International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V73I11P108

Volume 73 Issue 11, 87-106, November 2025

Original Article

Design and Implementation of a Maintenance Plan Based on Total Productive Maintenance in the Packaging of Chemical Products for the Agroindustrial Sector

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Received: 25 June 2025 Revised: 11 October 2025 Accepted: 03 November 2025 Published: 25 November 2025

Abstract - *The main purpose of this research was to apply Total Productive Maintenance with the purpose of improving productivity in the Agroindustry company, whose economic activity consists of the manufacture of fertilizers, insecticides, and herbicides. For this purpose, Lean Manufacturing techniques were used, such as: The Ishikawa diagram facilitated the analysis and detection of the points that affect the lack of a standardized system and the demotivation of the personnel in the production area; likewise, the application of the 5S methodology allowed optimizing the organizational environment, and finally, Autonomous Maintenance was implemented as a strategy to improve the operational efficiency of the equipment. The modality of the study is applied, with an orientation towards the design, which is pre-experimental and explanatory level, with a sample of 218 participants by means of probabilistic sampling. As a result, the degree of productivity of the organization improved from 46.62% to 77.49%. Finally, it should be noted that there is a lack of research on the implementation of TPM in the packaging stage within the agroindustrial sector, which limits the optimization of yield, reduction of losses, and assurance of quality under conditions of high seasonal demand and sanitary restrictions.*

Keywords - *Empowerment, TPM, Improvement plan, Time analysis, Productivity, 5S.*

1. Introduction

According to the authors [1], in the contemporary business environment, productivity is an essential factor for private sector development in any country. Promoting an efficient and productive corporate environment contributes to job creation, which represents a relevant contribution to national efforts to reduce poverty levels. However, according to the author [2], in the context of international trade, one of the objectives of the agroindustrial sector is to increase agricultural productivity, which is essential to meet the demands of a constantly growing global population that continues to grow. It is estimated that, in order to satisfy the 9.7 billion people projected for 2050, agricultural productivity must grow by 1.75% per year. However, the current growth rate is only 1.73%, which jeopardizes the long-term sustainability of food, fiber, and biofuel production. Furthermore, according to [3], in Latin America, this phenomenon is fueled by factors such as low investment, low labor efficiency, and fiscal restrictions, which hinder the implementation of effective policies for economic reactivation and addressing social and labor problems. At the national level, according to [4], one of the obstacles that negatively affects the improvement of productivity in the agroindustrial sector is the high rate of informal labor; more than 90% of the employees in this area do not have a formal labor relationship, and this figure has increased by 9.5% in the last twelve years. This situation prevents access to basic labor rights and affects the sector's competitiveness. At the local level, according to [5], although the city has a more developed infrastructure compared to other regions, production practices still show deficiencies in process synchronization, inventory control, and waste reduction. This reality generates cost overruns and reduces the competitiveness of local companies, which must face not only the pressure of external markets but also internal efficiency and quality requirements.

Likewise [6], he points out that in recent months unscheduled shutdowns and process defects have allowed equipment to be inoperative at key moments in the production flow. The potential causes were the excess of frequent mechanical failures, the forced use of corrective maintenance, lack of planning for the purchase of spare parts, environmental conditions, lack of maintenance programs to anticipate failures, poor operator practices, and the absence of specific monitoring for equipment performance, which would cause equipment to be unavailable in a timely manner. On the other hand, there is little research that addresses the implementation of TPM at the packaging stage within the agroindustrial sector; this gap limits yield optimization, loss reduction, and quality assurance under conditions of high seasonal demand and sanitary restrictions.

The main question of this study is:

To what extent could the implementation of Total Productive Maintenance contribute to improving productivity in the packaging of chemical products for the agro-industrial sector?

The following specific questions arise from it:

To what extent can the application of Total Productive Maintenance increase efficiency in the packaging of chemical products for the agro-industrial sector?

To what extent can Total Productive Maintenance optimize efficiency in the packaging of chemical products for the agro-industrial sector? The answers to these questions will facilitate the evaluation of the feasibility and advantages of the design and implementation of Total Productive Maintenance.

2. Literature Review

As a foundational reference, the study by the authors [7] introduces an Opportunistic Predictive Maintenance (OM) strategy tailored for a Serial-Parallel Multi-Station Manufacturing System (SP-MMS), which is distinguished by the heterogeneous degradation of its critical components and the presence of both economic and structural interdependencies. The proposed OM framework integrates Predictive Maintenance (PdM) scheduling at the component level with system-level OM optimization. At the component level, real-time degradation data is utilized to continuously update the posterior distribution of each component's degradation rate and its Remaining Useful Life (RUL), ensuring precise RUL estimations. Based on a cost-rate model, the optimal Preventive Maintenance (PM) time is then determined for each component. When a component reaches its optimal PM time, system-level OM optimization is triggered to determine the most cost-effective subset of components for joint maintenance. A novel group cost savings metric-encompassing penalty costs, production loss reductions, and maintenance/setup cost savings-is introduced to guide the selection of this optimal OM group, while accounting for both types of dependencies.

The optimization problem is formulated as a Mixed-Integer Linear Program (MILP), incorporating both discrete and continuous decision variables. Additionally, a classification method based on structural dependency is proposed to streamline the solution process by narrowing the decision space. The effectiveness and practical relevance of the policy are demonstrated through two case studies. In a more recent study by the author [8], the emphasis is placed on the development of an inspection and maintenance framework tailored for a two-component lubrication system involving a filter and a bypass valve, particularly in the context of centralized lubrication applications. Unlike traditional models dealing with redundant systems in cold, warm, or hot standby modes, this work introduces key distinctions. Notably, the filter and bypass valve differ in function and risk: the bypass valve may cause catastrophic failures if left unchecked over time, and there exists a stochastic dependency between the two components. The inspection protocol is centered on the valve, triggering a filter check only when the valve either fails to open or is found to be open.

Preventive maintenance is largely focused on the filter, involving scheduled replacements and corrective actions when an open valve or a clogged filter is detected during inspections. The sensitivity analysis indicates that the optimal maintenance strategy is more strongly influenced by the filter's lifespan parameters than by those of the valve. In their proposal, the authors [9] emphasize the central role of management in the rehabilitation and preservation of heritage buildings. Historically, documentation related to conservation and restoration efforts has been inconsistent, leading to a lack of standardized practices and limited knowledge transfer regarding previous interventions.

This gap presents significant challenges for current restoration initiatives and the preventive maintenance of heritage structures. The study presents the development and implementation of a Heritage Building Maintenance Management System (DD-HBIMMS) tailored to Architectural Heritage (AH). Existing literature on HBIMMS underscores the necessity of further research focused on comprehensive operational processes within historical architecture projects, as well as the practical application of such systems to strengthen cultural heritage conservation.

Utilizing a Design Science Methodology (DSM), the study establishes a structured protocol aimed at enhancing workflows in collaborative heritage architecture projects. The proposed HBIMMS functions as an online platform for storing heritage information and guiding operational tasks. A simplified and visually oriented HBIMMS protocol was developed and validated through a practical case study. However, the authors [10] aim to identify and prioritize the factors that guarantee an effective implementation of Total Productive Maintenance (TPM).

Design/methodology/approach:

The prioritization technique applied in this study is the Analytic Hierarchy Process (AHP).

Findings:

Leadership engagement emerges as the most critical factor in the successful implementation of Total Productive

Maintenance (TPM). Additionally, employee training plays a pivotal role. It is incumbent upon senior management to foster an organizational culture that supports open communication, shared responsibility, active employee participation, and a comprehensive approach to quality management. Manufacturing organizations wishing to increase their productivity by implementing TPM must first of all engage the management team and ensure their full support, as well as train staff in this philosophy. However, the results of the study cannot be generalized globally, as the contributions were based on AHP experts from a specific geographic region. This research demonstrates the application of the analysis to prioritize critical success factors. The prioritization of these factors provides top management with a solid basis for designing effective maintenance strategies, which significantly contribute to improving both productivity and overall organizational performance.

