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Proposal to enhance efficiency and minimize waste in spinach processing using preventive maintenance, process standardization, and circular economy approaches

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Dedicatoria

Dedico este trabajo a mi familia y a mis amigos más cercanos, quienes han sido mi mayor fuente de inspiración para mantenerme firme, perseverar y dar siempre lo mejor de mí. Asimismo, le dedico esta investigación a mis amigos más cercanos, quienes han compartido conmigo cada etapa de este camino, brindándome su compañía sincera y su apoyo constante.

Juan Diego Guerra Caro

Dedicatoria

Dedico este trabajo de titulación a mis padres y a mi hermana —Eber, Yaquelin y Hillary— por su amor, compromiso y apoyo constante a lo largo de toda mi carrera universitaria. También dedico este logro a mis amigos y a Dios; quienes han sido un pilar emocional y un soporte invaluable en mis momentos más difíciles, acompañándome siempre con paciencia y cariño. Finalmente, deseo dedicar este trabajo a mi perrita Sushi, cuya compañía fue esencial en las largas noches de estudio e investigación.

Greisy Vicky Palomino Retis

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Agradecemos profundamente a Dios por guiarnos y darnos fortaleza durante todo este proceso. Expresamos también nuestra gratitud a nuestras familias, por su apoyo constante y por acompañarnos en cada etapa de nuestra formación. Del mismo modo, extendemos nuestro sincero agradecimiento al profesor José Carlos Álvarez, al Dr. Orkun Yildiz y a la profesora Aracelli Macassi, cuya dedicación y orientación fueron fundamentales para el desarrollo del presente trabajo.

Juan Diego Guerra Caro & Greisy Vicky Palomino Retis

Resumen

El presente estudio se basa en la investigación, desarrollada por los autores, titulada “Re-Designing Business Process Models for Enhancing Sustainability in Spinach Production Through Lean Tools with Digital Transformation”, la cual se encuentra debidamente citada y referenciada en el presente documento como parte del proceso de formalización de la tesis en formato de artículo científico.

La investigación aborda la problemática de una empresa agroindustrial dedicada al procesamiento de espinaca, que enfrenta un elevado nivel de residuos orgánicos en su línea de producción. Las principales causas identificadas son la ausencia de un plan estructurado de mantenimiento preventivo, la deficiente organización del almacén y la falta de procedimientos estandarizados durante el proceso de lavado. Estos factores afectan la eficiencia operativa, el desempeño de la maquinaria y la rentabilidad. El propósito de la investigación es diseñar e implementar un modelo de mejora integral que incremente la eficiencia del proceso y minimice la generación de desperdicios, promoviendo prácticas sostenibles alineadas con los principios de la economía circular.

Para abordar la problemática, se aplicó un plan piloto basado en el ciclo PDCA (Plan–Do–Check–Act). En la fase de planificación se mapearon los procesos críticos y se capacitó al personal en mantenimiento preventivo bajo el enfoque TPM, orientado a reducir fallas y tiempos improductivos. En paralelo, se implementó el sistema de gestión FIFO (First In, First Out) para optimizar la rotación de productos en el almacén. Además, se capacitó al personal mediante la estandarización de procesos, que permitió establecer procedimientos correctos conforme a la normativa para el lavado de espinaca. Finalmente, se aplicó una propuesta de economía circular, que posibilitó la reutilización de residuos sólidos como insumo para compostaje.

La implementación del modelo generó resultados tangibles: la proporción de producto no conforme se redujo del 4.45% al 1.33%, los productos retirados oportunamente del almacén aumentaron del 98.48% al 99.73%, la eficiencia del proceso de lavado mejoró al incrementar el porcentaje de producto lavado correctamente del 98.17% al 99.47%, y la tasa de recolección (QCR) alcanzó el 98.12%, superando la meta del 97%. Estos indicadores evidencian una mejora sustancial en la eficiencia operativa, la trazabilidad y la sostenibilidad productiva.

El estudio demuestra que la integración de estrategias de mantenimiento preventivo, estandarización de procesos y economía circular constituye una solución efectiva para optimizar la eficiencia y reducir la merma en empresas agroindustriales. Asimismo, el modelo validado puede replicarse en otras industrias del sector alimentario, aportando valor a la sostenibilidad y competitividad empresarial en el contexto peruano.

Este trabajo originalmente fue publicado en Guerra, J. D., Palomino, G., Yildiz, O., Macassi, I. A., & Alvarez, J. C. (2025). Re-Designing Business Process Models for Enhancing Sustainability in Spinach Production Through Lean Tools with Digital Transformation. Sustainability, 17(13), 5673. https://doi.org/10.3390/su17135673.

Palabras clave: PDCA; TPM; FIFO; economía circular; sostenibilidad operativa.

Proposal to enhance efficiency and minimize waste in spinach processing using preventive maintenance, process standardization, and circular economy approaches

Abstract

The present research is based on the research conducted by the authors, entitled "Re-Designing Business Process Models for Enhancing Sustainability in Spinach Production Through Lean Tools with Digital Transformation," which is duly cited and referenced in this document as part of the process of formalizing the thesis in scientific article format.

This study addresses the challenges faced by an agro-industrial company dedicated to spinach processing, which presents a high level of organic waste along its production line. The main causes identified include the absence of a structured preventive maintenance plan, inefficient warehouse organization, and a lack of standardized procedures during the washing process. These factors affect operational efficiency, equipment performance, and profitability. The purpose of the research is to design and implement a comprehensive improvement model that increases process efficiency and minimizes waste generation while promoting sustainable practices aligned with the principles of the circular economy.

To address this issue, a pilot plan based on the PDCA (Plan–Do–Check–Act) cycle was implemented. During the planning phase, critical processes were mapped, and personnel were trained in preventive maintenance under the TPM (Total Productive Maintenance) approach, aimed at reducing failures and unproductive downtime. In parallel, the FIFO (First In, First Out) inventory management system was implemented to optimize product rotation in storage. Personnel were also trained through process standardization, which allowed for the establishment of proper procedures in compliance with regulations for spinach washing. Finally, a circular economy proposal was applied, enabling the reuse of solid spinach residues as inputs for composting.

The implementation of the proposed model generated tangible results: the proportion of nonconforming products decreased from 4.45% to 1.33%, on-time product withdrawals from storage increased from 98.48% to 99.73%, the efficiency of the washing process improved by increasing the percentage of correctly washed products from 98.17% to 99.47%, and the collection rate (QCR) reached 98.12%, surpassing the established goal of 97%. These indicators demonstrate a substantial improvement in operational efficiency, traceability, and production sustainability.

This work shows that using planned maintenance, standard methods, and recycling strategies is a great way to make agro-businesses more efficient and cut down on trash. Also, this tested model can be used again in other food industries. This helps make businesses in Peru more sustainable and competitive.

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Keywords: PDCA; TPM; FIFO; circular economy; operational sustainability.

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1. Introduction

The agro-industrial sector represents a fundamental component of Peru's national economy, serving as a key driver of growth and international competitiveness (Taghikhah et al., 2021). This industry has demonstrated strong performance in both domestic and global markets through the successful production and commercialization of high-value agricultural goods (López et al., 2022). Its economic relevance is underscored by the USD 6.113 billion in agricultural exports reported in 2022, marking a 23.5% increase from the previous year (Ministerio de Desarrollo Agrario y Riego [MIDAGRI], 2022).

Despite this progress, a critical challenge persists excessive organic waste generated in the spinach processing line of a Peruvian agro-industrial company dedicated to the cultivation and commercialization of fresh produce. This issue negatively affects productivity, limits sales, and reduces profitability (Ortiz-Porras et al., 2023). The magnitude of the problem becomes evident when observing the company's technical gap of 21.07%, given that the maximum acceptable loss in regional agro-industrial processing is approximately 5% annually (Bueno-Solano et al., 2022), while the spinach line currently reaches 26.07% waste. These inefficiencies translate into direct economic losses estimated at USD 39,992 due to rejected orders. Therefore, the objective of this research is to demonstrate, through evidence-based analysis, that the current spinach production process presents failures that hinder operational efficiency, process improvement, and the production capacity required to meet customer demand (Fikry et al., 2021).

To address these issues, an integrated improvement model was formulated and implemented, combining Total Productive Maintenance (TPM), FIFO inventory management, process standardization, and circular economy strategies. Together, these tools support a systemic approach to operational optimization while providing practical mechanisms for personnel to enhance their understanding and execution of daily factory operations.

This paper is structured into five main sections. First, a review of the literature summarizes the key concepts and successful applications of TPM, FIFO, standard work, and circular economy, along with the regulatory framework relevant to the industry. Second, the proposed improvement model is presented, including the rationale behind its design and the indicators selected for validation. Third, the implementation phase is described, detailing the activities conducted within the production environment. Fourth,

the validation and results are presented, showing the performance improvements achieved and the extent to which the model met its intended objectives. Finally, the discussion section compares the findings with existing literature and examines their practical implications for the agro-industrial sector.

The application of Total Productive Maintenance (TPM) sought to reduce equipment failures through preventive maintenance strategies designed to increase machine availability and production efficiency (Michlowicz, 2022). A structured FIFO (First In, First Out) system was implemented to prevent spoilage caused by prolonged storage and disorganized inventory flow (Karar et al., 2023). Circular economy practices were incorporated to manage the high volume of generated waste and promote the reuse of organic residues in alignment with sustainability principles (Lelicińska-Serafin et al., 2023). Additionally, process standardization established consistent and regulated procedures across the spinach line to ensure operational uniformity and quality (Bowonder & Yadav, 2005). Across these initiatives, active personnel engagement was prioritized, recognizing its importance in achieving successful change management and maximizing the benefits derived from the applied tools (Balk et al., 2020). As a result, the combined implementation of these strategies strengthens the company's competitiveness by reducing operational failures, enhancing process efficiency, and decreasing waste within the spinach production line (Kuznetsova et al., 2019).

This study also addresses a relevant gap in existing literature, as prior research has typically analyzed TPM, FIFO, process standardization, and circular economy principles separately, leaving limited empirical evidence on their integrated application within agro-industrial operations, particularly, in leafy-vegetable processing. By proposing a structured model and validating it through field implementation and quantitative results, this research contributes to the operations management field while providing practical guidance for agro-industrial firms aiming to strengthen sustainability performance and operational efficiency through lean and circular practices. In this context, the study is guided by the following research question: To what extent can the integrated application of TPM, FIFO, process standardization, and circular economy principles contribute to reducing waste and improving operational efficiency in the spinach production line of a Peruvian agro-industrial enterprise? (Guerra et al., 2025).

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2. State of Art

The following section synthesizes the principal theoretical and scientific contributions related to continuous improvement and key operational tools such as preventive maintenance, process standardization, the FIFO inventory method, and circular economy practices. This review establishes the conceptual and methodological foundation that supports the improvement model proposed for the spinach processing line that improves efficiency and reduces waste in agro-industrial operations.

