapes passing through selection met the required standards for each market, thereby minimizing the rejection of conforming kilograms. Additionally, a daily evaluation of grape losses per operator was conducted to measure and record the Processing Losses Index, aiming for continuous improvement in each reassessment. Finally, in the fifth stage, Sustain, training sessions titled "Manufacturing with 5S and Kaizen" were conducted for workers involved in grape selection. This training reinforced the importance of meeting each client's quality specifications and emphasized the significance of maintaining established standards.

c) Labor Productivity: Standard Work and 5S

The methodology was implemented in five stages. In the first stage, Sort, non-value-adding activities in the packaging process were eliminated, and a new standardized process was developed. A visual aid board outlining the procedure was created in the area. In the second stage, Arrange, bags and boxes were labeled for each market, and workstation materials were organized with the addition of organizers. In the third stage, Clean, cleaning standards for the area and equipment were verified, and a maintenance plan was established and monitored through a checklist. The fourth stage, Set a Standard, involved implementing a standard work board displaying the activity sequence dynamically, allowing for the recording of the Average Time per Worker for Packing daily. Finally, in the fifth stage, Sustain, training sessions titled "Manufacturing with 5S and Standard Work" were conducted for workers in the packing area. This training focused on the implemented tools and the new standardized processes.

3) Component 3: Implementation of the simulation model

This final component involved implementing the proposed solution. In this case study, a pilot of the 5S-Kaizen and Standard Work-5S tools were conducted during the company's processing phase. Additionally, a Monte Carlo simulation in Excel addressed water inefficiency. Based on the obtained data, the solution's validation was carried out through a simulation comparing pre- and post-proposal data. The current and proposed flows were modeled in Arena, incorporating changes from the lean tools applied. Running the model yielded KPIs for both scenarios, enabling a comparison to verify the achievement of objectives such as increasing productivity, reducing food loss, enhancing labor productivity, and improving water efficiency.

D. Indicators

The implementation process and outcomes will be monitored using specified indicators to demostrate the enhancements achieved though the tools outline in the model.

- Productivity: This indicator allows to measure the general efficiency of resource utilization in generating goods, in this case, kilograms of exportable grapes.

$$Productivity = \frac{kg\ of\ exportable\ grapes}{kg\ of\ harvested\ grapes}$$

- Blue Water Footprint: It quantifies the volume of water used specifically for irrigation and harvesting a certain amount of grapes. This metric provides a direct assessment of water consumption in agriculture, providing insights into water resource management.

$$Water\ footprint = \frac{lt\ of\ water}{kg\ of\ harvested\ grapes}$$

- Food Loss Index (FLI): It measures the total losses incurred during the processing and storage stages of grapes. This indicador is crucial for identifying areas of improvement to reduce waste.

$$FLI = \frac{kg\ of\ lost\ grapes}{kg\ of\ exportable\ grapes} x100$$

- Processing Losses Index (PLI): It measures the loss of grapes at the selection station during processing, typically categorized as wastage due to noncompliance with quality specifications.

$$PLI = \frac{kg\ of\ lost\ grapes\ at\ "Selection"}{kg\ of\ exportable\ grapes} x100$$

- Average Time per Worker for Packing: It refers to the amount of time it takes for an operator to complete the tasks at the packing station. This metric helps assess operational efficiency and labor productivity in the packing process. It is determined through a time study in the company

$$Average\ Time = \frac{Average\ minutes\ per\ worker}{one\ box}$$

- Labor Productivity: It measures the economic output per worker, reflecting efficiency in utilizing labor resources for grape production and packing, thereby indicating the company's ability to reduce labor costs

$$Labor\ Productivity = \frac{Value\ added\ in\ dollars}{Number\ of\ workers}$$

In the following table, it can be seen the initial values and the target objectives for each indicator presented.