In a similar vein, reference [11] addresses the growing presence of Urban Micro Wind Farms (UMWFs) and the increasing importance of optimizing their maintenance strategies to reduce operational costs and enhance wind energy utilization efficiency. This study formulates an optimization problem for UMWFs that takes into account both maintenance routing and resource allocation. To tackle this problem, the researchers introduce the Efficient Maintenance Value (EMF) as the objective function, which quantifies the value of maintenance activities. Building on this, a novel hybrid metaheuristic algorithm-Random Variable Neighborhood Descent and Cuckoo Search-Based Hybrid Discretized Artificial Fish Swarm Algorithm (RVNDCS-HDAFSA)-is developed to identify optimal maintenance strategies.

A series of experiments is carried out to assess the local search performance of the hybrid algorithm. Additionally, comparative tests against other algorithms across varying problem sizes are conducted, demonstrating that RVNDCS-HDAFSA outperforms existing methods, particularly for medium- and large-scale scenarios. Results from these comparisons, supported by ANOVA analysis, confirm the superior effectiveness of the proposed algorithm. Ultimately, real-world application tests validate the practical utility of the approach.

3. Objectives

3.1. Main Objective

The main purpose is to evaluate the impact of the design and implementation of TPM on the improvement of productivity in the agro-industrial sector.

3.2. Secondary Objectives

To determine the degree of influence of the design and implementation of TPM on the operational efficiency of the agroindustrial sector. To determine the impact of the design and implementation of TPM on the efficiency of operations in the agroindustrial sector.

4. Materials and Methods

The document establishes that the experimental design tends to comply with two fundamental conditions to guarantee control and internal validity: the manipulation of the independent variable and the equivalence of the groups before and after the treatment applied. In this study, a pre-experimental cross-sectional design will be used to evaluate the concrete impact of the design and implementation of the TPM. This methodological choice is in line with the explanatory approach of the research, since its main purpose is to compare productivity and decision-making before and after the implementation of the proposed system.

The approach adopted in the research is quantitative, which is used when it is required to collect and analyze numerical data or to test hypotheses. For this purpose, statistical and quantitative data corresponding to both variables of interest were collected in order to make a comparison. In particular, a pre-test and a post-test were applied in order to evaluate the impact [12, 13]. The study population focused on an agribusiness company in the years 2024 and 2025. To determine the sample size, the simple random sampling formula with a finite population was used, considering the total number of the company.

This procedure made it possible to identify the production packaging plant that would be the object of analysis. The population consisted of 500 employees belonging to the agroindustrial company, considered for both the pre-test carried out in 2023 and the post-test carried out in 2024. Exclusion Criteria: Employees who were with the Agroindustrial company before 2023 and after 2024 are excluded. The sample size was determined using the simple random sampling formula for finite populations, considering the entire company. The sampling for the present study is probabilistic for a finite population.

Where:

n = Sample size
N = Population = 500 employees
Confidence level 95% z = 1.96
e = Margin of Error = 5%
p = Probability of the event occurring = 50%.

$$n = \frac{\frac{z^2 \, x \, p(1-p)}{e^2}}{1+\frac{z^2 \, x \, p(1-p)}{e^2 \, N}}$$

A value of n = 218 was obtained

The sample number was taken from the collaborators at the Lima plant. In this research, a probability sampling of convenience type was used, taking as a sample the plant located in Lima. Likewise, the availability of historical data and relevant records was taken into account for the analysis. [14] During the research, the observation technique was used as the main method for data collection, with the aim of achieving a comprehensive understanding of the study variables and their respective indicators, detailed in Table 1: Efficiency Percentage and Percentage of Effectiveness. This technique represents an essential and general component of the data collection process, being key to obtaining accurate and relevant information [15, 16].

Table 1. Indicators, techniques, and instruments

Indicator	Technique	Instrument
Efficiency Percentage	Observation	Observation Form
Percentage of Effectiveness	Observation	Observation Form

Table 2. Schedule for the implementation of Total Productive Maintenance (TPM)

Phase / TPM Pillar	Main Activities	Estimated Duration	Responsible Parties
1. Preparation and Awareness	- Dissemination of TPM objectives.	2 months	Top Management / TPM Committee
	- Awareness sessions on zero breakdowns, zero defects, and zero accidents.		
	- Selection of pilot areas.		
2. 5S and Workplace Discipline	- Organization, cleaning, and standardization of work areas.	2 months	Operators / Supervisors
	- Initial 5S audits.		
	- Elimination of contamination sources and leaks.		
3. Autonomous Maintenance	- Training operators in inspection, cleaning, and lubrication.	2 months	Operators / Facilitators
	- Development of daily checklists.		
	- Implementation of basic equipment care routines.		
4. Planned Maintenance (Preventive and Predictive)	- Scheduling of periodic inspections.	2 months	Maintenance Department
	- Lubrication and calibration plans.		
	- Implementation of maintenance management software.		
5. Focused Improvement (Kaizen on Critical Equipment)	- Identification of chronic losses.	1 month	Multidisciplinary Teams
	- Analysis of recurring failures.		
	- Application of improvement tools (Ishikawa, FMEA, 5 Whys).		
6. Training and Skills Development	- Training in TPM, safety, SMED, and failure analysis.	1 month	HR / Facilitators
	- Development of internal trainers (multipliers).		
	- Certification of autonomous operators.		
7. Early Equipment Management	- Review of the maintainability and reliability of new equipment.	1 month	Engineering / Procurement / Maintenance
	- Involvement of maintenance in purchasing and project design.		
8. Safety, Health, and Environment (SHE)	- Accident prevention campaigns.	1 month	Safety Committee / Operators
	- Safety inspections.		
	- Integration of TPM with ISO 14001 and OHSAS 18001 standards.		
9. TPM Consolidation and Audits	- Evaluation of OEE (Overall Equipment Effectiveness) indicators.	12 months	TPM Committee / Top Management
	- Internal audits by the TPM pillar.		
	- Recognition of high-performance teams.		

5. Solution Implementation

Below is the schedule for the implementation of Total Productive Maintenance (TPM) (See Table 2).

5.1. Phase 1 - Diagnosis of the Current Situation

The fishbone (see Figure 1) and the Pareto chart (see Figure 2) were used to identify and classify the factors most closely related to the problems analyzed. Table 3 shows that the main problems identified in the organization were the absence of a continuous improvement system and the high frequency of corrective maintenance, lack of teamwork, lack of personnel training, etc.

The application of Total Productive Maintenance can improve productivity.

