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Effectiveness of the Application of the Six Sigma Model for the Productivity of an Organic Banana Exporting Company

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ABSTRACT

The highly competitive landscape of current markets forces companies to adopt effective models to improve their processes and increase their production levels. This study was carried out in an organic banana exporting company, to determine the impact on productivity when applying the Six Sigma methodology. The study had a quantitative approach, applied modality, with a pre-experimental design and an explanatory level. The techniques for collecting information were observation and documentary analysis. After implementing the five phases of the model, an increase of 24.7% in productivity was obtained; Likewise, it was observed that the process capacity would have gone from 0.60 to 1.16, and the Sigma level would have increased from 2.9 to 3.8, causing a lower number of defects per million opportunities in production.

1. Introduction

Currently, there is a wide diversity of methods, resources, and tools with which to deal with the various factors that represent threats to modern companies, in a dynamic that is as complex as it is unpredictable, and in which proper management can make a difference. The Six Sigma model is intended to improve the productivity of companies since it is a project-based methodology. This methodology focuses on reducing variance and defects, as well as improving the caliber of goods, services, and processes [1]. Thakur *et al.,* [2] explained that Six Sigma is a method to improve quality performance that is based on the DMAIC (Define, Measure, Analyze, Improve, and Control) process.

It is necessary to highlight how common it is for producing companies to record losses associated with higher quality margins due to export standards. In the case of banana exporting companies, Vásquez *et al.,* [3] pointed out that, in general, bananas that are not suitable end up being sold in local markets or as by-products.

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For Raman and Basavaraj [4], Six Sigma is a business philosophy that adds profitability, improves production and quality indicators, and consolidates teamwork. Besides, through its application, the overall results are strengthened [5]. Six Sigma is a methodology that has various advantages over others because it is developed systematically following the five DMAIC stages [6]. Likewise, it allows to reduce the variability of the product and the number of defective stocks [7].

Six Sigma has five phases: define, measure, analyze, improve, and control [8], [9]. In the first phase (define), the problems that need to be solved must be identified [10]. During the define phase, all issues concerning procedures, goods, suppliers, consumers, and requirements for high-quality goods are established [11, 12]. Besides, projects are defined and an implementation strategy is created [13, 14]. Study conditions are also replicated to generate a database that can be analyzed [15].

The next phase is measurement. Akanmu and Nordin [16] mentioned that the data collection of the measurement phase begins after defining the scope of the problem and the output technique. Sigma value is determined and a control chart is created to compare with customer requirements [17]. In this phase, the performance of the current process is evaluated [18, 19]. The quantity of inputs and crucial elements is also measured [20, 11].

In the next phase (analysis), data related to failures are collected [14, 21]. At this point, the data study is necessary to determine the deviations [22]. Multiple scenarios are also investigated, to determine the variables that have the greatest influence [23].

In the improvement phase, corrective actions are developed to improve the processes [24, 25]. In that sense, the objectives of this stage are to obtain a robust design and optimal control of the manufacturing process [11]. Advances in productivity are confirmed in the subsequent control stage [26].

The control stage, according to Ponsiglione *et al.,* [27] used a modeling strategy based on a linear regression analysis technique. Here, improved techniques are evaluated [28] and uniform metrics are created to monitor performance [29].

It should be noted that, fundamentally, the purpose of this stage is to follow up on the application to observe the effective change that has been presented [30]. On the other hand, Rojas *et al.,* [31] indicated that sometimes delays and deadlines are used as benchmarks to measure the effects of modifications. Periodic monitoring is important to ensure long-term benefits [32].

Through the application of the Six Sigma methodology, the aim is to improve productivity, which serves as a basis for economic indicators [33]. To increase productivity, the company must effectively manage the resources at its disposal [34, 35], mainly, those related to an adequate management of human talent [36]. Therefore, the more an employee identifies and is committed to the organization for which works, the more successful he/she will be in the development of his/her [37]. In this regard, Obando [38] mentioned that the basis of the company is employee training and motivation.

According to Orrego and Valencia [39], productivity is the cornerstone of long-term sustainability versus competitiveness. Similar reported by Yong *et al.,* [40]. Rodriguez *et al.,* [41] stated that companies can achieve their objectives by adopting specific measures and using resources such as time, people, materials, and equipment. For their part, Gordillo *et al.,* [42] state that productivity can be applied to any economic activity. In turn, Diaz [43] found a wide variety of positive and negative impacts on productivity when applying certain models. In summary, the objective of this study was to determine the impact on productivity when applying the Six Sigma methodology.

