Six Sigma Procedures and Their Impact on the Food Industries

Nolasco Mezares Silvia Joana [1]; Trujillo Vilcapoma Mayir Icotu[2]
[1]Universidad Tecnológica del Perú, Perú, *U20212016@utp.edu.*
[2]Universidad Tecnológica del Perú, Perú, *U20247919@utp.edu.*

***Abstract* – This study seeks to show the impact of Six Sigma (SS) procedures in the optimization of production processes in food industries. Therefore, a systematic literature review (SLR) of 172 articles was carried out. Applying the PRISMA and PICOC methodologies, 41 articles belonging to Q1 and Q2 were selected, which are aligned with the stated objective. The articles reviewed correspond to the meat, bakery, agricultural and nectar industries where SS procedures were implemented, highlighting the DMAIC procedure in 85.71% and among the benefits found, the optimization of resources, elimination of bottlenecks, cost reduction, waste minimization and increased customer satisfaction prevail. It is concluded that, the adaptation of SS through its DMAIC and DMADV procedures have a positive impact on the productive processes, which generates advantages that improve the competitiveness of each industry.**

Key words-- DMAIC, DMADV, Six Sigma, Food Industry, DFSS.

I. Introduction

The production of goods and services is the primary objective of organizations, which seek to generate economic benefits by ensuring that their products meet high quality standards to ensure their survival [1]. In this context, food companies are fundamental to meet the nutritional needs of the population, play a crucial role in the supply chain and ensure that products reach the final consumers in perfect condition [2];these companies constantly strive to improve their manufacturing processes and adapt to customer demands, seek to reduce variations and maintain consistent quality standards [3]; a clear example is a company in the food industrial sector, which through the application of DMAIC methodology, managed to increase the sigma level from 4.2 to 4.8 , indicating a reduction in variation and consistency of product quality [4] To implement the Six Sigma (SS) methodology used in process improvement and optimization, two main procedures are used: DMAIC (Define, Measure, Analyze, Improve, Control), suitable for existing systems, and DMADV (Define, Measure, Analyze, Design, Validate), useful for the development of new systems [1]. The purpose of this systematic literature review (SLR) is to demonstrate that SS procedures have a significant impact on improving production processes, optimizing operational efficiency and speeding up production in companies in the food sector. Despite its importance, it is undeniable that research on this topic is limited, which provides an opportunity to delve deeper into innovative methodologies and effective practices that benefit both companies and consumers.

II. Food Industries

The food industries comprise a set of activities focused on the transformation, storage and distribution of edible products. These industries collaborate with agriculture to obtain a wide range of essential inputs for manufacturing. In addition, proper transportation and storage ensures that goods destined for human consumption arrive in optimal conditions [5].

A. Importance of Food Industries in Society

According to [6] quality within food industries seeks to improve production processes, protect consumer health, reduce waste [7] and comply with Good Manufacturing Practices (GMP) such as proper temperature and lighting to keep the product in optimal conditions [8]. Otherwise, companies could face severe regulatory measures [9], negatively affecting their customer satisfaction and competitiveness [10].

B. Production Process

The production process is composed of various activities performed in a production line in order to meet the needs of the market [11], which are subject to quality standards, both nationally and internationally [12], safeguarding the health of consumers and the quality of food [5]. For example, in a dairy factory, tasks such as washing, cutting, cooking, freezing and pasteurization are performed [13].

C. Stages of the Production Process in the Food Industry

It involves activities focused on transformation, quality verification and distribution of food to points of sale or directly to consumers. According to [5] five stages of the production process are considered:

1) Raw Material Preparation: It is the safeguarding of components with animal or vegetable origin or a fusion of both, characterized by having a very short shelf life, i.e., it consists of keeping the raw material in optimal conditions to start the production process [14].

2) Food Processing: It is the transformation of raw food into products admissible for human consumption through physical and chemical processes. In the case of a bakery, this procedure would include the activities of milling, grain threshing and other essential processes to obtain bread as the final product [5].