2.1 Total Productive Maintenance (TPM)

By fostering shared responsibility and continuous improvement, TPM reduces unexpected downtime, enhances operational efficiency, and drives cost-effective improvements that lead to increases in Overall Equipment Effectiveness (OEE), product quality, and workplace safety (Skevas et al., 2018). In addition, improved operational performance under a TPM approach directly contributes to customer satisfaction and higher profitability for the industry (Pacal, 2024).

Based on the research of Singh et al. (2022), whose research focused on minimizing machinery errors and failures through TPM implementation, several organizational barriers were identified that can hinder the program's success. These include employee demotivation that limits active participation, resistance to new practices stemming from poor understanding of TPM's benefits, and insufficient commitment or leadership from upper management. In their study Xiang y Feng (2021), launched a TPM pilot program that helped identify the most critical equipment, resolve related issues, and build trust among staff.

The study identified the adoption of Industry 4.0 as a potential solution; when combined with TPM, this approach offers benefits such as a real competitive advantage over other companies that do not utilize digitalization, as well as the ability to monitor changes in real time. However, due to time constraints and financial limitations, we opted for solutions that were more within our budget (Tortorella et al., 2021).

There are organizational barriers, such as insufficient commitment from senior management and poor communication, which are common causes that further hinder the effective implementation of TPM initiatives (Au-Yong et al., 2022). Furthermore, the integration of TPM with Industry 4.0 is hindered by technological limitations, including the absence of digital systems and inadequate real-time data collection (Ghasemian

Sahebi et al., 2026). An example of this is the studies by Lucantoni et al. (2025) demonstrate the effectiveness of the proposal, which led to the implementation of 24 Kaizen actions, improving OEE by 14% by applying 7 of the 8 pillars of TPM.

2.2 Preventive maintenance.

This tool is vital to ensure the reliability and optimal performance of any sector's industrial infrastructure. The regular implementation of scheduled maintenance activities, such as inspections, adjustments, and part replacements, enables companies to anticipate failures and maintain high equipment availability. This preventive approach decreases unexpected stoppages, extends equipment lifespan, and improves safety conditions by lowering the likelihood of mechanical or electrical issues (Adenubi et al., 2021).

An effective preventive maintenance program delivers significant operational and economic advantages, particularly when supported by structured management practices and employee involvement. Empirical evidence reinforces this perspective; for instance, the study by Dal Forno et al. (2025) shows that integrating employees into maintenance management systems not only improves operational control but also enhances product quality and process reliability, achieving a 77% reduction in defects in the weaving process during January and February 2024.

Similarly, the integration of PDCA with Total Productive Maintenance (TPM) strengthens maintenance effectiveness by enabling a clearer differentiation between machine-related and human-related downtime in semi-automated production environments. This structured approach facilitates continuous monitoring and performance evaluation through indicators such as Overall Equipment Effectiveness (OEE), allowing organizations to optimize resource utilization and sustain higher production levels (Seedao et al., 2025).

In line with this, Hassan and Mazzlom (2024) demonstrate that the combined application of PDCA and TPM leads to measurable performance improvements, including increases of approximately 33% and 25% in key operational parameters. Additionally, the minimal variation observed in fracture energy (2%) and toughness (1%) reflects improved process stability and consistency, supporting the role of preventive maintenance in enhancing product quality while reducing variability and associated operational risks.

2.3 FIFO (First In, First Out)

This tool is a fundamental inventory management strategy that ensures the earliest received items are the first to be used or dispatched (Almeida et al., 2022). This principle is especially critical in the handling of perishable goods—such as vegetables—or products with limited shelf life, as it minimizes spoilage, shrinkage, and losses associated with expired or deteriorated units (Anichkina et al., 2022). When rigorously implemented, FIFO accelerates inventory turnover, reduces product obsolescence, and maximizes the efficient use of storage space. Sadiq & Anal (2023) argue that improving traceability is a cornerstone of modern food supply chain management; in practice, such a system enhances stock visibility, allowing operators to quickly identify older batches through color-coded labels or date-based classification methods.

Moreover, it establishes storage discipline by requiring that newer material be placed behind the older stock, thus ensuring the appropriate consumption sequence.

Empirical evidence underscores the operational benefits of FIFO implementation. Studies have reported substantial improvements in warehouse performance, including reductions in stock-handling costs, significant decreases in product spoilage, and an overall decline in storage expenses. For example, Palanivel et al. (2025) talk about a the model that provides ideas to optimize operational efficiency and promote sustainability in a rapidly changing global business environment, supported by empirical case studies and sensitivity analysis to mitigate inventory losses using FIFO. When complemented with appropriate staff training and supported by the organizational discipline provided by the 5S methodology, FIFO contributes to a more structured, reliable, and cost-effective inventory management system, ensuring that companies can meet market demand efficiently while safeguarding profitability.

An interesting study was conducted at FIFO to evaluate and treat cases requiring surgical procedures. The cost-effectiveness of the FIFO strategy for treating patients who want to undergo bariatric surgery was also evaluated. This study found that surgeries are normally performed on a first-come, first-served basis, but this time, the cost-effectiveness ratio was used to prioritize patients who would have the highest survival rate after surgery. This makes it possible to save more lives in less time due to the predictive success rates of these individuals with better life expectancy (Mocellin et al., 2026).

The FIFO system has recently become a topic of great interest in research, such as in computing, as problems also occur in the architecture of CPU and GPU processors. It should be noted that FIFO is much more efficient in some cases, such as real-time data processing, machine learning frameworks, and algorithms for finding the shortest route (Hossain et al., 2025). In this way, FIFO (First-In, First-Out) poses a challenge to unlock the true potential of modern hardware architectures, prompting research in this area to be exploited and optimized (Moussa et al., 2025).

Research is being conducted into the use of two inventory methodologies, FIFO and LIFO, with the aim of improving supply chain efficiency. The objective is to achieve efficient inventory control, taking into account the environment of modern supply chains. FIFO is useful for managing perishable products, to avoid obsolescence and minimize losses, while LIFO ensures a smooth flow of goods, reduces storage costs, and improves operational agility (Palanivel et al., 2025).

In conclusion, it can be said that FIFO is useful in certain specific cases, depending on the objective one wishes to achieve.

2.4 Process Standardization

Process standardization establishes the structural foundation necessary for continuous improvement, enabling the systematic identification of operational opportunities and the effective implementation of corrective and preventive actions. By defining clear performance metrics and consistently monitoring adherence to standardized procedures, organizations can detect trends, evaluate variability, and make informed decisions aimed at optimizing operational performance and sustaining long-term competitiveness (Singh & Awoke, 2023). Standardization not only promotes consistency and repeatability in daily tasks but also strengthens process reliability by ensuring that all personnel follow unified, validated practices aligned with organizational objectives.

Recent empirical evidence highlights the growing relevance of process standardization in contemporary industrial environments. From a Lean perspective, Contreras Castañeda et al. (2024), applied 5S and standardized operating procedures in panela production, achieving a 63% improvement in workplace order and cleanliness and a 10% reduction in production cycle time for 180 kg batches. The implementation included formal process characterization aligned with ISO requirements, PDCA-based

control structure, defined performance indicators, and documented procedures, confirming that operational standardization reduces variability, eliminates waste (movement, waiting, transport), and improves flow efficiency.

Similarly, another study developed a standardized quality detection protocol using a colorimetric sensor array combined with multivariate statistical modeling. Through structured data acquisition and predefined analytical procedures, Principal Component Analysis explained 93% of total variance, while PLS-DA achieved 95% fitting accuracy and 91% validation accuracy, and LDA reached 100% fitting accuracy with 91% cross-validation accuracy. In this study, it was demonstrated that standardization through controlled protocols, calibrated sensing elements, and statistical validation enhances reproducibility, discrimination reliability, and quality authentication performance (Borna et al., 2025).

Additional studies reinforce the strategic role of structured standardization frameworks. Zouhri et al. (2024) report up to 40% reduction in detection errors after implementing AI-based inspection systems supported by standardized detection protocols, highlighting the need for interoperability and unified quality criteria. Similarly, Andrade et al. (2025) demonstrate that standardized data formalization and structured anomaly detection models achieved 92% feature recognition accuracy, 88% detection accuracy, and real-time processing (0.02 s per part), improving diagnostic precision and decision support. In analytical quality control, Dahiya et al. (2025) established botanical and chemical standards using TLC fingerprinting and chemometric modeling (PCA and HCA), enabling systematic differentiation of plant parts and geographical origins and identifying enriched marker concentrations in specific components. Across these studies, standardized protocols, formal validation criteria, and structured analytical models were central to reducing variability and strengthening quality reliability.

Evidence of these benefits has also been reported in earlier studies. For instance, in a printing company where box packaging, printing, and manual publication represented 70% of total operations. Before the standardization, the deficiencies in workstation ergonomics exposed operators to physical risks, generating inefficiencies, health issues, and poor posture. Following the implementation of standardized procedures and ergonomic improvements, the company achieved a 20% increase in production rate, a 15% reduction in standard time, and a 40% decrease in unit cost. Additionally, the

redesign of workstations significantly reduced injury risks and enhanced operator performance throughout the production process (Massaro & Galiano, 2020).

Another relevant contribution is the study by Cumplido et al. (2020), which supports the standardization efforts of this project by outlining a structured five-step method for implementing the FIFO system to improve material control and reduce inventory costs. The methodology includes:

1. Monthly Colors: Use color-coded tags to identify the age of materials.
2. Quick Tagging: Put the monthly color tag on every container that arrives.
3. Storage Rule: Position newly arrived materials behind existing stock to maintain FIFO order.
4. Priority Use: Consume materials from the current month first.
5. Training: Train staff to ensure correct and consistent application of the system.

Figure 1

Example of FIFO tagging



Note. The figure shows an example of FIFO, in which the label indicating the arrival date of the material changes color each month, and each label includes the corresponding monthly color code. From "Manual de procedimientos y sistema FIFO en el manejo de inventarios", by A. Cumplido, C. Fernández, & A. Pérez, 2020 (https://www.researchgate.net/publication/335960724).

2.5 Circular Economy

Circular Economy practices aim to minimize waste generation and maximize resource utilization throughout the entire production cycle. In the context of vegetable processing, this approach seeks to reincorporate byproducts that would traditionally be

discarded, thereby creating a more sustainable and efficient system. The application of Circular Economy principles in the food sector promotes the reduction of post-consumer waste through the selective collection of organic materials and their subsequent transformation into value-added products (Lelicińska-Serafin et al., 2023). Research in urban food waste management has demonstrated significant progress, with purity rates in organic waste collection (QCR) ranging from 92% to 97%. However, notable variability in contaminant levels suggests that selective collection systems still require refinement to achieve higher accuracy and consistency.