TABLE II
INITIAL INDICATORS VS EXPECTATIONS

Indicators	As Is	To Be
Productivity (kg/kg)	0.77	0.83
Blue water footprint (lt/kg)	426	234
Food Loss Index (%)	8.97%	3.81%
Processing Losses Index (%)	6.20%	1.36%
Average Time for Packing (min)	4.00	2.84
Labor Productivity ($/worker)	19,372	23,060

In this manner, through the development of the selected tools and the validation previously presented, productivity is anticipated to increase by 7.8%. This enhancement is driven by improvements in other key indicators, addressing the three primary factors impacting overall productivity, such as inefficient usage of irrigation water, grape losses, and low labor productivity.

III. VALIDATION

In this study, validation is carried out in a Peruvian agro-export company dedicated to the production of fruits. For this research, the exportable grape production process is selected as the focus. The sources of information to evaluate come from this process including the harvesting phase. Previously, a diagnosis has been made, and the causes of the main problem have been identified. Furthermore, the engineering tools were selected, and finally, the integrated model was proposed to validate the solution and achieve the objectives of the case study.

A. Initial Diagnostic

Given the challenges observed in the selected case study, which directly impact the harvesting and production system, the primary issue identified is the current low productivity. The company reported a productivity level of 0.77, while a study on the productivity and efficiency of SMEs in the agriculture sector indicated that the global average productivity standard for the industry is 0.85 [16]. This gap in the indicator leads to a significant economic impact, amounting to 0.7 million USD per year, which is equivalent to 22.48% of the gross margin for the period under study. The main contributors to this economic loss are inefficient irrigation water usage, a high number of workers in the processing station, and significant grape losses; these factors directly affect profitability.

The root causes of low productivity were identified as follows: Inefficient water usage, high food losses due to non-compliance with quality specifications during selection because of poor handling and non-standardized operations, and low labor productivity due to a high number of workers with unproductive time, caused by a lack of standardization in packing activities.

B. Validation Scenario

The validation model for the project consisted of two phases. The first phase involved the implementation of Kaizen-5S and Standard Work – 5S as a pilot test in a confined area of the company, along with a Monte Carlo simulation for Circular Economy – 5S. The second phase simulated the entire process in Arena, using the results obtained from the first phase as inputs.

First, for the development of the Monte Carlo simulation, 10,000 random data points were generated based on the statistical distribution that best fits the blue water footprint indicator for the 36 harvest plots. Additionally, the pilot tests results pertain to the application of lean tools over a one-week period for the operations of Selection and Packing, to analyze grape losses and labor productivity. In this phase, preliminary results from the application of the tools are obtained to be used as inputs in the next stage.

Second, the base functional model is developed in two parts. The first one represents the harvesting and irrigation process of the grapes, modeling three harvests, each lasting approximately one month. The second part models the grape processing, including activities of Selection and Packing, with times determined by the appropriate statistical distributions. In these three processes, identified problems will be addressed using engineering tools, utilizing inputs obtained from the first phase.

C. *Validation Design Improvement*

1) *Monte Carlo Simulation*

A Monte Carlo simulation was conducted to validate the use of the 5S and 3R methodologies in improving water efficiency during grape irrigation. The simulation was based on a sample of 36 data points representing the water footprint during the last harvest season. Using the Input Analyzer tool, an exponential distribution was identified as the best fit, and 10,000 random data points were generated to simulate irrigation behavior.

Initially, the average blue water footprint for the orchard was 426 liters per kilogram of harvested grapes. Soil moisture analysis was performed using a tensiometer on plot L1S5, which cultivates Melody grapes over 5.8 hectares. Measurements were taken at a depth of 40 centimeters over five consecutive days, both before and after irrigation. The results indicated that daily irrigation was unnecessary, as soil moisture remained between 15% and 25%, sufficient for optimal crop absorption. To verify, irrigation was paused for three days, during which soil moisture stayed above 15%, demonstrating excessive water use.

Based on these findings, the 5S and 3R methodologies were implemented to reduce the orchard's water footprint, targeting the standard value of 96. By establishing water usage procedures, the orchard can pursue water reuse or reduction strategies, decreasing environmental impacts and costs.