3) Quality Control and Food Safety: At this stage, quality management systems allow to take care of food wholesomeness, through the Hazard Analysis and Critical Control Point (HACCP) plan, quality control and food safety are considered as main elements to assess biological, chemical and physical hazards throughout the food chain [15].

4) Storage: According to [5], during this stage, refrigerators, containers, appropriate spaces, ventilation, humidity, light protection and others are used to preserve food quality.

5) Distribution: According to [5], food distribution consists of planning and implementing mechanisms so that the final products arrive in optimal conditions to retail customers, wholesalers and government agencies, in accordance with previously established requirements, agreements and policies.

D. Problems in the Production Process

The most common problems faced by food industries are the high variability in their production processes and the detection of deficiencies [16], cost overruns due to inefficient manual tasks [17] and the large amount of raw material waste [18], which makes it difficult to meet the standards of the production process.

III. SIX SIGMA

Six Sigma (SS), a revolutionary methodology launched by Motorola in 1987, not only eliminates unnecessary activities [19], but also employs statistical tools to manage process variability and reduce errors, with the goal of achieving less than 3.4 defects per million opportunities (DPMO), as stated by [20].

A. Main Objective

Its main goal is to manage the fluctuation of processes, preserve resources and eliminate non-value-added tasks [21]; in addition, it enables the progress of companies seeking to maintain high quality standards, improve productivity and efficiency in their operations **¡Error! No se encuentra el origen de la referencia.**.

B. Implementation of Six Sigma and its Principles

To implement Six Sigma in a company requires the support of top management that encourages teamwork and decision making based on accurate data [5], considering the four principles that are the basis for developing the Six Sigma methodology and guarantee its success **¡Error! No se encuentra el origen de la referencia.**.

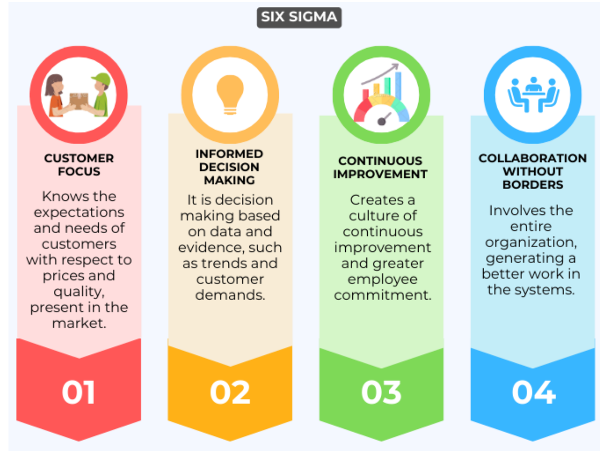

Fig. 1 The principles of six sigma. [19], [22], [23], [24]
Note: The graphic illustrates the essential principles of Six Sigma.

C. Six Sigma Procedures

According to several studies, there are a large number of Six Sigma procedures; however, the most successful in the market are DMAIC; DMADV belonging to DFSS [25].

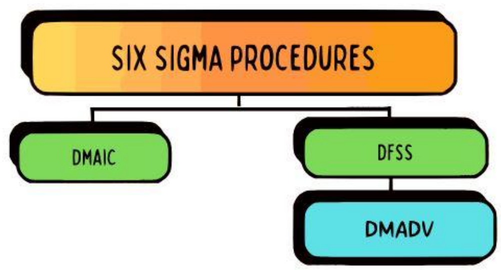

Fig. 2 Six sigma procedures. [25],[26]
Note: The schematic diagram of the Six Sigma procedures is shown below.

1) DMAIC: In today's competitive and dynamic environment, companies are constantly challenged to improve their operational performance and maintain high quality standards [27]. DMAIC, recognized as a Six Sigma tool to optimize processes in various industries [28], can be implemented independently as a procedure for quality assurance and process improvement [20]. This methodology increases efficiency at each step and mitigates problems related to process capability. To illustrate this, [22] in an investigation managed to reduce the scrap rate from 5.5% to 3.08%.