Despite these challenges, the adoption of Circular Economy strategies contributes to a measurable reduction in the volume of waste sent to landfills, fostering more ecological resource management and enhancing operational sustainability. This approach not only supports greater efficiency in food processing systems but also aligns with global sustainability guidelines encouraging responsible production and consumption.

The development of the case study for this project follows the methodological recommendations outlined by Díaz-Muñoz (2020), which include:

1. Planning: This phase establishes an essential framework for future research improvements. It requires a detailed protocol describing the problem, research questions, objectives, methods, and expected outcomes.
2. Sampling: Sample size must be sufficient to meet the pilot's objectives, considering the probability of undesirable events and adjusting statistical error values according to the study's purpose.
3. Information Gathering: Data should be collected from both the main study and the pilot phase, typically emphasizing descriptive analysis. Due to the inherent limitations of pilot studies, hypothesis testing or comparisons are generally discouraged.
4. Publication: The final report must explicitly describe the nature of the study, highlight feasibility insights, emphasize lessons learned and methodological limitations, and avoid overinterpretation of results.

2.6 PDCA (Plan-Do-Check-Act)

The PDCA cycle is a foundational framework for continuous improvement, operating through a structured and iterative sequence of planning, execution, evaluation,

and corrective action. This methodology enables organizations to systematically identify inefficiencies, implement targeted interventions, and refine processes through continuous feedback, thereby promoting organizational learning and enhancing overall performance (Rangel-Sánchez et al., 2024). Its disciplined approach ensures that improvements are based on evidence, measured outcomes, and progressive refinement rather than isolated or reactive initiatives. The cycle is composed of four critical stages:

1. Plan: Define the problem clearly, establish improvement objectives, and design an action plan supported by data analysis and root-cause identification.
2. Do: Implement the proposed actions on a small or controlled scale, ensuring appropriate resource allocation and clear communication with personnel.
3. Check: Evaluate the results obtained by comparing them to the objectives established during the planning stage, using performance indicators and analytical tools to assess effectiveness.
4. Act: Standardize successful practices, make necessary adjustments, and prepare the process for the next improvement cycle, reinforcing a culture of continuous learning.

Recent evidence confirms the operational strength of PDCA when embedded systematically into management routines. A longitudinal field intervention showed that integrating PDCA into a structured daily management routine increased Overall Equipment Effectiveness (OEE) from a baseline average of 42.0% to 63.3%, representing a relative improvement of more than 50%. Concurrently, total production output increased by 20% compared to the previous year (Fonseca & de Medeiros, 2026). In this context, PDCA functioned not simply as a corrective instrument but as a structured managerial framework supported by clearly defined triggers, escalation protocols, and formal verification stages, thereby reinforcing accountability and continuous performance monitoring. Similarly, the structured application of PDCA through an “8 steps and 7 tools” methodology enabled a significant reduction in production cycle time from 49 seconds to 38.9 seconds, achieving a 21% improvement and surpassing the takt time requirement (Jonny, 2025). By aligning Pareto analysis, fishbone diagrams, and root-cause validation within the Plan–Do–Check–Act sequence, the methodology ensured that each implemented solution was systematically evaluated before standardization (Barsalou, 2023).

Further integration of PDCA with Lean Manufacturing and Six Sigma principles strengthened process capability and efficiency in heavy component manufacturing. The intervention improved the sigma level from 3.361 to 3.748 and increased Process Cycle Efficiency (PCE) from 82.71% to 83.72%, demonstrating measurable stabilization of value-added activities through structured iteration (Fitriana et al., 2025). The PDCA framework facilitated continuous monitoring and data-driven refinement, particularly when combined with statistical process control and digital performance dashboards.

Additionally, the application of PDCA to reduce scrap in electric motor manufacturing exceeded a target scrap rate of 0.7%, eliminated approximately 500,000 nonconforming components, and generated annual savings of nearly USD 135,000 (Rangel-Sánchez et al., 2024). These results demonstrate how disciplined progression through planning, controlled execution, performance verification, and corrective standardization converts defect analysis into sustained financial and quality improvements.

Overall, the evidence confirms that PDCA remains a robust and adaptable framework for structured problem-solving, distinguished by its capacity to integrate analytical tools, validate corrective actions through measurable performance indicators, and institutionalize organizational learning. When implemented with methodological rigor and supported by clear metrics, PDCA enhances operational stability, strengthens quality performance, improves delivery reliability, and generates measurable economic value across diverse industrial contexts.

3. Methodology

This research adopts a case study approach with a descriptive and applied research design, supported by a combined lean management framework. The study focuses on a single agro-industrial company dedicated to spinach processing, with the objective of identifying operational inefficiencies and implementing structured improvement actions aimed at reducing waste and enhancing process efficiency.

According to the case study by Jebbor et al. (2023), the methodological framework was purposefully designed to be data-oriented, iterative, and supported by digital tools, ensuring accurate diagnosis and sustained operational improvement over time. In this context, the selection of lean tools was guided by an integrated approach grounded in prior research, which serves as a reference for the present study. At the same time, the choice of tools considered the types of waste identified during the diagnostic phase, such as sealing defects and inventory obsolescence, as well as the need to incorporate predictive analysis to evaluate the potential impact of improvement actions. Additionally, the framework accounted for the specific characteristics of the production system, including its agricultural setting, the perishable nature of raw materials, and its batch-based processing structure.

To address the efficiency challenges identified in the spinach production line, a structured improvement plan was developed using the PDCA (Plan–Do–Check–Act) cycle as the central implementation framework (see Figure 1). The PDCA methodology provided a disciplined and iterative structure for planning interventions, executing improvement actions, evaluating performance outcomes, and standardizing successful practices. Within this framework, specific engineering and management tools: Total Productive Maintenance (TPM), FIFO inventory management, process standardization, and circular economy practices, which where were systematically deployed. These tools have been widely validated in prior research and were adapted to the operational conditions of the case study to ensure feasibility, effectiveness, and sustainability of the proposed improvements.

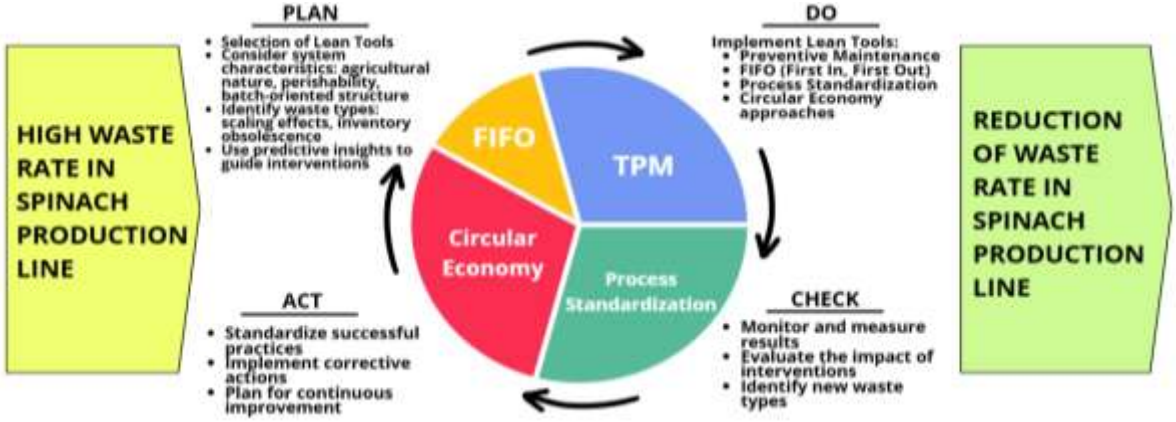
The PDCA cycle was used as the guiding framework to structure the modification and improvement of system operations within the spinach production line. This approach enabled a systematic and data-driven implementation of lean tools, ensuring that each intervention was aligned with the specific operational conditions of the case study.

- **Plan:** During the planning stage, the most appropriate lean tools were selected based on an in-depth analysis of the production system's characteristics and operational constraints. Attention was given to recurrent inefficiencies identified during the diagnostic phase, such as defective packaging seals, excessive non-conforming products, and inventory obsolescence caused by prolonged storage. Based on this analysis, the tools with the highest potential impact were prioritized.
- **Do:** In the implementation phase, the selected lean tools were deployed under controlled conditions within the production line. These interventions included the application of Total Productive Maintenance (TPM), the introduction of a FIFO inventory management system, the standardization of critical processes, and the incorporation of circular economy practices to manage organic waste.
- **Check:** This phase focuses on monitoring and evaluating the effects of the implemented actions. Key performance indicators were measured and compared against baseline values to assess improvements in process efficiency, waste reduction, and operational control.
- **Act:** Finally, the methodologies that demonstrate positive and consistent results were formally standardized and integrated into routine operations. Corrective adjustments were made where necessary, and successful practices were consolidated to ensure sustainability and continuous improvement.

Figure 2

PDCA cycle

QQ



Note. The figure illustrates the iterative four-stage structure of the Plan–Do–Check–Act cycle, where the input condition (high waste) is systematically addressed to achieve the desired outcome (waste reduction). Adapted from "PDCA Cycle Method implementation in Industries: A Systematic Literature Review", by D. A. Taufik & H. H. Purba, 2020 (https://doi.org/10.22441/ijiem.v1i3.10244)

This structured PDCA-based approach facilitated the effective integration of lean principles into the production system, ensuring that all improvement actions were grounded in empirical data rather than subjective judgment. As a result, FIFO, process standardization, TPM, and circular economy principles were coherently embedded into daily operations, reinforcing both operational efficiency and sustainability outcomes.

3.1. Total Productive Maintenance (TPM): Preventive Maintenance

The implementation of Total Productive Maintenance (TPM) focused on ensuring the availability and reliability of critical equipment within the spinach production line through structured preventive maintenance practices (Bechar & Vitner, 2019). TPM was adopted as a comprehensive maintenance strategy that promotes early failure detection, shared responsibility, and continuous improvement across organizational levels (Skevas et al., 2018). The process began with securing top management commitment, which was essential for allocating resources, authorizing maintenance activities, and encouraging operator involvement throughout the implementation phase (Pacal, 2024).