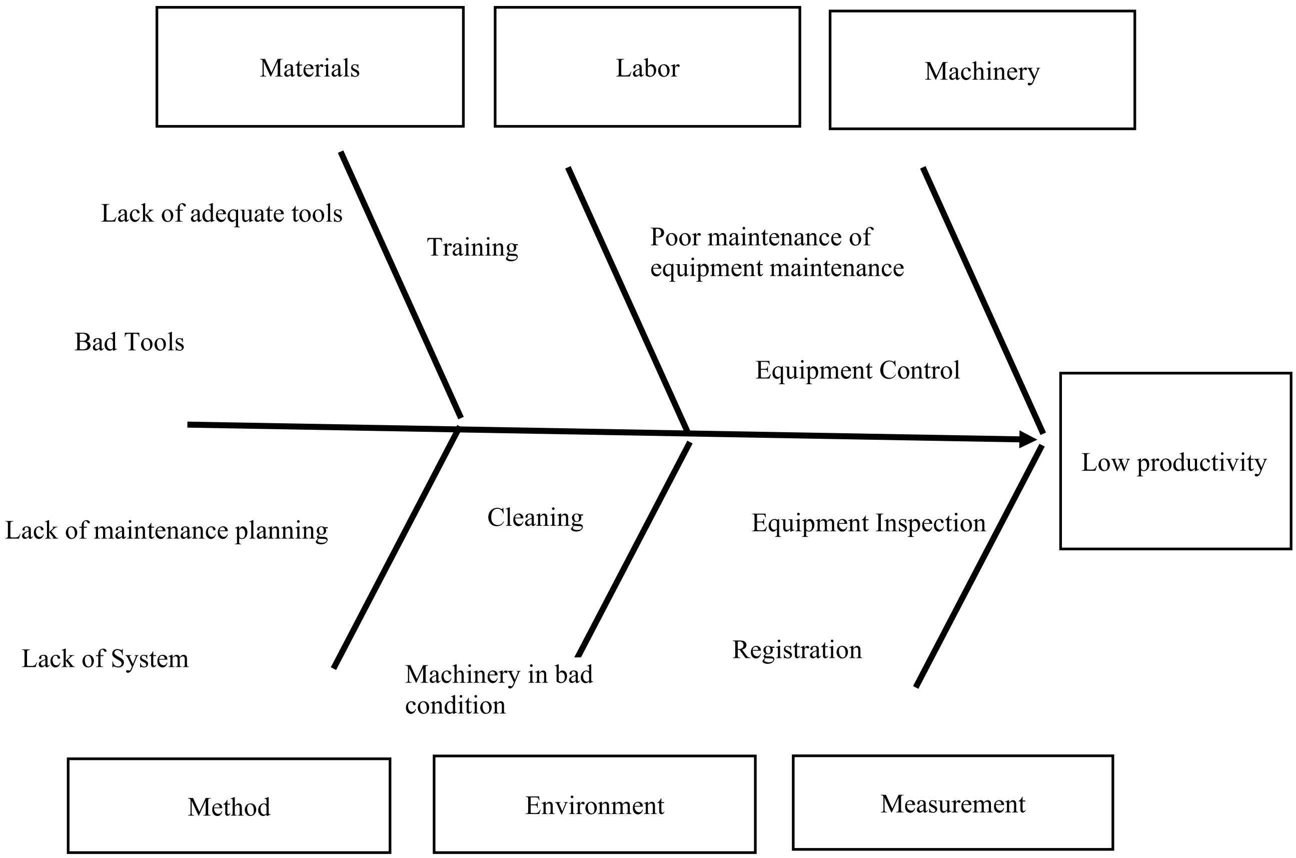


Fig. 1 Ishikawa diagram of low productivity

Table 3. Frequency of low productivity factors

Number	Problems	Frequency	Cumulative Percentage (%)
1	Lack of a Continuous Improvement System	60	18%
2	Excessive Teamwork	53	33%
3	Lack of teamwork	49	48%
4	Lack of staff training	38	59%
5	Lack of cleanliness and order	34	69%
6	Waste of raw materials	28	78%
7	Lack of preventive maintenance	23	84%
8	Lack of supervision	19	90%
9	Lack of employee motivation	16	95%
10	Use of obsolete equipment	11	98%
11	No noise control	7	100%

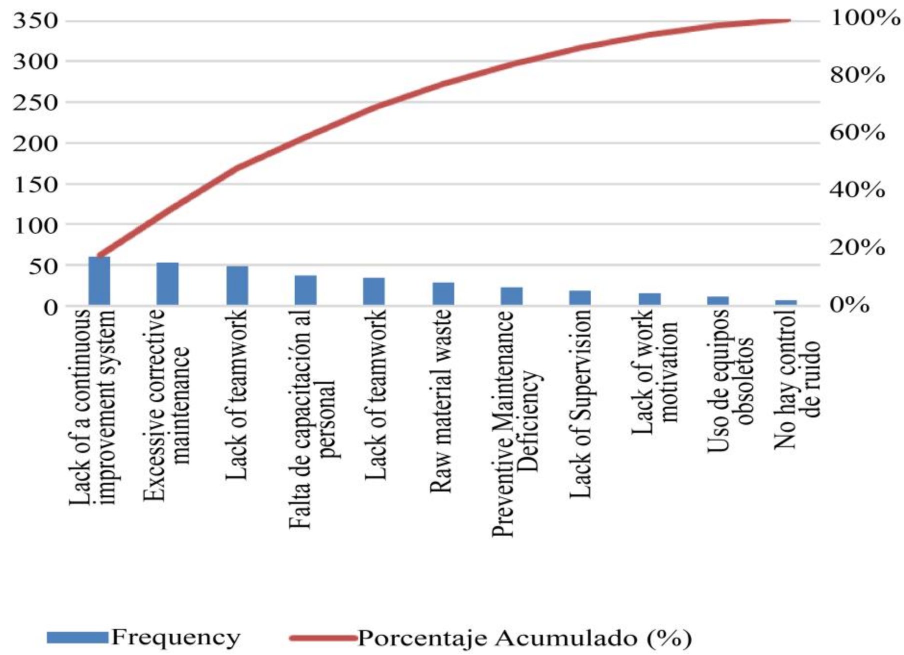


Fig. 2 Pareto chart of low-productivity factors

5.2. Phase 2 - Design of the Management Model

According to the authors [17], the TPM pillars constitute a set of fundamental principles aimed at promoting the continuous improvement of processes and equipment within an organization. This industrial management methodology is based on eight pillars. The details are shown in Table 4.

Table 4. Steps and description

Step	Description
Step 1: Announcement by Top Management of the Decision to Introduce Tpm	Management must clearly communicate its decision to implement TPM and encourage enthusiasm. It is essential to have their active commitment, as this is not guaranteed by the initial declaration of intent alone.
Step 2: Launching of the Educational Campaign	TPM training and dissemination should be initiated as soon as possible, not only to provide an understanding of the methodology, but also to strengthen staff morale and reduce resistance to change.
Step 3: Create an Organization to Promote Tpm	This committee must be made up of the heads of Management, Production, Technical Services, and Human Resources. Among its main functions are the selection of the pilot areas and the formation of the different working groups.
Step 4: Establish Tpm Policies and Goals	The initial policy consists of assuming a firm commitment to TPM and integrating specific processes for its development within the strategic plan of top management, both in the medium and long term. It is also essential to establish concrete and quantifiable annual goals, which must be disaggregated in each department and at the organizational level, in actions oriented to their fulfillment.
Step 5: Formulate a Master Plan for Tpm Development	The plan should include a daily TPM promotion program, starting from the preparatory phase prior to its implementation. In addition, the progressive application of the five TPM development objectives should be sought, adjusting them to the specific needs of each area.
Step 6: Tpm Output Triggering	The kick-off is a meeting of all employees where managers report on the plans prepared and the work accomplished, as well as the promotion structure, goals, and basic policies of the TPM.
Step 7: Equipment Effectiveness Improvement Program.	The kick-off event consists of a general coordination with the participation of all staff, during which senior management communicates

	the plans developed, the progress achieved, and presents the promotion structure, goals, and fundamental policies of the TPM. The master plan for the development of the methodology is also presented.
Step 8: Autonomous Maintenance Program (Am).	Autonomous maintenance is key in the preparation of the necessary conditions for the implementation of TPM by the corresponding committee. This phase represents one of the greatest challenges of the process, due to the difficulty involved in abandoning traditional work methods, which in turn demands greater effort and adaptation time.
Step 9: Planned Maintenance Program (Pm).	The objective of this step is to implement a periodic maintenance program under the responsibility of the Maintenance Department. Scheduled or preventive maintenance (PM) activities should be coordinated in an articulated manner with the autonomous maintenance (AM) actions performed by the Operations Department. Until the general inspection tasks are fully assumed by the operators, the continuous assistance of the Maintenance Department will be necessary.
Step 10: Early Equipment Management	Management aims to ensure equipment reliability and maintainability. This comprehensive approach is based on maintenance prevention (MP) and on a design oriented to minimize the need for maintenance, taking advantage of experience.
Step 11: Operation and Maintenance Training And Education Program	Strengthening operational and maintenance capabilities represents an investment in human capital that generates significant benefits.
Step 12: Full Implementation of Tpm and Setting High Goals.	The final stage consists of consolidating its implementation and setting more ambitious future objectives. During the stabilization phase, each member of the organization actively contributes to the sustained improvement of TPM results, ensuring its permanence over time.

5.3. Phase - Pilot Implementation

Step 1: Announcement to top management of the Top Management's decision.