2) DMAIC Stages: It follows standardized steps to solve problems [23], starting with detecting the problem, assessing the current process, analyzing the information, implementing improvements, establishing a monitoring system and making the solution sustainable over time [29] .

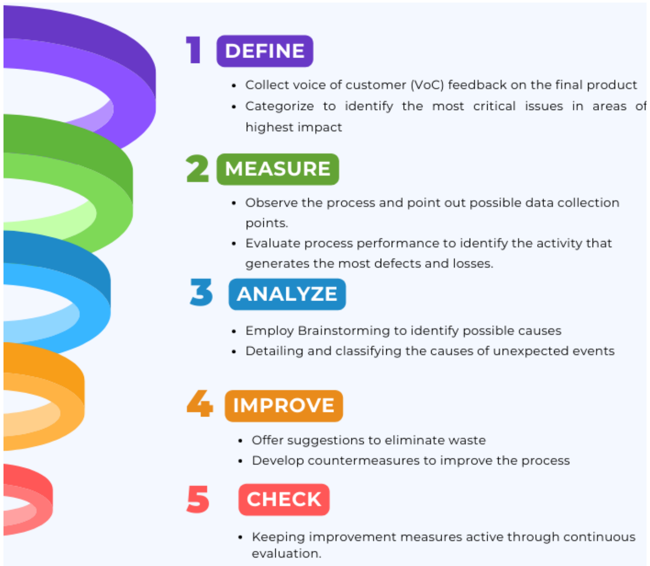

Fig. 3 DMAIC stages. **¡Error! No se encuentra el origen de la referencia.**,[13], [18], [29], [30],[31]
Note: This chart presents aspects necessary to adequately apply DMAIC in a company.

3) Tools for DMAIC Stages:

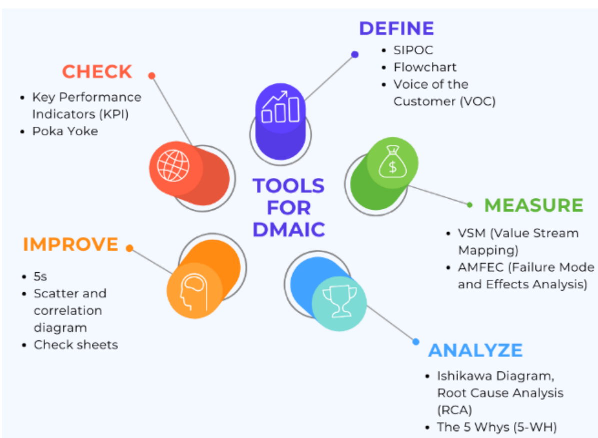

Fig. 4 DMAIC stages. [30], [32], [33], [34], [35], [41]
Nota: El gráfico muestra las herramientas que se pueden utilizar en cada etapa del procedimiento DMAIC.

4) Benefits of DMAIC in the food industry: According to [14], the following benefits are achieved by employing DMAIC:

- Helps to optimize process efficiency.
- Optimizes resources
- Increases customer satisfaction
- Increases profits
- Reduces costs
- Identify and eliminate bottlenecks
- Reduce waste

5) DFFS: DFSS (Design for Six Sigma) seeks to design products, services or processes according to customer needs using tools and techniques to give reliability and efficiency to the design [35]unlike more traditional approaches that solve problems after they happen; it identifies and corrects deficiencies of products available in the market, both in quality, usefulness and attractiveness to the end user with innovative ideas [24].