The simulation modeled a 90-day cultivation and harvesting period. The study concluded that irrigation every three days maintains soil moisture above the optimal 15% level, reducing irrigation days to 22 out of 90, and decreasing water use by 75.59%. This reduction factor was applied to the improved scenario in the Monte Carlo simulation, resulting in a new blue water footprint of approximately 103.74 liters per kilogram of harvested grapes. The improved indicator will be used as input for the consolidated model in Arena.

2) *Pilot plan*

- Kaizen y 5S

The first pilot test was conducted in the selection area, where the current process involves the selection of grapes based on appearance and quality specifications for the American, European, and Asian markets. Daily, 18 operators process approximately 65,282 kg of grapes in this area, with about 4.7% of them being discarded. Currently, there is no adequate manual to instruct operators on the distinctions in appearance and quality for each market, which, along with poor handling of grapes and disorganization in the workstation, results in high levels of losses compared to the standard recommended by the FAO. Therefore, a pilot was implemented using Kaizen and 5S tools to organize the work area and establish manuals that guide continuous improvement of the indicator. The main objective of this pilot is to reduce Processing Losses Index, which has been identified as a problem due to non-compliance with the quality specifications for each market.

For the pilot implementation, unnecessary elements were removed from the workstation, keeping only those necessary for the activity. Additionally, spaces for each element in the station were labeled and delineated, and a waste bin was added. A board with the quality specifications for each target market was created to be used as a visual reference to ensure that the kilograms of grapes passing the selection meet the standards required in each market and that compliant kilograms are not discarded. Furthermore, a daily evaluation of grape losses by each operator was included to measure and record the Processing Losses Index and continuously improve the percentage in each re-evaluation. Moreover, a training session was conducted for workers involved in grape selection. The session, attended by 25 workers, covered the implemented tools, emphasizing the importance of meeting each client's quality specifications and maintaining established standards. Fig. 2 illustrates the workstation before and after the implementation of the lean tools.

Figure 2. Before and after implemented Pilot Kaizen y 5S in Selection area.

Following the implementation of the tools in the selection station, 40 kilograms of grapes were processed per day for one week (5 boxes per day and 8 kilograms per box). As a result, only 1% of the grapes that entered the Selection process were discarded due to non-compliance, representing a significant improvement compared to initial loss levels.

- Standard Work y 5S

The second pilot test was conducted in the packing area, which immediately follows the selection process. Currently, this process suffers from low labor productivity, requiring approximately 70 operators to pack all daily orders. This inefficiency is due to the lack of standardization in packing activities, as well as poor organization in the work area. Operators begin by weighing a bunch of grapes from the selection process, placing it in a special package according to the market (American, European, or Asian), and then selecting a box to place the bagged grapes. This process is repeated eight times to fill a box with eight 1-kilogram bags, which are then packaged. A time study revealed that the weighing, previously completed during selection, is redundant and does not add value. Currently, it takes an operator 4 minutes to pack a box of grapes, significantly longer than the standard of 2.87 minutes. The workstation for each operator consists of a table with a scale, hangers for the bags, and boxes placed underneath. There is no clear distinction between bags and boxes by market destination, causing additional delays and inefficiencies. Therefore, a pilot was implemented using Standard Work and 5S tools to standardize tasks and organize the work area, aiming to reduce the Average Time per Worker for Packing.

For the pilot implementation, non-value-added activities were eliminated from the packing process, and a new process with standardized activities was established. This was displayed on a board in the area for easy visualization and application. Additionally, the work area and materials were organized and cleaned to facilitate ease of activities. Bags were labeled for each market, and station materials were organized with the addition of organizers. Boxes were also labeled and organized by market. Moreover, a standard work board was implemented to dynamically display the sequence of activities and record the daily Average Time per Worker for Packing. Finally, a training session was conducted for workers involved in packing area. The session, attended by 25 workers, covered the implemented tools, their application in the area, the new standardized processes, and the organized work area. Fig.3 and Fig. 4 illustrate the workstation before and after the implementation of the lean tools.