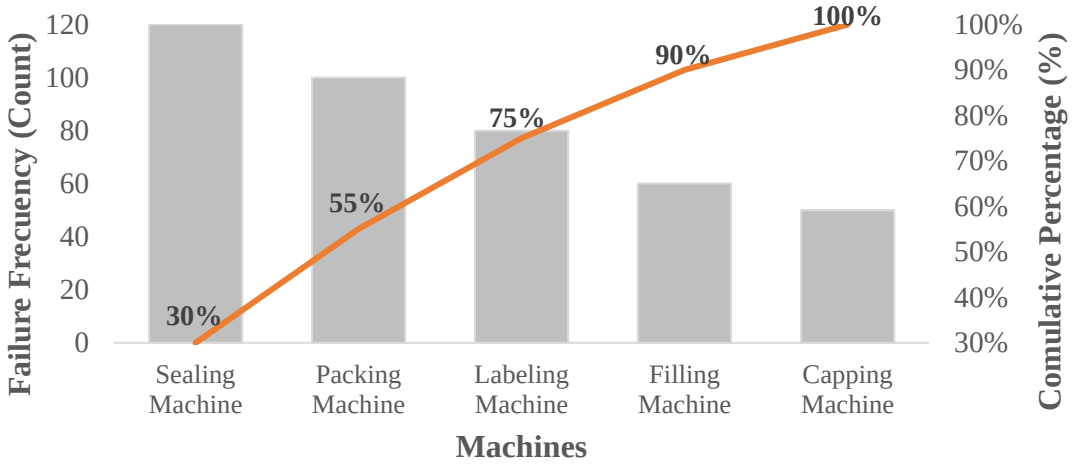
Subsequently, a TPM committee was established, composed of the General Manager, Production Manager, Production Supervisor, Production Operator, and Maintenance Technician. This multidisciplinary structure ensured coordination between operational and technical perspectives and facilitated informed decision-making regarding maintenance priorities (Guedes et al., 2021). As an initial diagnostic step, a comprehensive evaluation of production equipment was carried out based on failure frequency and operational criticality, using historical maintenance records as the primary data source.

To support equipment prioritization, a Pareto analysis was applied to identify the machines contributing most significantly to production disruptions, following established practices for maintenance optimization (Zhang et al., 2021). The analysis revealed that

the sealing machine concentrates the highest frequency of failures, accounting for approximately 30% of total recorded incidents. When combined with the packing machine, the cumulative failure percentage reaches around 55%, confirming that these two machines are the primary contributors to operational interruptions. The inclusion of the labeling and filling machines increases the cumulative percentage to nearly 75% and 90%, respectively, while the remaining equipment exhibits a comparatively minor contribution to total failures.

Figure 2

Pareto Diagram of Equipment Failure Frequency



Note. The diagram illustrates the distribution of equipment failure frequency, highlighting the primary equipment failure causes and supports corrective prioritization using the 80/20 principle.

Based on these results, the sealing machine was prioritized for the design and implementation of a preventive maintenance plan, as interventions on this equipment offered the greatest potential to reduce unplanned downtime, improve product quality, and minimize waste generation. The preventive maintenance plan was developed using the equipment's technical documentation, enabling the identification of critical components, inspection frequencies, lubrication requirements, and replacement intervals, in line with preventive maintenance best practices (Guedes et al., 2021).

Overall, this data-driven approach ensured that maintenance actions were aligned with actual operational needs and supported the TPM objective of minimizing losses through proactive intervention (Bowonder & Yadav, 2005).

3.2. FIFO system

The FIFO (First In, First Out) system was implemented as a key operational strategy to prevent product deterioration and preserve the freshness of spinach throughout the storage and handling stages. Given the perishable nature of leafy vegetables, improper inventory rotation had been identified as a critical source of waste and product non-conformity. Consequently, FIFO was selected to ensure that materials and finished products were processed and dispatched according to their order of arrival, thereby minimizing the risk of spoilage (Çalışkan, 2022).

The implementation process began with securing management commitment to allocating the necessary financial and operational resources, as well as defining clear objectives related to inventory control and waste reduction. An initial assessment of existing storage practices was conducted to identify operational risks, bottlenecks, and deviations from recommended handling conditions. This diagnosis revealed deficiencies in product traceability and storage order, which justified the redesign of the inventory management system.

Based on this assessment, the FIFO system was designed using simple but effective visual management tools. A color-coded labeling scheme was introduced to distinguish product batches by entry date, facilitating rapid identification and prioritization during storage and dispatch. In parallel, storage layout improvements were implemented to physically enforce FIFO logic, ensuring that newly received products were placed behind older stock to prevent incorrect rotation.

Subsequently, personnel involved in warehouse and production operations received targeted training focused on FIFO principles, standardized handling procedures, and the importance of inventory discipline in reducing waste. Once training was completed, the system was formally launched, accompanied by housekeeping activities to reorganize storage areas and eliminate non-compliant practices.

To support operational control and continuous improvement, performance monitoring mechanisms were established. Inventory-related indicators, such as the

obsolete or deteriorated stock rate, were defined to evaluate the effectiveness of FIFO implementation. Prior to full stabilization, the spinach line recorded a deteriorated stock rate of 1.52%, exceeding the commonly accepted threshold of 1% for food products, highlighting the need for systematic inventory control measures (Çalışkan, 2022). These indicators provided a baseline for subsequent evaluation in the results stage.

3.3. Process Standardization

Process standardization was implemented to ensure consistent washing conditions, enhance product quality, and guarantee compliance with food safety regulations throughout the spinach processing line. Given that washing is a critical control point in leafy vegetable production, deficiencies in this stage were identified as a significant contributor to quality deviations and product non-conformity. Therefore, standardization was selected as a key intervention to reduce variability and improve operational reliability (Soltanali et al., 2020).

To begin, management committed the necessary funding and personnel, providing the official backing needed to drive the standardization effort forward. A multidisciplinary team composed of production supervisors, quality personnel, and line operators was established to lead the analysis and implementation process. Initially, the existing washing procedure was documented and evaluated to identify inefficiencies and sources of variability. This assessment revealed that, during 2023, 3,317 out of 180,819 processed spinach units were improperly washed, indicating a clear deviation from expected quality standards.

Based on these findings, standardized operating procedures were developed and validated. Key improvements included adjusting the chlorine concentration to a controlled level of 100 ppm and introducing a two-stage washing protocol to ensure effective contaminant removal while preserving product integrity. These standards were designed in accordance with food safety regulations and best practices in vegetable processing.

Following procedure development, targeted training sessions were conducted to ensure that all operators understood and correctly applied the standardized washing steps. The standardized process was subsequently implemented and supported through continuous monitoring using a Process Activity Diagram (PAD), which allowed for

systematic verification of task sequences and identification of potential improvement opportunities.

To evaluate process performance and support continuous improvement, quality-related indicators were defined and monitored. Prior to full stabilization, the washing process achieved a quality indicator of 98.17%, which remained below the established target of 99%. This gap highlighted the need for sustained monitoring and corrective actions, serving as a baseline for subsequent evaluation in the results stage.

3.4 Circular Economy

The circular economy strategy was implemented as a structured waste management and resource recovery program aimed at reducing organic waste disposal and maximizing the reuse of biodegradable by-products generated during spinach processing. This approach sought to integrate sustainability principles into daily operations while ensuring regulatory compliance and operational feasibility within an agro-industrial environment (Lelicińska-Serafin et al, 2023).

The implementation procedure began with formal approval and commitment from top management, ensuring the allocation of physical resources, operational time, and personnel for the execution of the program. Once institutional support was secured, a diagnostic assessment of organic waste generation was conducted across the production line. This assessment involved identifying waste sources, quantifying discarded units, and classifying waste according to its origin. The analysis revealed that 17,527 spinach units were discarded during 2023, primarily at the sealing, washing, and storage stages, confirming the need for a targeted intervention.

Based on this diagnosis, a composting-based circular economy model was designed. The model included the installation of designated organic waste collection containers strategically located along the production line. These containers were selected and implemented in accordance with the sanitary and handling guidelines established by the National Agrarian Health Service (SENASA), ensuring compliance with food safety and environmental regulations for organic waste management in agro-industrial facilities. (Resolución Directoral 0050-2021 MIDAGRI-SENASA-DIAIA, 2021).

Standard operating procedures were then developed to define each stage of the waste recovery process. These procedures detailed waste segregation criteria, collection

frequency, internal transportation methods, and composting conditions, including humidity control, aeration, and maturation time. Clear visual guidelines were implemented to prevent contamination with non-organic materials and to ensure consistent application across shifts.

Training sessions were subsequently conducted for operational personnel involved in production, sanitation, and waste handling. These sessions focused on proper waste segregation, correct use of collection containers, compliance with sanitary regulations, and the environmental objectives of the program. Personnel participation was emphasized as a critical factor for the effectiveness and sustainability of the circular economy initiative.

Following training, the composting system was deployed initially as a pilot implementation within selected production areas. This phased rollout allowed operational validation and procedural adjustments prior to full-scale deployment. System performance was monitored using the waste collection rate indicator, which was initially recorded at 0%, establishing a baseline for future evaluation. A target collection rate of 97% was defined in alignment with best practices for organic waste recovery systems.

This circular economy initiative provided a structured foundation for reducing environmental impact, supporting regulatory compliance, and strengthening the company's sustainability strategy. Moreover, it aligned the organization with global environmental trends, potentially enabling access to environmentally conscious markets and reinforcing long-term competitive positioning.

4. Results

The results of the proposed improvement model demonstrate the tangible impact of integrating preventive maintenance, process standardization, FIFO inventory management, and circular economy strategies within the spinach processing line. The pilot implementation, structured under the PDCA methodology, addressed the main inefficiencies identified in equipment reliability, washing performance, warehouse management, and waste utilization. Data was collected during pre- and post-implementation stages to assess the effectiveness of each intervention using operational, quality, and sustainability indicators. The results show a consistent and measurable improvement across all evaluated areas, confirming that the combined application of technical and organizational measures significantly reduced waste levels and product nonconformities, while simultaneously strengthening process stability, operational traceability, and environmental performance throughout the production system.

4.1 Preventive Maintenance (TPM Approach)

The first intervention focused on the implementation of a preventive maintenance program based on the principles of Total Productive Maintenance (TPM). Prior to the implementation of the proposed model, the company did not operate under a structured maintenance schedule, which resulted in frequent unplanned stoppages and reduced equipment availability, particularly in critical stages such as washing, cutting, and sealing. Maintenance activities were predominantly reactive, as corrective actions were executed only after failures occurred. This approach caused production interruptions, partial processing batches, and an increase in nonconforming products, directly affecting operational efficiency and product quality.

To address these deficiencies, a TPM-based preventive maintenance plan was implemented, emphasizing both planned maintenance and operator involvement through autonomous maintenance practices. Preventive tasks were defined according to equipment criticality and technical specifications. These activities included lubrication routines every two weeks, as well as periodic mechanical and electrical inspections conducted quarterly, and every semester. To ensure proper execution and traceability, standardized maintenance checklists and manual inspection records were introduced, allowing operators and supervisors to document completed activities, detected anomalies, and corrective actions (Skevas et al., 2018). This structure aimed to promote shared

responsibility for equipment care, reduce failure recurrence, and improve overall machine reliability.