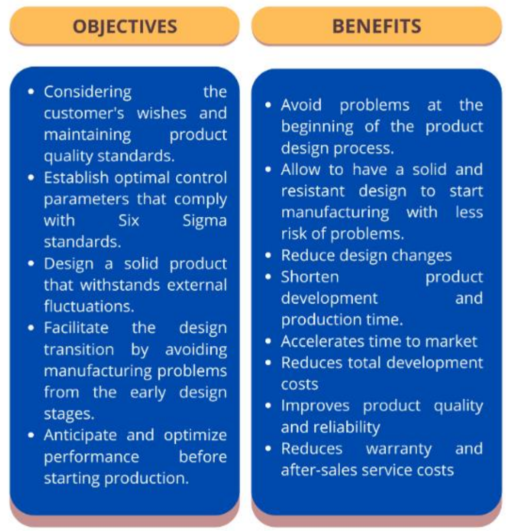

Fig. 5 Benefits and objectives of DFSS in food industries. [31], [37], [38], [39]
Note: The chart lists the most frequent objectives and benefits of research on food industries involved in the DFSS process.

6) Types of procedures in DFSS: In a study [25],[36], agreed, that the most recurrent procedures are:

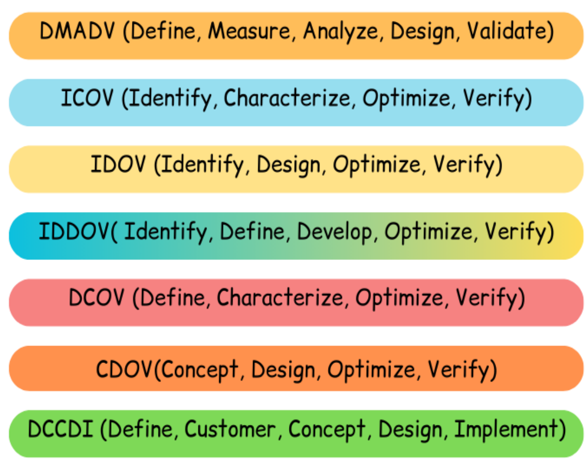

Fig. 6 Types of procedures in the DFSS. [25], [36]
Note: The chart details the types of procedures that exist within the DFSS.

7) DMADV: It is a Six Sigma procedure used for the development of new products, services or processes that consists of identifying customer needs (Define), analyzing and classifying them (Measure and Analyze); subsequently, appropriate techniques are sought for its design (Design) and it is verified that the designed solution meets the established requirements (Verify), in order to comply with quality standards.

8) Phases of the DMADV: According to [25], 5 stages of the DMADV procedure are considered fundamental to ensure that the new process or product meets the customer's expectations and needs from its conception.

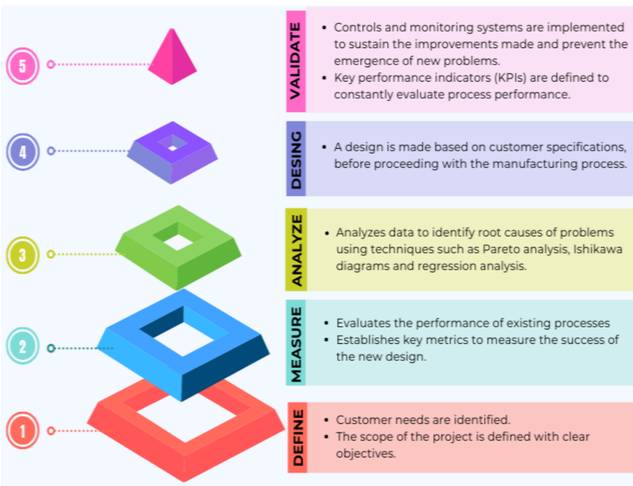

Fig. 7 DMADV stages. [25]
Note: The chart shows the steps necessary for the application of the DMADV within a company.

D. Benefits of an effective implementation of Six Sigma in the food industry

As mentioned in [7], [12] the main benefits are the elimination of activities that do not add value, the reduction of variability in production processes to ensure compliance with customer specifications. In addition, it allows streamlining the production process by preventing excess inventory, decreasing cycle time and eliminating bottlenecks [19], For example, in the meat industry, it reduced process waste, the need for reprocessing and machine downtime [6], and in the case of the dairy industry, it reduced raw material waste and unnecessary energy use [13].