2. Methodology

Research can be basic or applied [44]. In the research under development, the applied research modality was chosen because it provided solutions to problems through the production of knowledge [45].

There are different types of design, including pre-experimental, quasi-experimental, pure experiments, and factorial, among others, which are determined according to how the samples are manipulated [46]. In this study, a pre-experimental design was used due to the existence of a single analysis group with the absence of a control group [47], which sought to determine the impact of the Six Sigma model on productivity.

$$G \rightarrow O_1 \rightarrow X \rightarrow O_2 \quad (1)$$

where the experimentation group, G, stimulus, X, first measurement of the dependent variable, O_1 and second measurement of the dependent variable, O_2. The indicators considered are:

i. Process capability (Cp = ES- EI/6 σ)
ii. The Six Sigma level through DPMO (Defects per Million Opportunities) = DPO x 1000000.

This research consisted of the company's productivity records. Among the inclusion criteria, the company's productivity records for the years 2021 and 2022 were considered. The sample consisted of the productivity records grouped in weeks during eight months: from July to October 2021 and from March to June 2022, that is, four months before and four months after the implementation of the improvement. Sampling is the application of techniques used to find representative samples [44]. This research is non-probabilistic by convenience, because it selects nearby elements, before and after applying the improvement.

In addition, concerning data collection techniques and instruments, documentary analysis techniques were used, supported by the observation technique, to collect data on the independent variable. For this purpose, the productivity record card instrument was used, and information was collected four months before and four months after the application of the Six Sigma model, to subsequently determine its effect.

The data analysis method used was descriptive, carried out by organizing the data and analyzing tables and figures processed in Microsoft Excel. Inferential statistics were also used in the SPSS program to contrast the hypothesis and concluded with the application of the normality and t-student test. Likewise, within the framework of ethical aspects, it is stated that the information was obtained with the prior permission of the company; in this way, an authentic collection was carried out, since its results were not changed or adulterated, and the principles of professional ethics, veracity, and reliability were safeguarded.

3. Results

The obtaining, organization, and presentation of the results were based on the phases of the Six Sigma model, to improve the productivity of an organic banana exporting company. The initial conditions for calculating productivity were based on boxes of 80 units, weighing between 19.7 and 20 kilos. The raw material consisted of harvested bananas; the qualified collaborators made up the labor force.

3.1 Six Sigma Model: Define Phase

During this phase, the framework of the project was determined with the participation of the collaborators, to identify, evaluate, and categorize the factors that influence the decrease in production. To do this, the needs to be identified, the problems, the objectives, the scope, the work team, the metrics to be used for the different evaluations, and the customer requirements. The latter is one of the main aspects to be considered to orient production to the real needs of the market. Table 1 shows the customer specifications.

Table 1
Customer requirements

Characteristics	Objective	Specifications
Calibration	42.5 mm	39-46 mm
Cluster	5 fingers	4-7 fingers
Length	7.7 in.	7.5-8 in.
Weight	19.85 kg	19.70-20 kg
Labels	>2 labels per cluster	
Fruit health	No finger malformations, streaks or black spots.	
Cleanliness	Free of insects, fungi and stalks.	
Fruit cream	White and consistent.	

It is important to note that the specification most emphasized by the client is the calibration of the banana in a range of 39 to 46 millimeters. This is the biggest problem currently faced by the company in terms of production quality. Therefore, in this phase, aspects that allowed directing the study towards the solution of this problem were specified, setting out in an organized manner the necessary elements for the application of Six Sigma within the framework of the project, as shown in Table 2.

Table 2
Six sigma project frameworks

Purpose	To improve productivity of labor and raw materials
Company needs that must be met	Eliminate waste in the production process, reduce product and process variability.
Problem statement: Objective	42% of the products do not meet customer requirements, and resources are not used efficiently. Increase productivity by at least 15%. Decrease variability and increase Sigma level.
Scope	The entire production process.
Work team	Participant. Team role: Complement information. Dedication 100%.
Metrics	Variation in calibration, PM (Per Million), DPMO (Defects per Million Opportunities) and Sigma level.