Operators were trained to perform routine inspections, cleaning, and lubrication of key mechanical components, while supervisors were responsible for verifying compliance with maintenance schedules and updating records. In addition, visual management tools were installed near each critical machine to display maintenance frequencies, inspection results, and identified issues. This facilitated real-time monitoring of equipment condition and supported timely decision-making regarding maintenance interventions.

After two operational cycles under the preventive maintenance plan, a clear improvement in equipment reliability was observed. The average number of corrective maintenance interventions decreased by 43%, while downtime related to mechanical failures was reduced from 6.2 hours per week before implementation to 3.5 hours per week after implementation. This reduction in unplanned stoppages improved production continuity and stabilized material flow throughout the spinach processing line. Consequently, the proportion of nonconforming products decreased from 4.45% prior to TPM implementation to 1.33% after implementation, representing an approximate 70% reduction in defective output, a result consistent with TPM performance reported in similar industrial applications (Pacal, 2024).

To evaluate the sustainability of these improvements beyond the pilot phase, a Holt–Winters forecasting model was applied to extrapolate short-term results to an annual performance scenario.

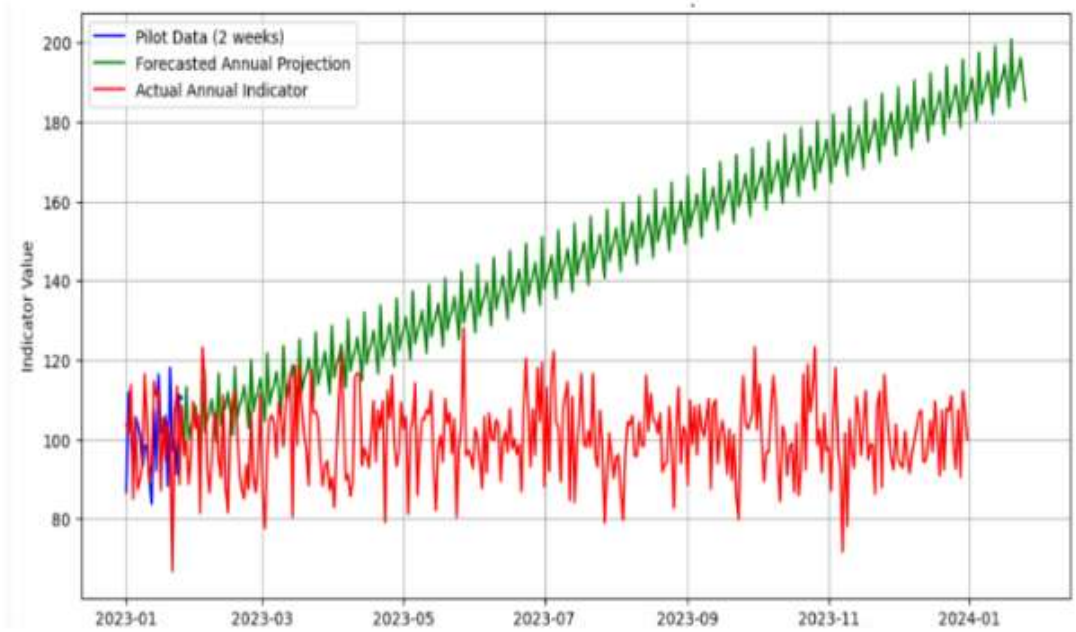
The Holts-Winter method has its limitations when it comes to obtaining accurate results in cases where data is missing, because there is not much real-time data available, and although the method is very good, it is not usually very accurate (Rumbe et al., 2024). Nonetheless, this method has its limitations when it comes to obtaining accurate results in cases where data is missing, because there is not much real-time data available, and although the method is very good, it is not usually very accurate (Kumar et al., 2024). An example of this is that the Holt Winters method has a linear prediction model to predict results by time intervals and seasons (He et al., 2024).

The Holt Winters method is also used for rapid and accurate diagnosis in transmission networks when they trip unexpectedly. Following Holt Winters' forecast, the 115/22 kV transformers between 2023 and 2024, considering the forecast for a year, which is what we will use for this study, revealed that the system could detect them all correctly and reduced the time needed to evaluate them from 448 s to 35.8 s, improving by 92% (Taksana et al., 2025).

Figure 4 presents the comparison between the pilot data collected over a two-week period, the forecasted annual projection generated by the Holt–Winters method, and the historical annual indicator. This model incorporates both trend and seasonal components, allowing the pilot results to be contextualized within the company's typical annual operational behavior.

Figure 3

Holt–Winters forecast of preventive maintenance performance indicators.



Note. The figure predicts preventive maintenance performance indicators, enabling proactive decision-making and improved operational stability through trend and seasonality analysis.

This chart illustrates the forecast of the pilot plan data (blue line), which was performed using the Holt–Winters method (green line) to estimate the annual performance and compare it with the actual annual indicator (red line). The forecasted

annual performance derived from the pilot data shows a marked improvement compared to the historical indicator. While historical data exhibit greater variability and higher defect levels, the projected trend indicates a sustained reduction in nonconforming output over time. Specifically, the forecasted results are consistent with the observed 70% reduction in defect rate, confirming that the benefits of the preventive maintenance strategy are not limited to short-term gains but can be maintained at an annual scale.

This statistical approach enabled the extrapolation of short-term pilot results to an annual performance horizon by incorporating both trend and seasonality components of the process. The resulting action plan was formally approved by management, with key responsibilities assigned to the operations manager for coordinating operator training_ and supervising maintenance activities. The primary objective of this strategy was to standardize cleaning and maintenance procedures, thereby reducing equipment failures and enhancing the overall operational efficiency and stability of the production line.

To complement the graphical analysis, detailed numerical results obtained during the pilot phase are summarized in Table 2. During the 15-day pilot period, 375 samples were evaluated, of which 370 units were correctly sealed, resulting in a success rate of 98.67%. Using the Holt–Winters model with a 95% confidence level, the annual projection estimates approximately 122 defective units per year, representing a substantial reduction compared to historical records prior to TPM implementation.

Table 1

Holt–Winters-based annual projection of defective units.

Year	Month	Fornight	t (X)	Waste (Y)	A	T	Ŷ	P
		Fornight 1	1	4	4	0		
	Month 1		2	3	4	−0.04617763	4	1
		Fornight 2	3	forecast $p = 1$			3.52	1
			4	forecast $p = 2$			3.48	2
		Fornight 1	5	forecast $p = 3$			3.43	3
	Month 2		6	forecast $p = 4$			3.38	4
		Fornight 2	7	forecast $p = 5$			3.34	5
			8	forecast $p = 6$			3.29	6
		Fornight 1	9	forecast $p = 7$			3.25	7
	Month 3		10	forecast $p = 8$			3.20	8
		Fornight 2	11	forecast $p = 9$			3.15	9
			12	forecast $p = 10$			3.11	10
		Fornight 1	13	forecast $p = 11$			3.06	11
	Month 4		14	forecast $p = 12$			3.02	12
		Fornight 2	15	forecast $p = 13$			2.97	13
			16	forecast $p = 14$			2.92	14
		Fornight 1	17	forecast $p = 15$			2.88	15
	Month 5		18	forecast $p = 16$			2.83	16
		Fornight 2	19	forecast $p = 17$			2.78	17
1 Year			20	forecast $p = 18$			2.74	18
		Fornight 1	21	forecast $p = 19$			2.69	19
	Month 6		22	forecast $p = 20$			2.65	20
		Fornight 2	23	forecast $p = 21$			2.60	21
			24	forecast $p = 22$			2.55	22
		Fornight 1	25	forecast $p = 23$			2.51	23
	Month 7		26	forecast $p = 24$			2.46	24
		Fornight 2	27	forecast $p = 25$			2.41	25
			28	forecast $p = 26$			2.37	26
		Fornight 1	29	forecast $p = 27$			2.32	27
	Month 8		30	forecast $p = 28$			2.28	28
		Fornight 2	31	forecast $p = 29$			2.23	29
			32	forecast $p = 30$			2.18	30
	Month 9	Fornight 1	33	forecast $p = 31$			2.14	31
			34	forecast $p = 32$			2.09	32
		Fornight 2	35	forecast $p = 33$			2.05	33
			36	forecast $p = 34$			2.00	34
	Month 10	Fornight 1	37	forecast $p = 35$			1.95	35
			38	forecast $p = 36$			1.91	36
		Fornight 2	39	forecast $p = 37$			1.86	37
			40	forecast $p = 38$			1.81	38
	Month 11	Fornight 1	41	forecast $p = 39$			1.77	39
			42	forecast $p = 40$			1.72	40
		Fornight 2	43	forecast $p = 41$			1.68	41
			44	forecast $p = 42$			1.63	42
	Month 12	Fornight 1	45	forecast $p = 43$			1.58	43
			46	forecast $p = 44$			1.54	44
		Fornight 2	47	forecast $p = 45$			1.49	45
			48	forecast $p = 46$			1.45	46
						Total	121.28	
						Total	122	

Note. The table presents the annual projection of defective units estimated using the Holt–Winters exponential smoothing model.

4.1.1 Results of TPM implementation

Overall, the results obtained from the TPM-based preventive maintenance intervention confirm a substantial improvement in both equipment performance and product conformity. Prior to implementation, the percentage of nonconforming products

was calculated as 4.45%, obtained from 7,840 defective units out of total production of 176,145 units.

$$\%Non - Conforming\ Product = \frac{Defective\ Units}{Total\ Units} \times 100\%$$

$$\%Non - Conforming\ Product = \frac{7840}{186145} \times 100\% = 4.45\%$$

This value exceeded the acceptable threshold for food processing operations and reflected deficiencies in equipment condition and maintenance practices (Singh et al., 2022). After the implementation of the preventive maintenance plan and the extrapolation of the two-week pilot results using the Holt–Winters method, the nonconforming product rate was reduced to 1.36%, corresponding to 122 defective units out of 9,000 units. This represents a reduction of approximately 69% compared to the initial figure, surpassing the established target value of 3%.

$$\%Non - Conforming\ Product = \frac{122}{9000} \times 100\% = 1.36\%$$

On the other hand, the AS IS availability indicator showed an initial value of 78.13%, reflecting frequent unplanned stoppages and limited operational continuity in the spinach processing line. Equipment availability was calculated using the standard maintenance reliability relationship between Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR) (Soltanali et al., 2020):

$$\%Availability = \frac{MTBF}{MTBF + MTTR} \times 100\%$$

First, the MTBF was determined based on the total effective operating time and the number of recorded failures:

$$MTBF = \frac{Total\ work\ time - Breakdown\ times}{n°\ of\ failures}$$

Substituting the observed values:

$$MTBF = \frac{2000\ hours - 437.5\ hours}{175\ failures} = 9\ hours$$

Next, the MTTR was calculated by dividing the total maintenance time by the number of repair interventions:

$$MTTR = \frac{Total\ maitenance\ times}{n°\ of\ repairs}$$

$$MTTR = \frac{26250\ minutes}{175\ repairs} = 150\,\frac{minutes}{repair}$$

Finally, both indicators were converted to the same time unit and substituted into the availability formula:

$$\%Availability = \frac{9\ x\ 60}{9\ x\ 60 + 150} \times 100\% = 78.13\%$$

This result confirms that, prior to the implementation of the TPM-based preventive maintenance strategy, equipment availability remained significantly below the target value of 90%, highlighting the need for structured maintenance planning and proactive failure prevention to improve operational stability.