E. Benefits of an effective implementation of Six Sigma in the food industry

- Ensure customer satisfaction by delivering excellent quality products or services [4].

- Improve food production and processing in a sustainable manner [40].

- Improve production efficiency without compromising superior quality to compete in the marketplace **¡Error! No se encuentra el origen de la referencia.**.

- Train in the five phases of Six Sigma, plan their time, resources and effort [22].

- Reduce costs without compromising product quality and safety [9].

IV. OTHER TOOLS USED BY COMPANIES

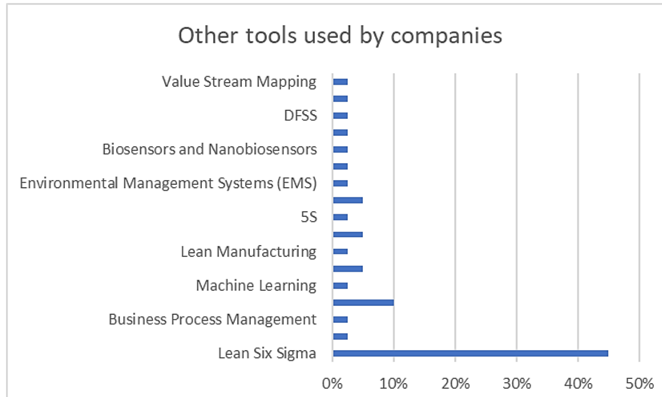

Fig. 8. Other tools used by companies
Note: The graph shows the different tools that companies have used to improve their processes and increase the quality of their products.

V. METHODOLOGY

The SLR presented in this study allowed collecting research on Six Sigma procedures within the food industries, indexed journals/of indexed journals that correspond to the Q1 and Q2 quartiles, as well as temporal parameters ranging from 2020 to 2024, ensuring the selection of high-quality studies in Scopus and Mendeley. On the other hand, the PICOC strategy (Population, Intervention, Comparison, Outcomes and Context) was used to obtain a clear and systematic framework of the research through key questions: What Six Sigma procedures are employed within the food industries from the SLR?, Is there research that applies DMAIC and DMDVA within the food industries?, What are the most frequent complications in manufacturing activities within the food industries that would require the application of SS?, How do SS procedures influence the quality of manufacturing activities within food industries?, Where in the world was research conducted regarding the use of Six Sigma procedures in food industries?, considering selection and exclusion guidelines to ensure quality during the SLR process.

Inclusion criteria were based on the relevance of the content to the research topic as detailed below:

TABLE I
CRITERIA FOR INCLUSION

COD	INCLUSION CRITERIA
CI 1	Studies carried out in the last 5 years (2020 - 2024)
CI 2	Investigations must employ or detail SS procedures.
CI 3	Research that compares the performance of food processes before and after the implementation of Six Sigma.
CI 4	The studies mention food industries worldwide.

Note: Inclusion criteria were based on the relevance of the content to the research topic.

Exclusion criteria were applied to eliminate those studies that did not meet the minimum methodological quality requirements of the SLR, as explained in the following table:

TABLA II
EXCLUSION FOR CRITERIA

COD	EXCLUSION CRITERIA
CE 1	Studies that do not belong to the last 5 years (2020 - 2024)
CE 2	Studies excluded by the quartile to which they belong.
CE3	Absence of information relevant to the RSL.

Note: Exclusion criteria were applied to eliminate those studies that did not meet the minimum methodological quality requirements of the SLR.