The framework of the Six Sigma project was aimed at improving the productivity of labor and raw materials; in this case, 42% of the products did not meet the customer's requirements, according to the information gathered. Then, exact measurements were taken to elucidate the company's production characteristics more extensively.

3.2 Six Sigma Model: Measure Phase

From this phase, we continued with the measurement of the processes, carrying out a repeatability and reproducibility study in which we ruled out whether the measurement system significantly influenced the variation. Three operators, ten parts and two replicates participated, giving a total of 60 measurements. The aim was to obtain at most 10 % total variation of the R&R (repeatability and reproducibility) to be valid. The final result was 0.2 %; then, the procedure was continued.

Subsequently, we proceeded to evaluate the measurement system, in which the percentage variation of the total R&R was 4.52 %, below 30 %, which is acceptable. Likewise, the part-to-part is 99.9 %, which represents the ability of the measurement system to differentiate between the parts, confirming that the use of a measurement system is reliable.

Similarly, with the data collected, we proceeded to calculate the process capability, which resulted in Cp = 0.60, and therefore, less than 1, which confirms that it is not able to meet the customer's requirements.

In the same way, the stability of the process was performed. For this purpose, the X and R control charts were created with 30 samples of 4 elements. The result showed that the process is unstable, since 14 of the 30 samples were outside the control limits. Subsequently, the Sigma level was evaluated in Table 3.

Table 3
Defects per million opportunities

Distance (m)	Velocity (ms^{-1})
Number of bananas inspected(U)	600
Number of bananas with defects (D)	380
Opportunities (O)	8
DPMO (defects per million opportunities)	79167
Sigma level	2.9

The results indicate production difficulties due to the fact that 79 167 defects per million bananas produced would have been found, which reaches a Sigma level of 2.9. This indicates that there is a large gap, considering the minimum Sigma level 0 and maximum Sigma level 6, for a 6.68 % and 99.0 % yield, respectively.

3.3 Six Sigma Model: Analysis Phase

The results obtained were complemented with previous records and contrasted by the company's team, which made it possible to consider the main causes that influence the decrease in productivity using the Pareto criterion. They were then categorized by taking 486 cases, as shown in Table 4.

Table 4
Categorization of causes

Main causes of productivity decline	Frequency	%	Accumulated
Variation in calibration	180	37	37%
Variation in case weights	160	33	69%
Waste of materials	50	10	80%
Incomplete clusters	40	8	88%
Untrained personnel	20	4	92%
Unregistered material	15	3	95%
Case erector malfunction	10	2	97%
Malfunctioning of labelling machine	5	1	98%
Lack of quality control	5	1	99%
High temperature in the environment	5	1	100%

Subsequently, the data were analyzed using Excel, Minitab and SPSS to determine the correlation and level of influence of the variables, excluding those that did not contribute to the variability. In this way, we sought to establish the influence between the variable's calibration and productivity, so we first determined their correlation, then the linear regression and, finally, obtained their coefficient of determination. The Spearman's correlation index was 0.785, which means that there is a high correlation between calibration and productivity. The linear regression model was established by the following equation: Productivity = 0.033 + 0.01 calibration. In addition, an R2 Coefficient of Determination of = 0.607 was obtained, indicating that 60.7% of the variation in productivity is explained by the calibration variable.

Subsequently, we proceeded to analyze the causes that generate variability in banana calibration between the factors harvest week, deflowering week and temperature. A multiple linear regression was performed, in which 5% of significance of the temperature variable was not significant for the model and was discarded. In this sense, the linear regression model was expressed as follows: Calibration = 5.607 + 2.904 Harvest Week + 0.546 Deflowering Week. Where the predictors: (Constant), Week of Deflowering, Week of Harvest and the dependent variable: Calibration; an R2 = 0.957 was obtained, which means that 95.7 % of the variation of the calibration is explained by the variables Deflowering Week and Harvest Week included in the linear model. Validation was performed, where the test statistic was F = 235.971 and p = 0.001 < 0.05. Therefore, the significance of 5% allowed affirming that the linear model is valid, that is, the variables Harvest Week and Deflowering Week significantly influence the calibration.

3.4 Six Sigma Model: Improvement Phase

Once the relationship of the variables with the calibration was clarified, a 32 factorial experimental design was elaborated with two factors: Harvest Week and Deflowering Week, each with three levels and three replications. Thus, it was obtained that the optimum values for having a caliber of 42.5 mm correspond to week 11 for harvesting and for deflowering to week 5-6, as shown in Table 5.