Figure 3. Labeling of bag and box for target market

Figure 4. Before and after implementation of Pilot Test for Standard Work and 5S in Packing area

Following the implementation of these tools in the station, 5 boxes per day were processed over one week. As a result, a time study conducted during this period revealed a significant reduction in the Average Time per Worker for Packing to 2.46 minutes per box, representing a 38.5% improvement.

3) Simulation of improvement proposal

A simulation was conducted using Arena software to validate the feasibility of the tools mentioned in the integrated model and verify their operational efficiency.

In this section, the simulation conditions were defined, including system scope, variables, sample size, entities, implementation areas, resources, failures, and frequencies.

The simulation begins with grape harvesting, generating entities corresponding to the harvest cycles with inter-arrival times uniformly distributed between 28 and 33 days to simulate three consecutive harvests. Each entity is assigned a quantity of grapes to be harvested, uniformly distributed between 2,500,000 and 2,750,000 kilograms. Subsequently, water consumption during irrigation is modeled with an unlimited resource of 426 liters per kilogram of grapes, determined by the Monte Carlo simulation. As a result, the total harvested grapes are accounted after the three arrivals.

In the second part, the simulation covers the processing and packing of the harvested grapes. Here, the continuous arrival of grapes to the daily process is managed efficiently. Specifically, daily quantities of grapes to be processed are established, uniformly distributed between 65,000 and 65,500 kilograms. The processing stages include reception, weighing, gas treatment, and selection, with specific times per kilogram of 0.0276, 0.0276, 0.01379, and 0.2482 seconds, respectively. After selection, 95.3% of the grapes pass, and 4.7% are discarded. Subsequently, packing is performed in 25 to 35 seconds per kilogram. Following a 24-hour storage period, 97.3% of the grapes are deemed exportable, while 2.7% are lost during storage. Ultimately, the simulation concludes with the proper management of discarded products. Fig. 5 shows the proposed model simulated and configured in Arena software with the mentioned parameters.

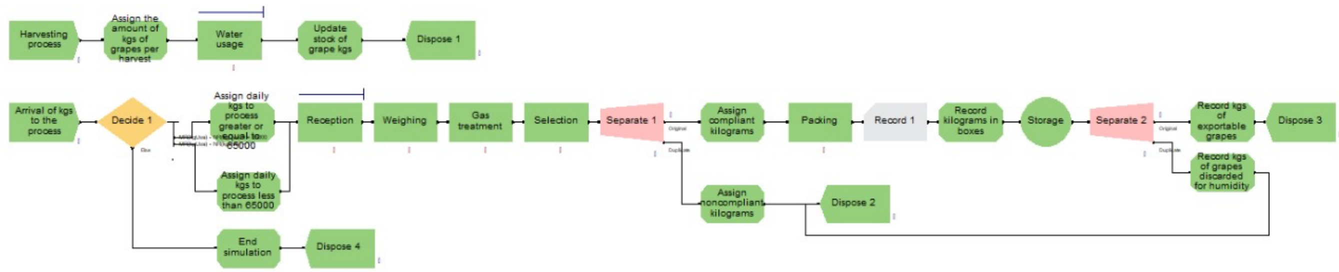

Figure 5. Simulation of the improved grape harvesting and production process

Following the Monte Carlo simulation, the application of the pilot plan based on Lean Manufacturing, and the Arena simulation, a new measurement of the indicators was conducted. Consequently, the results are presented in Table III.

TABLE III
ARENA SOFTWARE INDICATORS RESULTS WITH 132 REPLICATIONS

Indicators	Average	Standard Deviation	Minimum Value	Maximum Value
Productivity (kg/kg)	**0.85**	**8.06 x 10^{-3}**	**0.83**	**0.87**
Blue water footprint (lt/kg)	104	7.89 x 10^{-6}	104	104
Food Loss Index (%)	3.74%	1.11 x 10^{-4}	3.71%	3.77%
Processing Losses Index (%)	1.17%	1.11 x 10^{-4}	1.15%	1.20%
Average Time for Packing (min)	2.46	2.05 x 10^{-2}	2.41	2.51
Number of workers	45	3.87 x 10^{-1}	43	46

The results obtained using the Output Analyzer tool for the improved scenario are presented, with a 95% confidence level. The productivity indicator showed that, for every kilogram of harvested grapes, an average of 0.85 kg is exportable, with an interval of [0.83; 0.87] and a standard deviation of 8.06 x 10 -3, indicating high precision and low variability. Likewise, the remaining indicators demonstrate precise estimates with narrow confidence intervals and low standard deviations, affirming the reliability and consistency of the improved scenario.