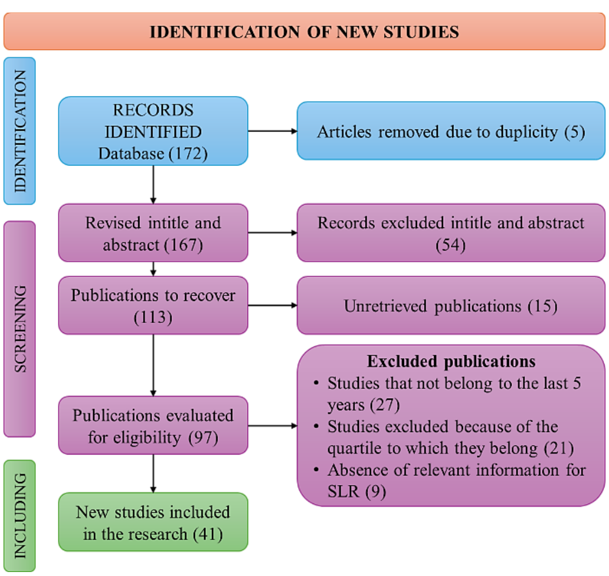

Fig. 9 PRISMA flowchart.

Note: The chart shows the organization of information used in the research.

VI. RESULTS

A. Sigma procedures used in food industries:

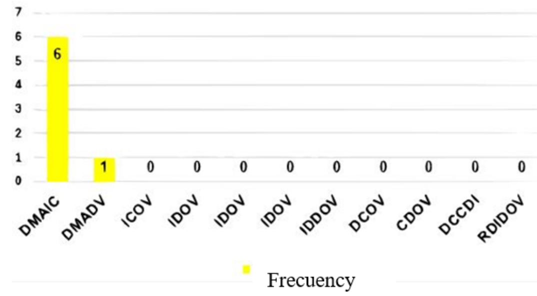

Fig. 10 Six Sigma procedures used in food industries.
Note: The graph represents the preference of food industries in using the various Six Sigma procedures.

In the food sector, 86% use DMAIC procedures, while 14% use DMADV. The other procedures show 0% use, which indicates that they are not widely implemented by the companies.

B. Research applying DMAIC and DMADV in the food industry

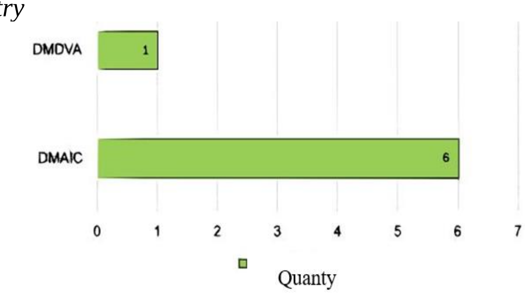

Fig. 11 Number of investigations that apply DMAIC and DMADV.
Note: The graph represents the number of investigations carried out with respect to the two selected procedures DMAIC and DMADV.

It is shown that there is research that applies DMAIC and DMADV, 86% of the articles studied use the DMAIC procedure, while 14% apply the DMADV approach, since it is applied to new processes and products.

C. Most frequent problems of production processes in food industries

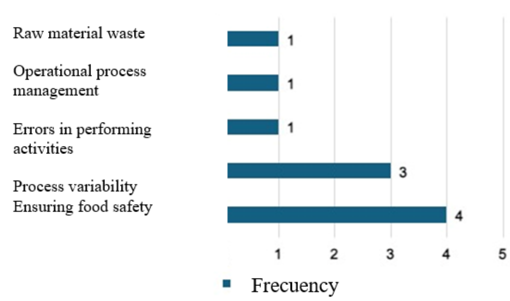

Fig. 12 Frequency of problems in food industries.
Note: The graph represents the recurrence with which industries suffer the same problems.

It is shown that ensuring food safety is a recurring problem and the less recurring, but no less important, problems are waste, inefficient management of operations and errors in carrying out activities.

D. Benefits of applying SS procedures in food industries

TABLA III
NUMBER OF BENEFITS THAT POSITIVELY INFLUENCE THE QUALITY OF PRODUCTION PROCESSES

Procedure	Benefits
DMAIC	• Helps improve process efficiency • Optimize resources • Increased profits • Increase customer satisfaction • Reduce costs • Reduce process variability. • Maintains the sustainability of the company. • Eliminate activities that do not generate value. • Reduce waste • Creates added value of products • Provides flexibility to changes in the company.
DMADV	• Problems are avoided at the beginning of the product design process. • Produces a solid and resistant design • Decreases the need for design changes. • Shorten product development and production time. • Accelerate your time to market. • Reduce total development costs. • Improves product quality and reliability • Reduce warranty and after-sales service expenses.