On the other hand, we proceeded to use the values found in the optimal model for banana production. After four months of follow-up, the improved process capability index was obtained by employing the Minitab 20.3 program, with a result of 1.16, this time higher than 1, which means that it is currently at an adequate level. Subsequently, although it would have been determined that the variation in calibration was the most important cause affecting productivity, through brainstorming the reasons and the solution to the other causes were found, as can be seen in Table 6.

Table 5
Factorial design 32

A: Harvest Week	B: Flowering Week		
	Major (7-12)	Regular (5-6)	Minor (3-4)
10	39- 38-38	43-43-42	47-46-46
11	38-38-38	42-42-43	46-45-46
12	38-37-36	41-41-42	45-45-45

Note: Analysis of the variables Harvest Week and Flowering Week to estimate the optimum calibration of 42.5 mm.

Table 6
Solutions to the rest of the causes affecting productivity

Cause	Reason	Solution
Inaccurate box weight	The sealed box for weighing without the exact weight. Must open and regulate weight, often resulting in overcrowding.	The box must be sealed after proper weight.
Waste of materials	Lack of control of incoming and outgoing materials.	Supervise the use of materials. Surplus materials are taken to a warehouse. Records of incoming and outgoing materials have been implemented.
Problems with the cardboard-forming machine	The machine is in bad condition. A broken rod has been detected in the lower part which decreases the pressure when gluing the box.	Replacement of the rod in the carton-forming machine.
Lack of quality control	Few quality control interventions	A schedule of interventions was established for the quality control of the process.

Finally, the new Sigma level was calculated and 10,208 defects per million bananas produced were reached. A Sigma level of 3.82 was thus reached, which would indicate that the Sigma level improved from its initial value of 2.9.

3.5 Six Sigma Model: Control Phase

The activities carried out by the employees were monitored using samples of size four, three times a day. Based on the Minitab 20.3 report, compliance with the established specifications was confirmed. Finally, for March and June 2022, the productivity indicators were calculated after the improvements, where a productivity variation of 24.7% was observed, as shown in Table 7.

Table 7
Comparison of Productivity Indicators

Factor	Before	After	Units
Labor productivity	32.05	40.44	Boxes/Worker
Raw material productivity	0.72	0.80	Boxes/kg
Combined productivity	0.097	0.121	Boxes/S

4. Discussion
4.1 Six Sigma Model: Define Phase

In the case of the study, it was possible to determine, among the product specifications, a 42.5 mm calibration as the major customer requirement, so it was possible to corroborate that 42% of the production did not meet the required standards and, based on this, the project framework would be generated. Ariga *et al.,* [10] focused its definition on the processes, for which it evaluated the times for each process inherent to the packaging of banana cartons, from the cutting and transport of the bunch to labeling. This is in agreement with Guilcapi and Obando [48], for whom the main productivity problem in a banana company was the poor execution of the work, so they developed their action plan based on this. In the case of Arreaga [49], the main problems were labeling, packing, and cable transport; the latter was the problem that was most related to productivity.

In the definition phase, Raval *et al.,* [14] succeeded in determining the main objectives of the company's drivers, choosing important processes and customers, as well as defining the projects, and creating an implementation strategy, thus posing the critical steps currently practiced by manufacturing organizations. This is in agreement with Knop *et al.,* [13] who during this phase specified the main problem, the current and target status, the expected benefits of the improvement project, and the Six Sigma tools that would be used to address workplace safety in automotive companies. Finally, Ricciardi [15] established a working group and divided the analysis tasks.

4.2 Six Sigma Model: Measuring Phase

The result obtained in the variation of the repeatability and reproducibility model was 4.52 %, and the differentiation between the parts was 93.80 %, which means that the measurement system is under control and can differentiate between the measured elements. These results are confirmed with those obtained by Ozturkoglu *et al.,* [50], who after improving the calibration in the process, obtained repeatability and reproducibility (R&R) of 8.21 %.

Similarly, they agree with Sharma *et al.,* [51], who evaluated a measurement system with a two-level, six-factor design. The total R&R of the caliper was 8.63 %, meaning that there is no special cause and the collaborators present similar levels of performance despite the destructive part design. The research findings reinforce that statement; otherwise, it is possible that it would have failed and the operators would not pass the validation. On the other hand, they helped to get information on execution, process performance, and finding and isolating defective products [52].