The comparison presented in Table IV shows a significant improvement in productivity, confirmed by a paired-t test indicating statistical significance. The blue water footprint saw a notable reduction from 426 lt/kg to an average of 104 lt/kg. Similarly, the Food Loss Index decreased significantly, and the Processing Loss Index followed suit, indicating statistically significant differences based on a paired-t test. Finally, the average time for packing per box was reduced from 4 to 2.46 minutes, and consequently, the number of workers required for this activity decreased from 70 to 45, indicating a substantial reduction in labor need in the improved scenario.

TABLE IV
INITIAL INDICATORS VS FINAL RESULTS

Problem / cause	Indicators	Initial Situation	Improved	Variation
Main Problem	**Productivity (kg/kg)**	**0.77**	**0.85**	**+10.39%**
Inefficient water usage	Blue water footprint (lt/kg)	426	104	-75.59%
Food Loss	Food Loss Index (%)	8.97%	3.74%	-58.31%
	Processing Losses Index (%)	6.20%	1.17%	-81.13%
Low Labor Productivity	Average Time for Packing (min)	4.00	2.46	-38.50%
	Labor Productivity ($/worker)	19,372	23,300	+20.28%

IV. DISCUSSION

A. *Scenario vs Result*

The proposed model that seeks to increase the operational efficiency of an SME in the agricultural industry using Lean Manufacturing and Circular Economy tools can be adapted to other enterprises facing similar problems identified in this study, such as low productivity, water inefficiency, food loss, and low labor productivity. The results of the model application are presented in Table IV.

Regarding water inefficiency, initially, the cultivation stage exhibited a water footprint of 426 liters per kilogram of harvested grapes. Following the implementation of 5S and 3R tools in the irrigation stage, this indicator was reduced on average to 104 liters per kilogram of grapes harvested, representing an improvement of 75.59%. While these results surpass those achieved by previous studies that reported a 45% reduction in water consumption [9] using similar tools, they still do not meet the industry standard of 97 liters per kilogram of grapes harvested [7], primarily due to the high initial indicator value, suggesting a potential need for additional technology-related tools to reach global standards.

In addition, regarding the indicators of Processing Losses Index, the baseline model showed an average of 6.2%. With the implementation of 5S and Kaizen tools, these losses were reduced to 1.17%, implying an 81.13% improvement. These outcomes align with a previous study reporting a 78% reduction in losses applying these tools in a coffee agricultural company

[8]. Moreover, the Food Losses Index, considering losses in processing and storage, improved by 58.31%, approaching the 3.75% standard [6].

Additionally, an improvement in labor productivity was observed. The Average Time per Worker for Packing decreased from 4 minutes per box in the baseline model to 2.46 minutes with the implementation of Standard Work and 5S, representing a 38.5% improvement and approaching the standard time of 2.87 minutes per box for this activity. These results surpass the 29% improvement in average time reported in a similar study [17]. This improvement leads to a reduction in the number of operators in the packing process from 70 to 45, as well as a 20.28% increase in labor productivity.

Finally, the company initially had a productivity of 0.77 kilograms of exportable grapes per kilogram of harvested grapes. After the improvements, this indicator increased to 0.85, reflecting a 10.39% improvement. Compared with other studies reporting improvements of 17% and 23%, these enhancements are significant [8][16]. Considering the company already had more efficient productivity values than the industry average in the country, these improvements are aimed at approaching global productivity standards.