Management communicates the benefits expected with the implementation of the TPM methodology, highlighting the achievements it will generate in the organization. Within this framework, productivity is defined as the main indicator of success, based on the principles of availability and operational reliability. The decision was formally announced by the plant manager, who has the support of both supervisors and operating personnel.

At the same time, the shop floor manager is in charge of informing about the start of the TPM implementation process through internal and external communications, explaining that this tool will be applied to optimize the process of packaging chemical products for the agroindustrial sector, with a view to increasing productivity levels. Likewise, the plant manager designates the maintenance supervisor as responsible for leading this initiative, in coordination with the operators and mechanical technicians, in order to guarantee an adequate implementation of the TPM methodology.

Step 2: TPM implementation information

Information related to improvement-oriented decision-making is duly channeled with the objective of implementing TPM in the packaging plant for the agro-industrial sector. This responsibility falls on the management levels, who must ensure that all personnel involved - including managers, supervisors, operators, and maintenance technicians - receive the relevant communication.Paso 3: Crear una organización para promover el TPM The organizational structure necessary for the development and implementation of the TPM is defined, assigning a responsible person who will be in charge of the rigorous control and proper execution of this management tool.

Plant Manager:

As the highest authority, he/she leads the TPM implementation process in the packaging plant oriented to the agro-industrial sector. His main functions include the official launching of the methodology, the planning and execution of the objectives defined in the improvement plan, the evaluation of the resources necessary for its implementation, and the supervision of the fulfillment of the established deadlines.

Step 3: Maintenance Supervisor (TPM Supervisor)

Will be responsible for managing information and ensuring the correct execution of the TPM implementation process, both in operational terms and in the coordination of the personnel involved. Among his functions are: to ensure effective compliance with the TPM methodology, to develop the documentation required to achieve the proposed objectives, to monitor the defined indicators, to collect with the operational staff the technical information necessary to identify opportunities for improvement, as well as to develop, monitor, and analyze the indicators related to productivity. Additionally, he/she must train the operational and maintenance personnel on the implementation guidelines, the use of the corresponding documentation, and the objectives demanded by the process.

Step 4: Establish policies and goals for the TPM Policies

The fundamental policy is to strengthen staff commitment to performing their duties, with the aim of reducing the incidence of equipment breakdowns. It also seeks to extend the useful life of machinery and technological infrastructure through responsible and systematic operation. The incorporation of good operating practices will be encouraged.

Step 3: Objectives and goals

To increase by more than 50% the productivity of the packaging system for products destined for the agroindustrial sector. Increase operational efficiency by strengthening the reliability of the equipment that makes up the compressed air supply system.To optimize the performance of the system by increasing the availability of the equipment associated with compressed air.

Step 5: TPM Master Plan

It is proposed to develop a specific plan for the implementation of TPM methodology, in order to ensure a structured, progressive, and aligned execution of the strategic objectives of the organization, which will integrate sequential activities aimed at meeting the previously established goals. To this end, the execution of the following actions is contemplated: Autonomous Maintenance Plan:

A specific plan will be developed covering all the packaging machines involved, which will be accompanied by a standardized format designed internally to facilitate its implementation and monitoring Activities aimed at improving productivity: Specific actions will be carried out to increase the availability and reliability of the equipment, in order to optimize the overall performance of the packaging system.Would the user like this section to be developed with examples of specific actions (such as autonomous maintenance, failure analysis, etc.)? They can help the user expand it.

Step 6: Scheduled Maintenance Plans

Detailed plans will be defined that include a structured schedule of systematic inspections for the packaging machines. In addition, quality assurance mechanisms will be implemented for preventive maintenance activities, which will include the periodic review of technical instructions and the formats used during the process. Early equipment management: A prior analysis will be carried out to define the tools, materials, and supplies required for effective maintenance. This early management, together with adequate planning of procurement times, will ensure timely attention in accordance with the established program, thus contributing to efficient compliance with the planned maintenance plan.Paso 6: Disparo de Salida del TPM The execution of the proposal for the implementation of the TPM methodology in the agrochemical packaging plant for the agroindustrial sector has begun. To ensure its effectiveness, clear and timely communication to the personnel involved is essential, highlighting the institutional commitment and willingness to adopt this tool as part of the organizational culture. The purpose of this communication is to prevent possible delays, promote greater coordination between areas, and ensure orderly execution. Likewise, specific responsibilities will be assigned, allowing an adequate follow-up of the activities and an effective systematization of the reports generated during the implementation process.

Step 7: Equipment Effectiveness Improvement Program.

In order to improve operational effectiveness, all equipment and its respective networks were considered, based on the analysis and description of the problems identified. Based on this, the following specific improvement actions were proposed for each problem detected:

Problem 1: Leaks and deterioration in the compressed air networks.
Proposed action: The implementation of a maintenance plan focused on periodic inspections of the compressed air networks is proposed. This plan will include a segmented evaluation of the piping and outlet devices in order to diagnose their current condition and schedule the necessary preventive interventions in a timely manner.

Problem 2: High maintenance costs
Proposed Actions: The formats used for the daily collection of operational data, including failure and performance reports, will be reviewed and optimized. In addition, a monitoring system will be implemented to perform detailed analyses of equipment operation. This analysis will make it possible to establish correlations between average operating hours, frequency of failures, and spare parts consumption, which will facilitate the identification of specific opportunities for improvement and cost reduction.

Problem 3: High number of failures in the packaging lines
Proposed actions: It is proposed to analyze failures per machine in order to systematize the technical information related to recurring incidents. Proactive and predictive actions will also be identified and recorded, which will be evaluated for possible integration into existing maintenance plans or as a basis for the design of a new plan aligned with actual operating conditions. The following is a more detailed description of the proposed improvement actions: Maintenance plan through visual inspection: Inspections were carried out on the equipment and output devices to evaluate their functional status. This diagnosis made it possible to know the current state of the networks at both the physical and documentary levels, allowing for the updating of plans and serving as a basis for the preparation of a preventive maintenance plan, which will be developed in stage 8 of the

project. Document review: The formats used to record operational failures were analyzed and redesigned. In particular, the structure of the failure report form was reinforced, incorporating specific fields to facilitate its correct completion by the operating personnel. The required data include: detailed description of the failure, date of occurrence, identification of the responsible operator, and the person in charge to whom the incident is reported. This structured record will provide a numerical and qualitative database that reflects the frequency and nature of the failures, facilitating corrective decisions in the shortest possible time. (See Table 5)

Table 5. Failure report

FAILURE OR MALFUNCTION REPORT FORM		Code	FR-2024-011
		Version	1.2
		Date	2024.11.07
		Page	1 of 1
Machine and/or Equipment	Packaging Machine 1	During operation, the conveyor belt stopped unexpectedly. The motor showed signs of overheating, and a burning odor was detected. A visual inspection revealed that the drive belt was misaligned and partially frayed.	
Code	PKG-01		
Place of Occurrence	Packaging Area – Line A		
Machine status	In Operation (stopped due to failure)		
Date and time of occurrence	2024-11-07 – 14:32		
Failed system or element	Conveyor drive motor and belt assembly		
Horometer	4587 hours		
Reported by	C. Porras, Maintenance Technician		

In the operating records of the machines, the information corresponding to the operation of the packaging machines is compiled on a daily basis, making it possible to determine the total hours of operation per day and consolidate a monthly database. The new operating format will include details of the activity of each packaging machine, as well as the operating status of the equipment. This stage of the implementation has made it possible to define the minimum data required to ensure that the format is properly filled out, which must comply with the basic requirements demanded in eventual audits, in accordance with the organization's standards. (See Table 6) A database has been developed for the analysis of failures by machine, structured on the basis of the new failure report format. This tool will make it possible to generate statistics classified by type of failure, facilitating the identification of the systems that require greater attention in terms of time and budget. In addition, the information gathered will serve as input to design and implement proactive activities focused on reducing the recurrence of failures, thus strengthening the predictive and preventive maintenance strategy. (see Table 7)

Table 6. Format for recording the operation of the packaging machines

		FORMAT					Code	F-001-24
							Version	01
		HOURS OF OPERATION					Date	15/10/2024
							Page	
Team		Packaging Line			Code		PKG-AG01	
ID	DATE	STATUS			HOURS OF OPERATION			REMARKS
		OPER	INOP	MANTTO	H. HOME	H. TERM	H. TOTALS	
1	2024.10.15	X			07:00	15:30	8.5	Normal operation, no incidents.
2	2024.10.15		X				0	Machine stopped due to lack of raw material.
3	2024.10.15			X	08:00	12:00	4	Preventive maintenance (belt alignment, lubrication).