Following the pilot implementation of the TPM-based preventive maintenance plan, the availability indicator was recalculated to evaluate the impact of the intervention on equipment reliability and operational continuity. First, the updated Mean Time Between Failures (MTBF) was obtained using the same formulation applied in the AS IS analysis:

$$MTBF = \frac{2000\ hours - 144\ hours}{144\ failures} = 12.89\ hours$$

This result reflects a substantial reduction in failure frequency compared to the pre-implementation scenario, indicating improved equipment reliability as a direct consequence of the preventive maintenance activities introduced during the pilot phase. Next, the Mean Time to Repair (MTTR) was calculated as follows:

$$MTTR = \frac{26250\ minutes}{175\ repairs} = 185.71\,\frac{minutes}{repair}$$

Finally, the post-implementation availability (TO BE) was calculated by converting both indicators to the same time unit and applying the availability equation:

$$\%Availability = \frac{12.89\ x\ 60}{12.89\ x\ 60 + 60} \times 100\% = 92.80\%$$

The resulting availability value of 92.80% demonstrates a significant improvement compared to the initial AS IS level of 78.13%, and it exceeds the target threshold of 90%

established for the process. This improvement is directly attributable to the reduction in unplanned failures achieved through the pilot preventive maintenance plan. The increase in equipment availability to 92.80% indicates a notable improvement in the operational continuity of the sealing area. Higher availability reduces downtime, enabling a more stable and predictable production flow, which is essential for meeting demand without interruptions. Moreover, surpassing the defined target minimizes reliance on corrective maintenance interventions, contributing to a more reliable, efficient, and cost-effective operating environment.

These results confirm that the TPM approach effectively stabilized equipment performance, reduced failure-related disruptions, and directly contributed to improved process reliability and product quality. In addition to these operational gains, the intervention strengthened operator involvement and maintenance discipline, consolidating a preventive culture aligned with sustained performance improvement, consistent with findings reported in TPM literature (Park & Han, 2021).

4.2 Process Standardization

The second intervention focused on the standardization of operational procedures in the washing stage of the spinach processing line, one of the most critical phases for ensuring product quality and compliance with food safety requirements. Under AS IS conditions, this stage presented a high level of process variability due to the lack of clearly defined and consistently applied work methods. Variations in washing time, sanitizer concentration, and handling practices were observed between shifts, resulting in uneven cleaning performance, reprocessing activities, and quality deviations detected during inspections.

To address this issue, process standardization was implemented as a structured approach aimed at reducing variability and ensuring uniform execution of operations. As a first step, the existing washing process was mapped using a Process Activity Diagram (DAP), which allowed the identification and classification of each activity as value-added, non-value-added, or necessary non-value-added. This analysis made it possible to detect inefficiencies, redundant steps, and control gaps that directly affected washing effectiveness and product quality. Based on the DAP findings, the optimal sequence of activities and control points was defined to ensure consistent washing conditions throughout the process.

Standard Operating Procedures (SOPs) were then developed as a formal reference framework to support the standardized process. These procedures established clear operational parameters (such as sanitizer concentration, washing duration, inspection criteria, and safety requirements), ensuring that all operators followed the same technical guidelines. The standardized process was reinforced through personnel training, visual aids at workstations, and supervisory checklists designed to verify compliance and record deviations during daily operations.

Clearly defined operational procedures were implemented, including the use of three sequential tanks dedicated to the washing, disinfection, and rinsing stages. Continuous control of critical parameters, such as chlorine concentration, pH levels, and water temperature, was established to ensure consistent process conditions. Additional handling practices, including controlled agitation and a final rinse with potable water, were standardized to guarantee the effective removal of contaminants and residual chemicals from the product.

Personnel training constituted a key component of the pilot plan, as operators were instructed on the relevance of each washing stage and the correct handling of chemical agents involved in the process. During the 15-day pilot implementation, 375 samples were collected and analyzed to assess process performance. The results indicated that only two units presented deficiencies in the washing operation, reflecting the positive impact of the standardized procedures. Based on this data, the Holt–Winters forecasting model was applied to estimate annual performance, projecting a total of 48 units with washing-related issues, which represents a substantial improvement compared to historical results.

4.2.1 Results of Process Standardization implementation

Following the implementation of process standardization, variability in the washing operation was significantly reduced. The proportion of correctly washed spinach increased from 98.17% to 99.47%, indicating greater consistency in operator performance and closer adherence to the established washing parameters.

The quality indicator (Q) was calculated to evaluate the effectiveness of the washing process, following the approach proposed by Soltanali et al. (2020). This indicator measures the proportion of acceptable products relative to total processed units, allowing the identification of losses associated with improper washing that led to product spoilage:

$$\%Quality = \left(\frac{Processed\ units - Incorrect\ units\ processed}{Processed\ units}\right) \times 100\%$$

$$\%Quality = \left(\frac{180819 - 3317}{180819}\right) \times 100\% = 98.17\%$$

The AS IF result, which has a value of 98.17%, was below the minimum quality target of 99%, which is generally required for food processing operations to ensure adequate product safety and compliance (Soltanali et al., 2020). After applying the pilot plan for the standardization of spinach washing methods, the quality indicator was recalculated:

$$\%Quality = \left(\frac{9000 - 48}{9000}\right) \times 100\% = 99.47\%$$

The post-implementation value of 99.47% exceeds the minimum limit of 99%, confirming that the standardized washing procedures effectively improved product quality. These results demonstrate that the pilot plan for process standardization in the washing stage was successful in achieving an optimal quality indicator.

Moreover, the standardization effort enhanced coordination between shifts and departments, reduced reliance on individual operator experience, and supported knowledge retention despite personnel rotation, contributing to more stable and reliable process execution.

4.3 FIFO Inventory Management

The third intervention focused on improving warehouse management through the implementation of the FIFO (First In, First Out) inventory system. Under AS IS conditions, the company did not have a structured mechanism to ensure proper product rotation, which led to the accumulation of older spinach lots in storage and occasional delays in dispatch. The absence of visual controls and standardized storage rules increased the risk of handling errors, reduced traceability, and contributed to product deterioration prior to shipment.

To address these issues, the FIFO system was implemented as a structured inventory control approach aimed at ensuring that products were dispatched in the same order in which they were received. The first step involved evaluating the existing warehouse layout and storage practices to identify bottlenecks and risks associated with poor rotation. Based on this assessment, storage zones were reorganized according to

product entry date, and a visual identification system was introduced using color-coded labels to clearly distinguish product age. This visual system allowed operators to quickly identify which batches should be dispatched first, reducing reliance on memory or manual judgment.

The FIFO implementation was reinforced through personnel training, focusing on correct product placement, rotation rules, and verification procedures during dispatch activities. Clear instructions were established to ensure that newly received products were always placed behind existing stock, preventing mixing between older and newer batches. Supervisors were assigned responsibility for monitoring compliance and documenting any deviations observed during daily operations.

4.3.1 Results of FIFO implementation

After full implementation, the results demonstrated significant operational improvement in warehouse performance and product rotation discipline. The percentage of products withdrawn on time increased from 98.48% under AS IS conditions to 99.73% after the pilot plan, indicating a more consistent application of the dispatch sequence and a substantial reduction in delayed withdrawals and unrotated stock.

To evaluate the impact of FIFO on waste reduction in the storage area, the obsolescence indicator was calculated following the approach proposed by Çalışkan (2022), which measures the proportion of obsolete inventory relative to total inventory value:

$$\%Obsolescence = \frac{Obsolete\ inventory}{Total\ inventory\ value} \times 100\%$$

$$\%Obsolescence = \frac{2563}{168305} \times 100\% = 1.52$$

In the case of the company, the obsolescence percentage was about 1.52%. This value exceeded the recommended threshold for the food industry, where obsolescence levels should be equal to or lower than 1% to ensure efficient inventory management (Çalışkan, 2022). After the implementation of the FIFO pilot plan, the indicator was recalculated:

$$\%Obsolescence = \frac{71}{9000} \times 100\% = 0.79\%$$

Finally, following the implementation of the new FIFO storage system, the obsolescence rate was reduced to 0.79%, a figure below the limit considered optimal, demonstrating that the pilot plan had a positive impact on the storage area. This reduction in obsolescence represents a substantial improvement in inventory management, particularly for perishable products such as spinach. By keeping spoilage losses below 1%, the system aligns with established food industry standards, ensuring better product rotation and minimizing inventory value loss.

Such improvements not only optimize resource use and reduce waste but also enhance operational efficiency by ensuring products remain in proper condition until dispatch. Moreover, FIFO improved traceability, allowing better monitoring of product movement, faster audits, stronger quality assurance, and higher customer satisfaction. Ultimately, the adoption of FIFO transformed warehouse operations from a reactive system into a systematic, data-driven process that supports the company's broader goals of efficiency and sustainability.

4.4 Circular Economy

The final intervention focused on introducing circular economy practices aimed at reducing organic waste and generating environmental value from the by-products of spinach processing. Before the implementation, all organic residues—including rejected leaves, stems, and trimmings—were disposed of as waste, generating additional handling costs and contributing to the company's environmental footprint. The absence of a recovery plan meant that potential resources were being lost and that the company's sustainability goals remained largely unaddressed.

Based on the evaluation of waste and the results obtained, a composting system was designed and implemented to transform organic residues into useful resources, such as soil fertilizer. Following the technological approach of Lelicińska-Serafin et al. (2023), key parameters were identified and applied to ensure the efficiency of the composting process, aligning with operational needs and current regulations.

The team responsible for waste management and composting was trained to follow best practices in the separation and processing of residues. Personnel received instruction in the necessary quality controls to ensure compost free of chemical contaminants, according to the guidelines established by SENASA.

The implemented composting system is accessible, functional, and complies with regulatory standards (Resolución Directoral 0050-2021 MIDAGRI-SENASA-DIAIA, 2021).

To facilitate waste management and utilize circular economy principles, labeled 120-liter containers were installed for organic waste. The system underwent an adjustment phase: initially, waste was collected every 24 hours, but after an efficient analysis, the frequency was changed to three days. This change allowed for better resource utilization and maintained cleanliness and quality in the treated areas. The transport of organic residues to the 20-square-meter composting area followed strict waste management regulations. The roofed and ventilated space ensured that climatic conditions did not interfere with the process, preventing overhydration of the material.