B. *Economic impact*

The implementation of improvements requires a total investment of 17,122 USD, covering costs for materials, training, additional labor, and other expenses. Additionally, projected annual savings and costs associated with the improvement were calculated over a three-year period to assess economic feasibility. A leveraged beta of 1.25, factoring 40% debt and 60% equity for the initial investment, was used to calculate a Cost of Capital of 12.20% using the CAPM method, considering market return, risk free rate, and country risk. Furthermore, sensitivity analysis scenarios anticipate an average Net Present Value of 271,091 USD. This indicates that the project is economically viable and will bring profits to the company.

C. *Social impact*

First, the Balance of Trade indicator was calculated, which shows a positive value of 1.3 million USD due to the increased kilograms of exportable grapes without any imports. This surplus can positively impact regional development through reinvestment in local infrastructure and corporate social responsibility programs, as well as contribute to the national balance of payments. Additionally, the foreign exchange earnings indicator was calculated to be 0.0136, indicating that for each monetary unit invested, the company generates a significant amount of foreign exchange. This demonstrates high capital efficiency in increasing export revenues.

D. *Environmental impact*

An environmental impact analysis was conducted using the Leopold Matrix, rating magnitude and importance of each impact from 1 to 10 for grape cultivation and processing, to compare the initial and final situation after the application of engineering tools. The Table V details the evaluation criteria of the aggregate impact, which is calculated by summing the multiplications of magnitude and importance for each individual impact. The criteria apply to both positive and negative values.

TABLE V
EVALUATION CRITERIA FOR AGGREGATE IMPACT

Impact Type	Evaluation criteria
Low impact	1-30
Medium impact	31-61
Severe impact	62-92
Critical impact	>93

In the following table, the variation in the aggregate impact has been beneficial, as the impacts for irrigation and selection activities have been significantly reduced. This is due to the implementation of improvements that have optimized water use and reduced waste generation, thereby reducing negative impacts on water quality, soil, and biodiversity. However, in the packing stage, employment generation has been adversely affected, as improved productivity has led to job reductions, decreasing the positive impact in this socioeconomic aspect.

TABLE VI
VARIATION OF LEOPOLD MATRIX

Environmental Impact	As Is	To Be
Water depletion	-40	-12
Water quality degradation	-56	-12
Soil quality degradation	-42	-6
Soil contamination	-25	-4
Biodiversity alteration due to irrigation	-30	-6
Biodiversity alteration due to waste	-12	-1
Employment generation	56	35
Aggregate impact	**-149**	**-6**

IV. CONCLUSION

The case study has demonstrated that implementing an operational model that integrates lean principles and tools, alongside Circular Economy strategies, can enhance the productivity rate in an agricultural SME. This comprehensive approach addressed root causes such as food loss in processing activities, inefficient water usage for irrigation, and low labor productivity in packing, leading to more sustainable and efficient operations.

The combination of improvements implemented in the identified issues resulted in a significant increase in overall productivity in the case study, rising from 0.77 to 0.85, marking a 12.24% improvement and aligning with industry standards. These enhancements aim to bridge existing technical gaps and achieve global productivity benchmarks, thereby enhancing sustainability and competitiveness in Peru's agro-export sector. The limited adoption of lean tools in the industry underscores the transformative potential of this integrated model for enhancing productivity in agricultural SMEs. It promises substantial economic benefits, such as an annual increase of approximately 1,602,638 USD with a modest investment of 17,122 USD. Moreover, these improvements bolster environmental sustainability by reducing impacts and contribute to social sustainability.

Future research should address seasonal variability in agricultural product availability, expanding beyond exported grapes to include other fruits and seasons for a comprehensive productivity analysis. It's also crucial to broaden the scope of tools beyond current limitations in time and resources. For instance, implementing the 3R approach (reduce, reuse, recycle) for irrigation water management could help achieve industry standards for water footprint reduction, especially through technologies facilitating water reuse in irrigation. Additionally, improving storage technologies to reduce grape losses, despite current technological constraints, should be explored. Feasibility studies for integrating new technologies are essential for optimizing the proposed model and identifying improvements across the value chain stages.

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