Note. This table shows the benefits that positively influence the production processes of food industries.

DMAIC methods provide 37.5% more benefits that positively affect the quality of production processes compared to Six Sigma's DMADV approach. Both methods offer a structured framework that helps organizations improve their operations, minimize waste, elevate excellence and increase customer satisfaction. Together, these benefits translate into an overall improvement in the efficiency and performance of manufacturing processes.

E. Companies applying for Six Sigma

The Six Sigma methodology has been studied in several global research studies. In order to improve clarity and organization, we have classified the studies on Six Sigma procedures in the food industry.

TABLA IV
NUMBER OF COMPANIES THAT USED SIX SIGMA

Continent	Country	Industry	Company
North America	México	Panificadora	Bimbo
North America	EE. UU	Bebidas	Coca Cola
North America	México	Cerveza	Corona
North America	EE. UU	Chocolate	HERSEY'S
North America	México	Menestras	Verde Valle
North America	México	Bebidas	FEMSA
North America	EE. UU	Snack	PEPSICO
Europe	Suiza	Sector alimentario	NESTLÉ
Europe	Bélgica	Cerveza	ABInBev

Note. The table shows which companies applied Six Sigma considering their industry, country and continent.

F. Investigations of SS procedures within the food industries in the world

TABLA V
MANUFACTURING INDUSTRIES USING SIX SIGMA

Food Industry	*Place*	*Continent*	*Procedure type*
Manufacturing industry	Nigeria	ÁFRICA	DMAIC
Meat industry	Irlanda	EUROPA	DMAIC
Juice industry	India	ASIA	DMAIC
Nectar industry	Perú	AMÉRICA DEL SUR	DMAIC
Sugar industry	Kenia	ÁFRICA	DMAIC
Agri-food industry	Indonesia	ASIA	DMAIC
Baking industry	Indonesia	ASIA	DMDVA
Further investigation	***Indonesia***	***ASIA***	***DMAIC Y DMDVA***

Note. This table shows in which place and continent the most research was found regarding the Six Sigma DMAIC procedure.

In the analysis of the distribution of research using the DMAIC procedure, it was observed that 42.85% of these studies were conducted in Asia. In relation to the research that were carried out, one was found in India that was conducted in a juice industry and in Indonesia 2 works were found in the agri-food industry and the bakery industry. This data highlights the growing adoption of Six Sigma in various industrial sectors of the African and Asian continent, reflecting a significant interest in optimizing the efficiency and excellence of processes in this region.

VII. DISCUSSION

According to [25], [36], Six Sigma approaches vary considerably. However, according to SLR, in the context of the food industry, DMAIC and DMADV procedures predominate, as illustrated in Figure 10. These methods stand out for their significant positive impact on production processes. Furthermore, the widespread use of DMAIC and DMADV in the food industry suggests that these methodologies are considered effective in addressing specific quality and efficiency challenges in food production.

According to **¡Error! No se encuentra el origen de la referencia.**, DMAIC focuses on improving existing processes by improving their efficiency and troubleshooting within established food production systems, focusing on continuous optimization, which is crucial for maintaining and improving quality standards in production. On the other hand, DMADV stands out for its application in the design phase of new processes to ensure that high levels of quality and efficiency are achieved from the conception of a new production system, thus minimizing the risks associated with the implementation of innovations in the food industry. According to the SLR presented in Figure 11, research applying DMAIC or DMADV shows a significant impact on food industries, with an application ratio of 6 to 1 in favor of DMAIC.