Table 7. Database of failures in TPM packers

Description	Fault Detail	Clasif_Falla1	Clasif_Flake2
Packaging Machine 1	Change of Temperature Indicator, Compressed Air	Electric	Dashboard Gauges (Fuel, Water, Oil, Pressure, etc.)
Packaging Machine 2	Change of Temperature Indicator, Compressed Air	Mechanic	Engine - Mechanical Part
Packaging Machine 3	Change of Temperature Indicator, Compressed Air	Mechanic	Mechanical Couplings
Packaging Machine 3	Change of Temperature Indicator, Compressed Air	Mechanic	Water System

Packaging Machine 4	Change of Temperature Indicator, Compressed Air	Electric	Electric Motor
Packaging Machine 4	Change of Temperature Indicator, Compressed Air	Hydraulic	Lubrication Elements
Packaging Machine 5	Change of Temperature Indicator, Compressed Air	Mechanic	Water System
Packaging Machine 6	Change of Temperature Indicator, Compressed Air	Electric	Electric Motor

Step 8: Development of an autonomous program

An inspection program was established for the packaging machines, based on evaluations by the functional sections of the system. This program has specific instructions that guide the technical review process, which are presented in Table 8.

Table 8. Autonomous maintenance program

LINEA	CHRONOGRAM												TYPE	Task Description
	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SET	OCT	NOV	DIC		
PACKAGING MACHINE 1	X						X						Insecticide	Cleaning and inspection
PACKAGING MACHINE 2			X						X				Herbicide	Lubrication
PACKAGING MACHINE 3					X						X		Fertilizer	Replacement of filter
PACKAGING MACHINE 4						X						X	Fertilizer	Inspection

Step 9: Planned maintenance program

As of the time of the update, an adjustment was made to the maintenance activities, with the objective of aligning the integral plan with the principles and guidelines established by the TPM methodology. In this sense, a new Maintenance Plan has been formulated, complemented with the respective technical instructions, which can be consulted in Annexes 17 and 18. It is important to point out that the instructions have been reviewed and updated, highlighting the following main modifications: The maintenance frequency was redefined according to the new operating hours, seeking a greater degree of precision and efficiency in the scheduled interventions. The list of required materials was updated to incorporate products and resources that were not previously included, particularly those related to the packaging of the entire range of agroindustrial products processed at the plant.

Step 10: Early equipment management

The main objective of the training strategy is to develop and strengthen personnel competencies in accordance with the principles of the Total Productive Maintenance (TPM) methodology. This training will be focused on the development of knowledge in good operating practices, failure analysis, and predictive maintenance. In order to achieve an integral participation in the implementation of TPM, two key components have been defined: Incentive system for operating personnel:

In order to encourage motivation and strengthen commitment in the execution of assigned tasks, economic incentives have been established to recognize the contribution of personnel in the improvement process. These are: An incentive of 5 % on the daily wage for those workers who manage to identify and correct a fault during their routine inspections. An incentive of 5 % of overtime pay in the event that personnel are able to perform an effective analysis of a fault by applying the knowledge acquired during training, using tools such as the fault tree diagram.

2. Technical training program: The purpose of these sessions was to raise staff awareness of the benefits associated with the implementation of Total Productive Maintenance (TPM), highlighting its impact on improving productivity and institutional commitment, both on the part of senior management and the technical team. The trainings were designed and executed by experienced internal personnel, as well as external specialists, addressing the following topics: TPM fundamentals, good operating practices, failure analysis techniques, predictive and preventive maintenance strategies, and the use of diagnostic tools (such as root cause analysis and tree diagrams).

Step 11: Operation and maintenance training program

Given the time of use of the equipment, the anticipated management will focus primarily on guaranteeing the timely availability of the materials and instruments required for the correct operation of the equipment. To this end, an exhaustive review of the corresponding instructions was carried out, and based on the analysis of previous failures, the critical spare parts that must be kept in stock were identified and determined to guarantee a quick and efficient response to possible incidents.

Step 12: Full implementation of TPM and setting high goals

Once the TPM methodology has been implemented in the agro-industrial packaging plant, the effects and results generated during the period following its implementation are evaluated.

6. Results

6.1. About Expert Validation

The tools used to collect information showed reliability as they were chosen from reliable sources, such as the SAP system and production reports, in relation to the independent variable associated with Operator Focused Management. In relation to the dependent variable, focused instruments were used to measure rigorously by experts, see Table 9.

Table 9. Indicators of validity

Indicator	Score		
	Expert 1	Expert 2	Expert 3
Clarity	85%	80%	90%
Objectivity	80%	80%	85%
Currentness	90%	85%	90%
Organization	85%	85%	85%
Sufficiency	95%	90%	95%
Intentionality	100%	90%	85%
Consistency	100%	90%	90%
Coherence	90%	85%	90%
Methodology	80%	80%	90%
Relevance	85%	81%	86%

6.2. Descriptive Analysis

Table 9 clearly shows the improvement in the degree of compliance with Productive Maintenance during the transition from pre-test to post-test after its implementation. In 2023, compliance was 25%, but after implementing TPM, there was a notable increase, reaching 96% in 2024. There is a clear trend towards continuous improvement (see Table 10 and Table 11).

Table 10. Checklist before the implementation of total productive maintenance (2023)

Evaluation Criteria 0=Bad, 1=Regular, 2=Acceptable, 3=Good, 4=Excellent						
NRO	Detail	0	1	2	3	4
Autonomous Maintenance	Operators perform daily cleaning		X			
	Anomalies are detected and reported.		X			
	Lubrication points are marked and accessible.		X			
	The autonomous maintenance checklist is updated.		X			
Planned Maintenance	Preventive maintenance plans are followed.			X		
	Maintenance records are kept.		X			
	Failure downtime history evaluated		X			
Focused Improvements	The main losses (OEE) are identified.		X			
	Corrective actions are applied to major losses.		X			
	Improvements have been achieved in cycle time, availability, or quality.			X		
Training And Education	Operators are trained in TPM.		X			
	There are training plans for each role.		X			
	Operating manuals are updated.		X			
Early Team Management	Maintenance is involved in equipment design/selection.		X			
	Lessons learned are applied to new machines.			X		
	Considered to be easy to clean, inspect, and lubricate.		X			
Quality Control In The Process	Quality standards are applied in each process.		X			
	Defects are detected at the source.		X			
	Critical process parameters are controlled.			X		
Tpm In Administrative Areas	Continuous improvement principles are applied in offices.		X			
	Reduced administrative wastage (time, errors, etc.)		X			
	The efficiency of administrative processes is measured.			X		
Seguridad, Salud Y Medio	Unsafe conditions exist on the line or machine.		X			

Ambiente	Se realizan inspecciones de seguridad.			X		
	Se controla el impacto ambiental del proceso.		X			
Subtotal		0	19	12	0	0
TOTAL		25/100				

Table 11 shows that the percentage of compliance with Total Productive Maintenance initially started at 25%, reflecting the low motivation of the plant personnel. After the implementation of TPM, determine the actual productivity in order to demonstrate the improvements obtained in the process (see Table 12).