Composting was carried out weekly following a standardized protocol. Piles were built with alternating layers of dry material (leaves and straw) and enriched with minerals such as natural phosphate, bone meal, agricultural lime, wood ash, rock dust, and agricultural gypsum, as recommended by Resolución Directoral 0050-2021 MIDAGRI-SENASA-DIAIA (2021), improving the quality and efficiency of the final compost as soil fertilizer. Weekly turning ensured proper aeration, with periodic temperature and humidity checks to maintain optimal conditions. Under normal circumstances, the compost matured within approximately one week.

4.4.1 Results of Circular Economy implementation

The implementation of this strategy generated both environmental and operational benefits. The Quality Collection Rate (QCR) indicator was calculated, as presented in the study by Lelicińska-Serafin et al. (2023):

$$\%QCR = \frac{Amount\ of\ waste\ collected}{Total\ amount\ of\ wate\ generated} \times 100\%$$

This indicator measures the efficiency of vegetable waste collection for circular economy utilization. As shown below, the company's initial waste collection rate was 0%, due to the absence of a formal waste collection system:

$$\%QCR = \frac{0}{3807} \times 100\% = 0\%$$

According to the research, for the circular economy tool to be effective, the collection rate must reach 97% across all processes. After implementing the pilot plan, the indicator was recalculated to assess the achieved collection rate:

$$\%QCR = \frac{261}{266} \times 100\% = 98.12\%$$

In the end, this result demonstrates that not only does the achieved QCR of 98.12% fall within the optimal range, but it also confirms that the circular economy pilot plan was executed efficiently.

The implementation of the circular economy pilot plan has had a significant impact on waste collection efficiency, achieving a QCR of 98.12%. This exceeds the 97% threshold required to consider the circular economy effective within the company's processes. Prior to this implementation, the lack of a collection system resulted in a QCR of 0%, highlighting the underutilization of residues.

With the new collection rate, the company not only reduces its environmental impact by minimizing unutilized waste but also creates opportunities to reuse these residues in composting or renewable energy processes, aligning with sustainable practices. Overall, the circular economy approach transformed waste management from a cost center into a value-creating activity.

Finally, the implementation of the integrated improvement model produced consistent and measurable results across all operational areas of the spinach processing line. Each intervention (preventive maintenance, process standardization, FIFO inventory management, and circular economy practices), contributed to enhancing the company's overall performance, while their combined effect established a more reliable, efficient, and sustainable production system. Quantitative indicators confirmed significant gains in equipment availability, product quality, process traceability, and waste recovery, while qualitative observations revealed improvements in organizational discipline, communication, and environmental awareness among employees. These outcomes demonstrate the effectiveness of the proposed model as a holistic approach to operational excellence in the agro-industrial sector, demonstrating its capacity to integrate technical efficiency with sustainable value creation.

The following section explores the broader implications of these findings and their potential applicability to similar production environments.

5. Discussion

The results of this study confirm that the integrated improvement model, combining Total Productive Maintenance (TPM), process standardization, FIFO inventory management, and circular economy practices, effectively enhance both operational performance and sustainability within the spinach processing line. These findings reinforce the theoretical foundations of the PDCA continuous improvement cycle and the TPM framework, which emphasize the systematic elimination of losses, proactive maintenance, employee engagement, and standardization of work procedures. Similar outcomes have been documented in previous research on Lean and sustainable manufacturing, where structured maintenance and process mapping contributed to reductions in waste and productivity losses.

The most substantial improvement was observed in product conformity. The percentage of nonconforming products decreased from 4.45% to 1.36% following the TPM-based preventive maintenance intervention, demonstrating the strong link between equipment reliability and product quality. Correspondingly, equipment availability increased from 78.13% to 92.80%, surpassing the 90% target and confirming that preventive maintenance effectively stabilized operations while reducing unplanned downtime. These results validate TPM as a cornerstone for Lean operations in agro-industrial environments.

Process standardization similarly yielded measurable benefits. The washing quality indicator improved from 98.17% to 99.47%, exceeding the 99% threshold required for food safety compliance. Standardization minimized process variability, strengthened inter-shift coordination, reduced dependence on individual operator experience, and supported knowledge retention despite personnel rotation. Collectively, these improvements highlight how consistent procedures foster reliability and maintain product integrity in critical processing stages.

From a logistics standpoint, the implementation of the FIFO system contributed to near-perfect inventory accuracy and reduced waste from outdated or deteriorated stock. The obsolescence rate decreased from 1.52% to 0.79%, falling below the 1% optimal threshold for perishable products. Timely product rotation not only minimized losses but also improved traceability, facilitated faster audits, strengthened quality assurance, and increased customer satisfaction. This result aligns with studies highlighting the

importance of traceability and inventory visibility in achieving efficient supply chain performance. Furthermore, integrating FIFO with digital barcode tracking created a bridge between Lean principles and digitalization.

Circular economy practices extended the benefits of the integrated model beyond operational efficiency to environmental sustainability. The Quality Collection Rate (QCR) increased from 0% to 98.12%, surpassing the 97% threshold required for effective resource recovery, confirming that the pilot plan efficiently captured and repurposed organic residues. By converting waste into compost, the company reduced environmental impact and generated value from previously discarded materials, aligning with the principles of closed-loop production and long-term competitiveness (Lelicińska-Serafin et al., 2023). Additionally, circular economy not only mitigates environmental impact but also reinforces long-term competitiveness. The closed-loop system implemented in this study demonstrates how sustainability can be embedded into production processes without compromising productivity.

These results illustrate the synergistic effect of integrating TPM, process standardization, FIFO, and circular economy strategies. Operational improvements are reinforced by complementary environmental and managerial gains, demonstrating that efficiency and sustainability are mutually reinforcing rather than conflicting objectives.

Despite these achievements, certain limitations were identified. The pilot covered a single production line, and while the results are promising, large-scale implementation across all product categories will require additional evaluation of capacity constraints and process interdependencies. Moreover, digital integration was limited to barcode tracking; future studies should explore the use of real-time monitoring systems or IoT-based solutions to further enhance process visibility and decision-making.

Overall, the study demonstrates that structured, data-driven methodologies can bridge Lean operations and sustainable practices within agro-industrial contexts. The integrated improvement model provides empirical evidence that operational excellence and environmental stewardship are compatible, offering a practical framework for other firms seeking to reduce waste, enhance product quality, and promote sustainable productivity. Future work should focus on scaling these interventions, incorporating advanced digital tools, and evaluating long-term economic and environmental impacts across diverse production settings.

6. Conclusions

6.1. Conclusions

The implementation of the integrated improvement model demonstrated that combining Total Productive Maintenance (TPM), process standardization, FIFO inventory management, and circular economy practices is an effective strategy to enhance both efficiency and sustainability in agro-industrial operations. The results confirm that integrating technical and organizational measures within a PDCA-based framework produces consistent operational improvements across all stages of spinach production.

TPM-based preventive maintenance increased equipment reliability and reduced mechanical downtime, contributing to a 69% reduction in nonconforming products, from 4.45% to 1.36%, and improving equipment availability from 78.13% to 92.80%. Process standardization minimized variability in the washing stage, raising the washing quality indicator from 98.17% to 99.47%, ensuring compliance with food safety standards and optimizing the use of water and sanitizing resources. FIFO inventory management improved product rotation, reducing obsolescence from 1.52% to 0.79%, enhancing traceability, and minimizing waste due to storage inefficiencies. Circular economy practices increased the Quality Collection Rate (QCR) from 0% to 98.12%, enabling the transformation of organic residues into value-added compost and reducing waste disposal by 31%, thereby strengthening environmental performance.

These results demonstrate that Lean principles, when aligned with sustainability-oriented strategies, deliver measurable economic and environmental benefits. The study validates that sustainable competitiveness in the agro-industrial sector can be achieved through systematic, preventive, and data-driven management practices, bridging the gap between traditional production systems and modern frameworks integrating digitalization and circular economy concepts.

6.2. Recommendations

It is recommended that the company scale the implementation of this model to other production lines to assess its adaptability across different products. Future research should explore the use of advanced monitoring technologies, such as IoT sensors and predictive analytics, to enhance real-time control over maintenance and production parameters. Expanding circular economy initiatives through partnerships with external stakeholders,

such as compost distributors or organic fertilizer producers, could further increase the program's economic and environmental impact.

From an academic perspective, further studies may investigate the joint application of Lean and circular economy principles in other agro-industrial contexts, examining long-term effects on cost reduction, resource optimization, and social impact. Finally, it is recommended to reinforce a culture of continuous improvement among employees, as their active participation remains a decisive factor in sustaining the operational and environmental gains achieved through this project.

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8. Anexos

Anexo 1

Información de gestión del proyecto

A11. Objetivo general

Desarrollar una propuesta que permita reducir la merma de la línea de producción de espinacas y mejorar la eficiencia aplicando las herramientas de TPM, Estandarización de procesos y economía circular en una empresa agroindustrial.

A12. Objetivos específicos

• Identificar los principales factores que afectan a la generación de la merma, mediante un árbol de problemas.

• Seleccionar e implementar herramientas lean para reducir el nivel de fallas en la maquinaria, establecer un procedimiento estándar para el proceso de lavado y una organización adecuada en el almacén, factores que afectan al resultado de la merma.

• Determinar los resultados de la implementación de herramientas lean en la empresa agroindustrial.