The SLR, depicted in Figure 12, has identified several key factors that significantly affect customer satisfaction in the food industry. Prominent among these are food safety assurance, operational mismanagement, errors in task execution, and process variability. These findings underscore the importance of addressing these issues to improve service quality and customer experience. In line with these findings, [12] points out the importance of other aspects that also influence customer preferences, such as brand and location. These additional factors are equally essential, as they can affect how consumers perceive a food product, directly influencing their purchasing decisions and brand loyalty. Integrating these findings reveals a complete and complex picture of the factors that influence customer satisfaction in the food industry. In addition to food safety and operational efficiency, which are crucial for mitigating risks and improving perceived product quality, other elements such as brand reputation and geographical accessibility also play a crucial role in customer loyalty and satisfaction.

According to [36], [14], DMAIC and DMADV procedures are recognized for their significant ability to improve quality in production processes. SLR confirms that the application of these procedures not only improves quality but also optimizes operational efficiency at each stage of the process, as detailed in Table 3. These findings underscore the critical importance of adopting structured methodologies such as DMAIC and DMADV, especially in sensitive sectors such as food production, where efficiency, safety and traceability are critical to meeting regulatory requirements and customer expectations.

The SLR revealed that Six Sigma has had a notable impact on improving production processes within Asian food industry sectors, as detailed in Table 5. Among the most prominent sectors were bakery, agri-food and juice production. These results highlight that Six Sigma has proven to be very effective in optimizing operations and increasing product quality. Despite this success in Asia, Table 4 indicates that the application of Six Sigma is currently concentrated mostly in companies located in North America where it has been widely integrated as part of continuous improvement strategies. This geographic difference in Six Sigma adoption could be attributed to several reasons, such as market maturity, levels of industrial development, and different cultural perspectives on quality and operational efficiency. These results highlight that while Six Sigma is universally recognized as an effective methodology for improving quality and efficiency, its adoption and implementation can vary considerably depending on regional context and industry specificities.

VIII. CONCLUSIONS

Although there are several Six Sigma procedures, food industries prefer to use the DMAIC and DMADV approaches that generate a positive impact on their production processes, since they allow them to optimize activities, prioritize efficiency and improve quality in their daily practices.

It is concluded that 86% of the total number of articles studied apply the DMAIC procedure to optimize the efficiency of existing production processes, while 14% prefer to use DMADV to design new products and processes. Both allow the development of innovative solutions that meet changing market demands and customer expectations, demonstrating the significant impact of Six Sigma in the food industries.

In summary, non-compliance with food safety standards and variability in production processes are the most frequent problems faced by food industries to protect customer health and meet quality standards in their products.

In short, Six Sigma DMAIC and DMADV procedures have a positive impact on manufacturing activities because they ensure operational sustainability by eliminating non-value-added activities and facilitating the sound design of a quality product launched to the market, respectively.

In summary, there are several studies worldwide on Six Sigma procedures in food industries, mainly in countries such as India and Indonesia, belonging to the Asian continent, due to their high effectiveness and impact on the optimization of food industrial processes.

IX. RECOMMENDATIONS

It is recommended that companies in the food sector implement the Six Sigma DMAIC and DMADV approaches, considering that the former focuses on improving existing processes, while the latter is aimed at the design of new production systems. These tools are highly effective in optimizing operations and ensuring quality in various areas of the food industry. For example, in the chocolate industry, the application of DMAIC has significantly reduced cocoa variability, improving flavor consistency and texture of the final product, resulting in significantly improved products.

Despite the advances, there is still little academic documentation on Six Sigma in the food industry. In addition, the adoption of proactive approaches such as DMADV is scarce, limiting the potential impact of Six Sigma in this sector. Therefore, it is suggested that future research should focus on identifying and analyzing the cultural, organizational and structural barriers that hinder the implementation of Six Sigma in various contexts, especially in the food sector.

In addition, it is recommended to evaluate the effectiveness of these methodologies in emerging industries in the food sector, such as alternative proteins, functional foods and products based on the circular economy. This will not only help to increase current knowledge but will also allow Six Sigma to be adapted and expanded to meet the challenges and opportunities of the future in the food industry.

THANK YOU

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