Table 11. Level of total productive maintenance compliance (before implementation)

Detail	Score Achieved	Puntaje Meta	Compliance (%)
Antes DE Empezar EL TPM - 2023	25	100	25%

Table 12. Post implementation of total productive maintenance checklist (2024)

Evaluation Criteria 0=Bad, 1=Regular, 2=Acceptable, 3=Good, 4=Excellent						
NRO	Detail	0	1	2	3	4
Autonomous Maintenance	Operators perform daily cleaning					X
	Anomalies are detected and reported.					X
	Lubrication points are marked and accessible.					X
	The autonomous maintenance checklist is updated.				X	
Planned Maintenance	Preventive maintenance plans are followed.					X
	Maintenance records are kept.					X
	Failure downtime history evaluated					X
Focused Improvements	The main losses (OEE) are identified.					X
	Corrective actions are applied to major losses.				X	
	Improvements have been achieved in cycle time, availability, or quality.					X
Training and Education	Operators are trained in TPM.					X
	There are training plans for each role.					X
	Operating manuals are updated.					X
Early Team Management	Maintenance is involved in equipment design/selection.					X
	Lessons learned are applied to new machines.					X
	Considered to be easy to clean, inspect, and lubricate.				X	
Quality Control in the Process	Quality standards are applied in each process.					X
	Defects are detected at the source.					X
	Critical process parameters are controlled.					X
Tpm in Administrative Areas	Continuous improvement principles are applied in offices.					X
	Reduced administrative wastage (time, errors, etc.)					X
	The efficiency of administrative processes is measured.					X
Seguridad, salud y medio ambiente Autonomous maintenance	Unsafe conditions exist on the line or machine.				X	
	Se realizan inspecciones de seguridad					X
	Operators perform daily cleaning.					X
Subtotal		0	0	0	12	84
Total		96/100				

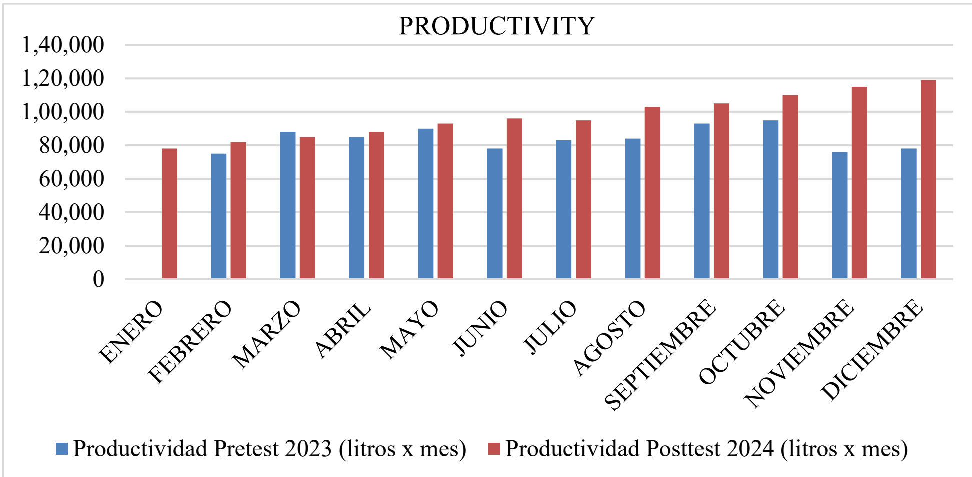
Table 13. Level of total productive maintenance compliance (after implementation)

Detail	Score Achieved	Target Score	Compliance (%)
One Year After Implementation	60	64	94%

Table 13 shows that the verification showed a compliance level of 94%, which indicates that the TPM contributes to improving plant management.

6.3. Variable Productivity

Figure 3 shows that, during the year 2023, the average productivity was 84 thousand liters per month. In contrast, during the subsequent evaluation carried out in 2024, the average was 84 thousand liters per month, reflecting a significant increase of 84 thousand liters per month between the periods analyzed. The data obtained clearly shows that the implementation of TPM has had a positive impact on productivity levels. As evidenced in Table 14, post-implementation, the productivity variable experiences a significant increase. In 2023, the mean increased from 83.75 to 77.49, while the median increased from 45.91 to 79.13, reflecting an average improvement in productivity after the intervention. The mode increased from 83.50 to 95.50, indicating a change in the trend toward higher values in the most frequent data. On the other hand, the standard deviation increased from 6.66 to 13.16, suggesting that, although productivity improved on average, there is greater variability in the changes observed between the different groups (months).



Detail	01	02	03	04	05	06	07	08	09	10	11	12
Pre-test Productivity 2023 (Thousand liters per month)	80	75	88	85	90	78	83	84	93	95	76	78
Posttest Productivity 2024 (Thousand liters per month)	78	82	85	88	93	96	95	103	105	110	115	119

Fig. 3 Descriptive analysis of the pre-test (12 months of the year 2023) and post-test (12 months of the year 2024) of the variable Productivity

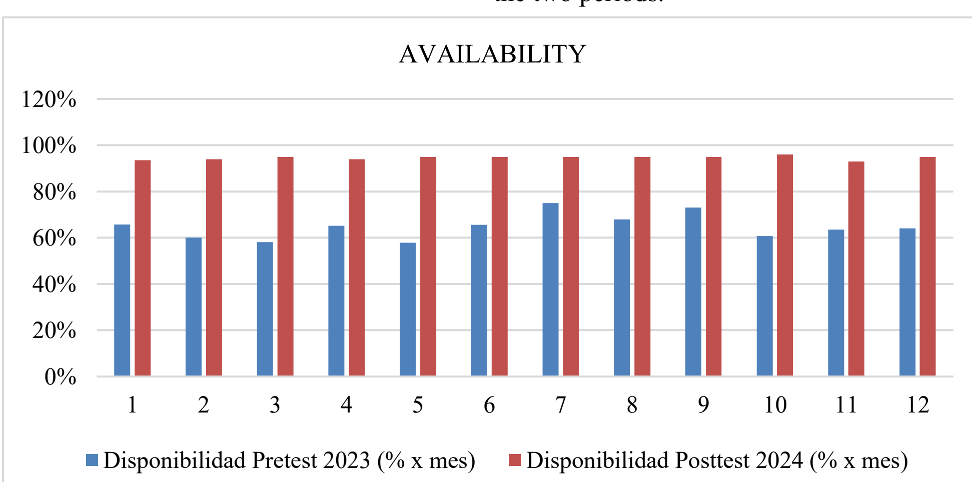
Table 14. Descriptive analysis of pretest - posttest productivity

Statistics			
		Productivity Pretest	Productivity Posttest
N	Valid	12	12
	Lost	0	0
μ		83.75	97,41
Md		83,50	95,50
M		77,00	152,00
σ		6,66	13,16

6.4. Availability Dimension

Figure 4 shows that, during 2023, the average availability was 65%.

In contrast, in the 2024 post-test evaluation, the average rose to 95%, representing a remarkable 30% increase between the two periods.



Detail	1	2	3	4	5	6	7	8	9	10	11	12
Availability Pretest 2023 (% x month)	66	60	58	65	58	66	75	68	73	61	63	64
Availability Posttest 2024 (% x month)	94	94	95	94	95	95	95	95	95	96	93	95

Fig. 4 Descriptive analysis of the pre-test (12 months of the year 2023) and post-test (12 months of the year 2024) of the availability variable

Table 15. Descriptive analysis of availability pretest-posttest

Statistics			
		Availability Pretest	Posttest Availability
N	Valid	12	12
	Lost	0	0
μ		64,75	94,67
Md		64,50	95,00
M		63,14	80,02
σ		5,37	0,77