4.3 Six Sigma Model: Analyze Phase

The purpose of this phase is to clarify the possible relationships and correlations between the different variables of the process [53]. We proceeded to use the Ishikawa diagram, which is an effective tool in the synthesis of a main problem since it performs a cause/effect integration [54]. As a result, variation in banana calibration would have been established as the main element that was theorized to be influenced by the variables temperature, Blossom Removal Week, and Harvest Week, whose data were processed for correlation analysis, simple and multiple linear regression, which allowed the influence and importance of the variables to be evaluated. The data did not meet the assumptions of normality, for that reason, Spearman's method was used, which determined the degree of association of the variables [55]; as a consequence, only the variables Deflowering Week and Harvest Week would have shown association and could be addressed with actions that would allow improvements.

4.4 Six Sigma Model: Improvement Phase

The model was optimized. As a result, week 11 was found to be optimal for harvesting and weeks 5-6 for deflowering. This factorial technique gives an advantage to the Six Sigma model in the identification of key factors, compared to other improvement methodologies [51]. The study by Arreaga [49], after applying a Pareto analysis, oriented the improvement of the process in the cutting and transport stage by extending the cableway, so that it could reach the point of the pools where the classification, sanitation, and rinsing of the banana is carried out.

4.5 Six Sigma Model: Control Phase

Once the improvements were implemented, the Shapiro-Wilk hypothesis test was applied in SPSS 28.0 software to confirm that the implemented modifications would not have affected the normal distribution of productivity. It was essential to take into account the careful implementation and constant control of the results [56]. Using the t-student test of the Six Sigma model significantly increased the productivity of the company, which in this case would have been 24.7 %. Abualsaud *et al.*, [26] concluded that the model followed a structured systematic methodology that helped improve organizational performance, quality, customer satisfaction, and productivity and eliminate waste.

Valdivieso *et al.,* [57] found that productivity, measured in kg per man-hour, would have increased by 6.45 %, and raw material efficiency by 5.3 %, by eliminating half of the transport processes. Ramírez *et al.,* [58] with the help of the Six Sigma methodology, determined that, due to inexperience in the handling of machinery, productivity per work shift only reached 2.06 ha/day, lower than the productivity of 2.5 ha/day of manual transplanting; this situation could be detected and improved. Likewise, Gómez [59] examined man-hours and production costs and obtained that with the application of changes, productivity grew by 30.59 %.

When referring to raw materials, Torino [60] highlights its importance, since companies transform raw materials to meet the demands of society. Likewise, Arellano *et al.,* [61] point out that an investment study of the costs and expenses related to the recovery of raw materials from industrial or agro-industrial waste should be included. Narciso *et al.,* [62], due to the lack of a consistent procedure, found that the evisceration region presented the lowest raw material yield (42.20 %). Likewise, Acosta *et al.,* [63] mention that processes should be considered to reduce costs without affecting raw material quality. This is because low productivity is usually a consequence of high input and raw material acquisition costs [64].

On the other hand, it must be recognized that improvements are not obtained in all cases when reaching the control phase. In this regard, Magodi *et al.,* [65] suggest doing research with greater temporality, adding other factors in the variability, some of which are critical, such as management commitment, which is essential to ensure success. Also, it should be noted that Six Sigma solutions should be examined on an ongoing basis, along with training for workers [66].

5. Conclusion

At the end of the study, it was found that the development of the Six Sigma model was effective and could be executed optimally in each of its phases. Thus, in the beginning, the calibration in the thickness of the bananas was the main cause detected that affected productivity, with a correlation of 0.785. This led to the analysis of the different variables that affect the average calibration. In this action, temperature would have been discarded, since it was not significant, while the variables Blossom Removal Week and Harvest Week were highly correlated. Therefore, we proceeded to use a factorial analysis model applied to the week of deflowering and the week of harvest. This resulted in week 11 for harvest, and weeks 5 and 6 for deflowering. After the application of the improvements, new measurements were made, from which the process capability would have gone from 0.60 to 1.16, while the Sigma level went from 2.9 to 3.8, which implied a lower number of defects per million. In this sense, according to the t-student results, when assessing the relationship between the application of the Six Sigma model and productivity, a value of 0.001 was obtained, which indicates a very high relationship. Likewise, it was determined that productivity increased by 24.7% in labor, raw material, and both combined.

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