A13. Cronograma proyectado

CRONOGRAMA TENTATIVO DE DESARROLLO DEL DISEÑO

HITOS	ACTIVIDAD	ESTADO	MES															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Capacitación al personal directivo de Mantenimiento Preventivo	¿Por qué implementar TPM y cuáles son los pilares?	Pendiente																	
	Implementando TPM	Pendiente																	
	Monitoreo de la implementación	Pendiente																	
	Estandarizando el TPM	Pendiente																	
Capacitación a los operarios de Mantenimiento Preventivo	Importancia de implementación de TPM en el trabajo	Pendiente																	
	Cambios por implementación	Pendiente																	
	Reporte de accidentes	Pendiente																	
	Formatos de TPM	Pendiente																	
Aplicación de Mantenimiento Preventivo	Limpieza de la Selladora Exterior	Pendiente																	
	Mantenimiento Autónomo	Pendiente																	
	Cambio de Correas	Pendiente																	
	Cambio de las Bandas de Teflón	Pendiente																	
	Revisión Mecánica de la Selladora	Pendiente																	
	Revisión Eléctrica de la Selladora	Pendiente																	
	Limpieza General de Cada Pieza	Pendiente																	
	Lubricar las partes de la máquina	Pendiente																	
Capacitación a operarios de Economía Circular	Objetivos de Economía Circular y metas	Pendiente																	
	Elaboracion de Compostaje	Pendiente																	
Capacitación para el Área de Lavado	Introducción a los estándares de calidad	Pendiente																	
	Aspectos clave de evaluación	Pendiente																	
	Procedimientos estandarizados	Pendiente																	
	Discusión de casos prácticos	Pendiente																	
	Evaluación	Pendiente																	
Capacitación para el Área de Almacenamiento	Conceptos básicos de FIFO	Pendiente																	
	Implementación práctica del sistema FIFO	Pendiente																	
	Monitoreo y seguimiento	Pendiente																	
	Resolución de problemas y casos prácticos	Pendiente																	
	Evaluación	Pendiente																	

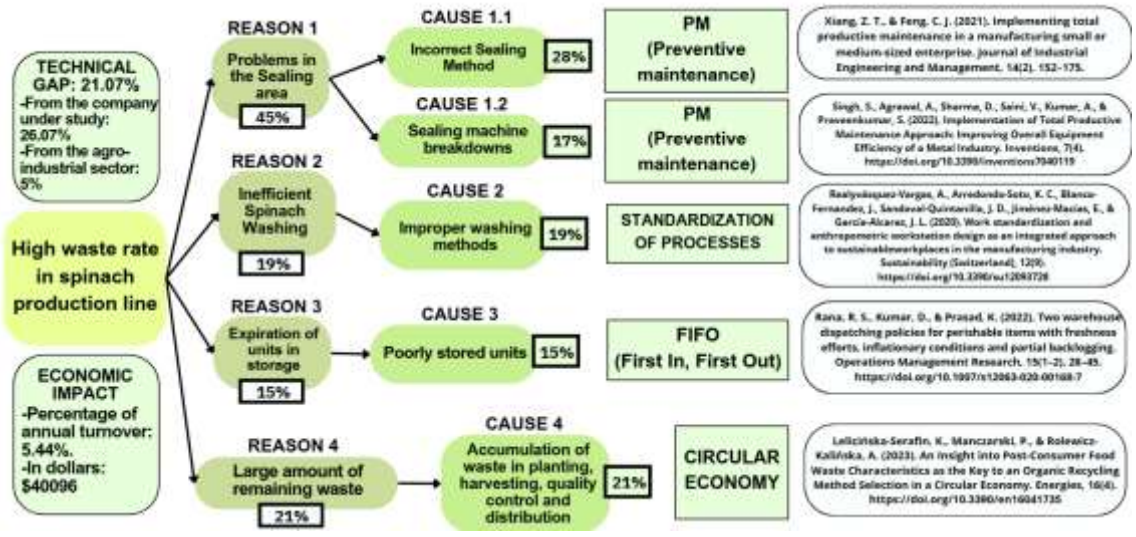
Este cronograma proyectado se realiza con el fin de tener planificada la ejecución de la implementación del proyecto que incluyen el uso de las herramientas Lean mencionadas en la empresa.

Gestión de recursos / presupuesto

La tabla siguiente refleja el costo de los recursos necesarios para poder desarrollar la investigación en un plazo de 11 meses.

PRESUPUESTO DE LA SOLUCIÓN			
Recursos	Cantidad	Costo Unitario	Sub Total
1. Mantenimiento Productivo Total (TPM)			S/4,920.00
1.1. Sesiones de Capacitación de Personal (en H-H)			S/880.00
1.1.1. Capacitación al personal directivo de Mantenimiento Preventivo	8	S/50.00	S/400.00
1.1.2. Capacitación a los operarios de Mantenimiento Preventivo	8	S/60.00	S/480.00
1.2. Aplicación de Mantenimiento Preventivo (en veces/semana)			S/4,040.00
1.2.1. Limpieza de la Selladora Exterior	48	S/20.00	S/960.00
1.2.2. Mantenimiento Autónomo	48	S/35.00	S/1,680.00
1.2.3. Cambio de Correas	5	S/30.00	S/150.00
1.2.4. Cambio de las Bandas de Teflón	5	S/20.00	S/100.00
1.2.5. Revisión Mecánica de la Selladora	2	S/65.00	S/130.00
1.2.6. Revisión Eléctrica de la Selladora	6	S/75.00	S/450.00
1.2.7. Limpieza General de Cada Pieza	6	S/15.00	S/90.00
1.2.8. Lubricar las partes de la máquina	24	S/20.00	S/480.00
2. FIFO			S/440.00
2.1. Sesiones de Capacitación de Personal (en H-H)			S/440.00
2.1.1. Capacitación a los operarios de FIFO	8	S/55.00	S/440.00
3. Estandarización de Procesos / Economía Circular			S/2,420.00
3.1. Sesiones de Capacitación de Personal (en H-H)			S/2,420.00
3.1.1. Capacitación para el Área de Lavado	19	S/80.00	S/1,520.00
3.1.2. Capacitación para Economía Circular	15	S/60.00	S/900.00
4. Costos Adminsitrativos (en unid.)			S/2,170.00
4.1.Elaboración de Formatos	15	S/12.00	S/180.00
4.2.Contratación de Analista	1	S/1,990.00	S/1,990.00
PRESUPUESTO TOTAL			S/9,950.00

A14. Árbol de problemas



El alto índice de desperdicio de las líneas de producción de espinaca se centra en los problemas de postcosecha. Con el fin de resolver las causas de estos problemas se usaron TPM, FIFO, Estandarización de procesos y Economía Circular.

A15. Alcance

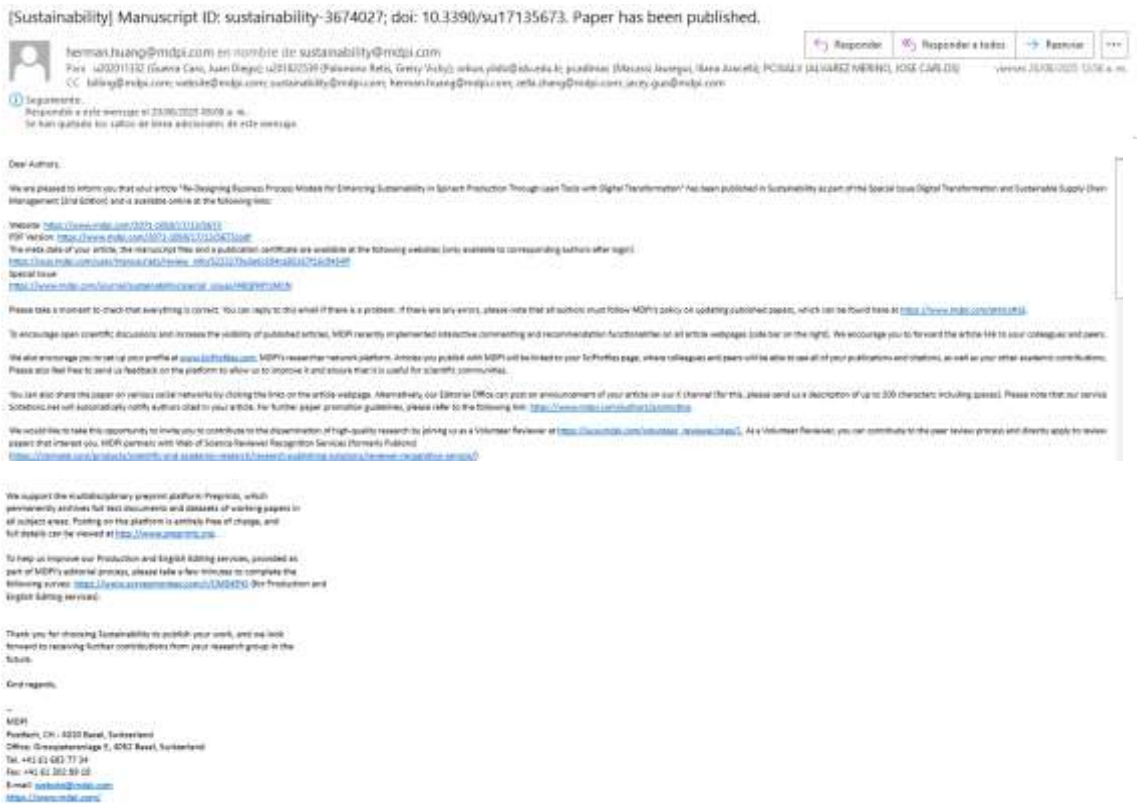
La presente investigación se centra únicamente en la línea de producción de espinaca de una empresa agroindustrial, seleccionada por ser la que genera el mayor porcentaje de

merma. El objetivo es mejorar el proceso de producción y reducir los pedidos defectuosos mediante la aplicación de herramientas de diagnóstico y la implementación de un plan de mantenimiento preventivo específico para las máquinas de sellado. Este estudio está limitado por el desarrollo en un periodo de 11 meses, el cual constituye el tiempo límite disponible hasta la sustentación del proyecto. Como principales limitaciones, el acceso a la planta está restringido por los horarios ocupados y los días laborables de los trabajadores, ya que no hay personal disponible en la instalación durante otros días. Adicionalmente, el estudio se centra únicamente en esta empresa de productos, lo que restringe la aplicación de los resultados a empresas del sector servicios.

ANEXO 2

Documentos importantes complementarios

- **Carta de aceptación del artículo sometido a medio indexado (conference o revista)**



[Sustainability] Manuscript ID: sustainability-3674027; doi: 10.3390/su17135673. Paper has been published.

- **Bibliometrics Format for a Research Article indexed in SCOPUS.**

Guerra, J. D.[1], Palomino, G.[1], Yildiz, O.[2,3,4], Macassi, I. A.[1], & Alvarez, J. C.[1]

Re-Designing Business Process Models for Enhancing Sustainability in Spinach Production Through Lean Tools with Digital Transformation.
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- **Constancia de conformidad de la empresa**

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Lima, 6 de octubre de 2025

Señores
Universidad Peruana de Ciencias Aplicadas – UPC
Presente.-

De nuestra consideración:

Por medio de la presente, tenemos el agrado de dirigirnos a Ustedes, a fin de informarles sobre la solicitud para el uso de información de mi representada requerida por vuestros alumnos **Juan Diego Guerra Caro** con **DNI 70492005** y **Greiny Vicky Palomino Retis** con **DNI 72494743** para el desarrollo del Trabajo de Suficiencia Profesional.

Al respecto, de manera expresa autorizamos que dicha información sea de carácter público, sin identificar expresamente a la empresa a fin de salvaguardar la confidencialidad de la misma, y sea utilizada dentro de los fines académicos que son propios de la naturaleza de este tipo de trabajos, entre los cuales está su publicación, una vez concluido el mismo, en el repositorio de la Universidad Peruana de Ciencias Aplicadas.

Sin otro particular, nos despedimos de Ustedes, expresándole las muestras de nuestra mayor consideración.

Atentamente,

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GERENTE GENERAL

Tina Noriega Maldonado
Gerente General
Empresa - Invernaderos Hidropónicos del Perú SAC