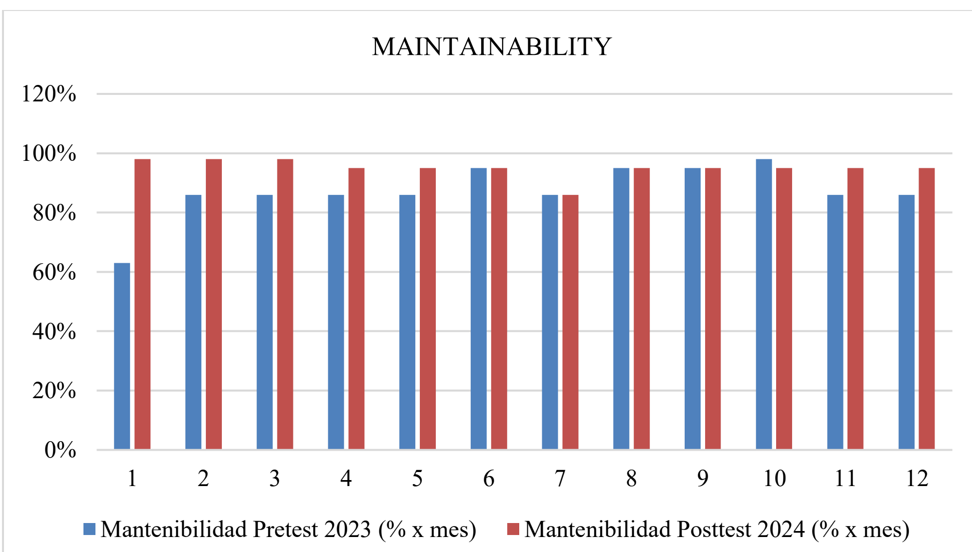
The results demonstrate a favorable impact of the implementation on overall availability performance. Table 15 shows a significant increase in availability after implementation.

The mean increased from 64.75 to 94.67,and the median increased from 64.50 to 95.00, indicating an average improvement in availability after the intervention. Likewise, the mode increased from 63.14 to 80.02, indicating a trend toward more efficient levels.

Although the deviation dropped from 5.37 to 0.77, its relatively small value indicates that the improvement was maintained steadily over the months analyzed. These results are promising and point to a positive effect of the intervention on availability.

6.5. Maintainability Dimension

According to Figure 5, the average maintainability in 2023 was 88%, while in the 2024 post-test evaluation, this figure rose to 95%, showing a remarkable increase of 7% between the two periods. These results clearly show that the methodology had a favorable impact on maintainability. Table 16 shows an increase in the maintainability variable after implementation. The mean increased from 87.33 to 95.00, while the median increased from 86.00 to 95.00, indicating an average improvement in maintainability after the intervention. The mode increased from 86.00 to 95.00, reflecting a change in the trend toward higher values in the most frequent data. The standard deviation decreased from 9.01 to 3.13, suggesting that the improvement was sustained over the months. The results are encouraging and point to the implementation having an effect on maintainability.



Detail	1	2	3	4	5	6	7	8	9	10	11	12
Maintainability Pretest 2023 (% x month)	63	86	86	86	86	95	86	95	95	98	86	86
Maintainability Posttest 2024 (% x month)	98	98	98	95	95	95	86	95	95	95	95	95

Fig. 5 Descriptive analysis of the pre-test (12 months 2023) and post-test (12 months 2024) of the maintainability variable

Table 16. Descriptive analysis of the pretest-posttest maintainability

Statistics			
		Pretest Efficiency	Posttest Efficiency
N	Valid	12	12
	Lost	0	0
μ		87,33	95,00
Md		86,00	95,00
M		86,00	95,00
σ		9,01	3,13

6.6. Inferential Análisis

6.6.1. Normality Test

Table 17 shows the results of the normality applied to the productivity, availability, and maintainability variables. Since the sample size is less than 50, the Shapiro-Wilk test was used to perform the normality analysis.

6.7. Student's t-test for dependent samples

6.7.1. General Hypothesis

H1: The implementation of total productive maintenance improves productivity in the packaging of chemical products for the agro-industrial sector

H0: The implementation of total productive maintenance does not improve productivity in the packaging of chemical products for the agro-industrial sector.

Significance level: 5%

Identification of test statistic: t

Decision rule: If the p-value > α, the Ho is not rejected.

If the p-value is ≤ α, the Ho is rejected.

Calculation of the p-value.

Table 17. Normality test of the productivity variable and its dimensions, effectiveness, and efficiency

Group		Shapiro Wilk		
		Statistics	gl	Sig
Availability	Pre Test	0,938	12	0,467
	Post Test	0,841	12	0,029
Maintainability	Pre Test	0,358	12	0,002
	Post Test	0,417	12	0,001
Productivity	Pre Test	0,947	12	0,588
	Post Test	0,967	12	0,875

Table 18. Paired samples test productivity

Paired samples test								
	Matched differences							
				95% de Confianza				
	Media	Standard deviation	Measurement of standard error	Inferior	Superior	t	gl	Sig (bilateral)
Prod Pret-Post Test	-13,6	14,26	4,11	-22,73	-4,60	-3,3	11	< .001

p-value: 0.0000

Decision**:**

As the p-value in both cases is ≤ 0.05, the Ho is rejected.

6.8. Interpretation

A significance value of less than 0.05 was identified, indicating the existence of statistically significant differences between the productivity results obtained in the pre-test and the post-test. Likewise, the positive values indicate that the results of the post-test exceeded those of the pre-test, which supports the acceptance of the stated hypothesis. H1: The implementation of Total Productive Maintenance improves the packaging of chemical products for the agroindustrial sector (see Table 17).

Specific hypotheses:

Specific hypothesis 1:

H1: The implementation of total productive maintenance improves availability in the packaging of chemical products for the agroindustrial sector.

H0: The implementation of total productive maintenance does not improve the availability of the packaging of chemical products for the agroindustrial sector.

Significance level: 5%

Identification of test statistic: t

Decision rule

If the p-value > α, the Ho is not rejected.

If the p-value is ≤ α, the Ho is rejected. Calculation of the p-value.

Table 19. Efficiency paired samples test

Paired samples test								
	Matched differences							
	Media	Standard deviation	Measurement of standard error	95% de Confianza				
				Inferior	Superior	t	gl	Sig (bilateral)
Efi Test-Efi Post Test	-29,91	5,38	1,55	-33,33	-26,49	-19,24	11	< .001

p-value: 0.0000
Decision:
Since the p-value in both cases is ≤ 0.05, the Ho is rejected.

Interpretation:

The analysis produced a significance value below 0.05, indicating statistically significant differences between the pre-test and post-test availability results. Furthermore, the presence of positive ranks suggests that post-test values were consistently higher than pre-test values, thereby supporting the acceptance of the research hypothesis.

H1 The implementation of total productive maintenance improves availability in the packaging of chemical products for the agroindustrial sector.

Specific Hypothesis 2:

H1: The implementation of total productive maintenance improves maintainability in the packaging of chemical products for the agroindustrial sector.

H0: The implementation of total productive maintenance does not improve maintainability in the packaging of chemical products for the agroindustrial sector.

Significance level: 5%
Identification of test statistic: t
Decision rule: If the p-value > α, the Ho is not rejected.
If the p-value is ≤ α, the Ho is rejected.
Calculation of the p-value

Table 20. Paired samples test efficacy

Paired samples test						t	gl	Sig (Bilateral)
	Diferencias emparejadas							
	Media	Standard deviation	Measurement of standard error	95% de Confianza				
				Inferior	Superior			
Efficacy Test - Efficacy Post Test	-7,66	10,1	2,94	-14,13	-1,19	-2,61	11	< .001

p-value:0.0000
Decision:
As the p-value in both cases is ≤ 0.05, the Ho is rejected.

Interpretation:

A significance value below 0.05 was identified, indicating statistically significant differences between the pre-test and post-test results for the maintainability variable. The presence of positive ranks further suggests an improvement in post-test scores compared to the pre-test. Based on these findings, the research hypothesis is accepted:

H1: The implementation of Total Productive Maintenance (TPM) enhances maintainability in the packaging process of chemical products within the agro-industrial sector. The results clearly demonstrate that the implementation of TPM significantly contributes to the improvement of maintainability within the organization. In parallel, it also reinforces other key aspects such as teamwork, the delegation of responsibilities through self-managed cells, process stability, and a motivating work environment-all of which collectively lead to enhanced performance outcomes. In addition, it is evident that the participation of employees has increased, being able to strategically retain them; however, even though the study shows the existence of an awareness on the part of employees.

7. Discussion

In conducting this study, based on the data obtained, the alternative hypothesis is accepted, which suggests that the implementation of the Total Productive Maintenance (TPM) methodology contributes to increased productivity in the packaging system of the agro-industrial sector. The research is quantitative in nature and adopted a pre-experimental design. On the other hand, authors [18, 19] show an increase in productivity in a food industry dedicated to the processing and slaughter of animals for human consumption and steel manufacturing; however, it is important to highlight that these studies focused primarily on simulations or theoretical analyses. In contrast, the present study is characterized by applied research with an explanatory approach, providing empirical evidence of the results obtained.

Likewise, according to authors [15], in the study "Productivity Improvement with TPM and Lean Manufacturing: A Case Study of Asparagus Processing in Peru," productivity improved by 21%. Similarly, according to authors [25], in their study "Operational Excellence in the Steel Industry Using the Lean Six Sigma Approach: A Case Study," its effectiveness in the steel industry improved by 40% after its implementation. In the present study, as shown in Figure 3, a 9% increase in productivity was observed, supporting the validity of the general hypothesis. The study confirms that the implementation of Total Productive Maintenance (TPM) has had a positive impact on production performance.

On the other hand, according to authors [20], in the study “Proposal for improvement to increase the productivity of an SME in the primary manufacturing sector using standardized labor and TPM tool”, productivity in the primary manufacturing sector increased efficiency from 33.2% to 53.2%, resulting in a 20% increase in the industry. Similarly, according to authors [21], in the study “Improving OEE Performance Using a Lean Six Sigma Approach: A Case Study of Italian Manufacturing”, the metalworking industry's efficiency improved by 9.7%. As in study [22], which shows a 60% improvement in efficiency in the steel industry, in the present study, a 30% increase in availability was achieved, which supports the validity of specific hypothesis number 1 and demonstrates that the implementation of Total Productive Maintenance has had a positive impact on operational efficiency.

Finally, in the authors' research [23], in the study “Operations management model based on 5S, TPM, and SMED to increase equipment effectiveness in a plastics company,” the plastics industry faces a major challenge. After implementing the methodology, effectiveness improved by 53.10%. Likewise, according to the authors [24], in the study “Increasing operational availability in agricultural fertilizer industry production: a TPM approach with the Internet of Things (IoT),” efficiency improved by 7.26%. In the present study, efficiency improved by 7.26%, validating specific hypothesis number 2 and demonstrating that the implementation of TPM has had a positive effect on the operational efficiency of the system. Traditional TPM (Total Productive Maintenance) has been widely valued for its ability to improve operational efficiency, but it has been criticized for not explicitly incorporating sustainability criteria. Therefore, the concept of Sustainable Total Productive Maintenance (STPM) has emerged in recent literature, which adapts TPM principles to incorporate environmental, social, and economic dimensions in a balanced manner [26].

7.1. Evolution towards STPM

Hallioui et al. propose that STPM emerged to fill the "lack of sustainability" of traditional TPM, integrating maintenance management with a triple-impact vision (economic, environmental, social) and Industry 4.0 technologies [26]. In this sense, STPM is characterized by incorporating "sustainable maintenance" as an additional pillar that complements the eight traditional pillars of TPM [26].

7.2. Contributions of TPM/STPM to Sustainability

7.2.1. Environmental Dimension

By reducing unexpected failures, optimizing equipment use, and minimizing waste (raw materials, energy, inputs), TPM contributes to cleaner production and minimizes environmental impacts. Chen et al. show that TPM-related practices in manufacturing environments have positive influences on environmental performance, such as reduced waste generation and emissions in related processes [27].

Furthermore, emerging technologies applied to TPM-such as condition monitoring, data analytics, and automation-allow predictive maintenance, reducing unnecessary interventions and promoting the efficient use of resources [28].

7.3. Economic Dimension

TPM improves Overall Equipment Effectiveness (OEE) by reducing downtime, unplanned shutdowns, defects, and minor losses, leading to operating cost savings and increased competitiveness. Empirical literature reports significant improvements in OEE after TPM implementations, which translate into improved asset utilization and lower unit costs. In the STPM approach, these economic improvements are harmonized with sustainability objectives, preventing the emphasis on productivity from compromising the environment or social well-being [26].

7.4. Social Dimension

Traditional TPM promotes training, operator empowerment, and a culture of autonomous maintenance, which strengthens the company's human capital. In the STPM model, the human factor takes on additional emphasis, as social sustainability requires safe, fair working conditions that promote long-term well-being [26]. This includes dimensions such as health, occupational safety, worker involvement in maintenance decisions, and the ability to operate clean technologies, among others.

7.5. Challenges and Barriers

Traditional TPM can focus excessively on technical efficiency, without addressing side effects such as increased energy consumption or hidden environmental costs. The classic barriers to TPM implementation-resistance to cultural change, lack of management commitment, and limited resources-can be exacerbated when sustainability expectations are added. The transition to STPM requires incorporating new skills in environmental management, advanced monitoring, integration with digitalization, and assessment of sustainable impacts.

7.6. Proposed Integrative Framework

A plausible proposal for articulating TPM with sustainability could include: Extending the classic pillars of TPM to incorporate an explicit Green Maintenance pillar, responsible for monitoring energy consumption, emissions, waste management, and eco-friendly materials. Integrating with Industry 4.0 technologies (sensors, IoT, predictive analytics) to anticipate failures and optimize interventions, thereby improving operational and environmental efficiency [28]. Establishing multidimensional indicators: not only OEE, MTBF, and MTTR, but also carbon footprint, energy consumption per unit produced, waste emissions, job satisfaction index, etc. A systemic and life-cycle approach: linking maintenance with decisions regarding equipment, spare parts, and materials design based on sustainability criteria. Fostering an organizational culture that aligns productivity goals with environmental responsibility and social well-being.

Despite the advancement of modern methodologies such as predictive maintenance with artificial intelligence or prescriptive systems, TPM continues to stand out for its comprehensive approach that combines technical and human aspects. Its emphasis on the participation of all personnel, continuous improvement, and shared responsibility differentiates it from techniques focused solely on technology, which may lack a solid cultural foundation. As a result, TPM reduces downtime, increases productivity, and promotes a sustainable preventive culture, maintaining its relevance and offering a lasting competitive advantage. Finally, among the main limitations of this study are the resistance to organizational change that often occurs during the implementation of Total Productive Maintenance (TPM) in companies, as well as the presence of personnel with limited technical skills, which requires sustained investment in training. Furthermore, the presence of outdated technological infrastructure and a lack of leadership and ongoing managerial commitment are factors that may restrict the effectiveness of the proposed model.

For future research, it is suggested to analyze in greater depth the impact of transformational leadership on the adoption of TPM, as well as to evaluate technical training strategies that can reduce knowledge gaps among operational staff. It would also be relevant to explore the relationship between the digitization of maintenance processes and long-term organizational sustainability.

8. Conclusion

In relation to the first objective, which is to determine the extent to which the implementation of Total Productive Maintenance can improve productivity in the packaging of chemical products for the agroindustrial sector, an increase in the average production is evidenced, going from 84 thousand liters per month in the pre-test to 97 thousand liters per month in the post-test, which represents an increase of 13 thousand liters per month. Regarding the second objective, which aims to determine the degree to which the implementation of Total Productive Maintenance can improve efficiency (availability) in the packaging of chemical products for the agro-industrial sector, a significant increase was recorded, going from 65% in the pre-test to 95% in the post-test, which is equivalent to an increase of 30%. Likewise, the third objective, to determine to what extent the implementation of total productive maintenance can improve the efficiency (maintainability) in the packaging of chemical products for the agro-industrial sector, shows an increase from 88% in the pre-test to 95% in the post-test, an increase of 7%.

For future work, it is recommended to evaluate whether the maintenance plan developed can be adapted to industries with similar processes, such as pharmaceuticals, cosmetics, or food, which would broaden the applicability of the study's findings. Also, a deeper focus on human and cultural factors could enrich future research, addressing aspects such as resistance to change, commitment of operating personnel, and continuous training.

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