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Application of Six Sigma methodology to enhance the quality of cream-filled coconut biscuit manufacturing at XYZ company

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Abstract

XYZ is one of the companies engaged in the food and beverage processing industry sector in Indonesia. XYZ currently sets one of the indicators in the KPI regarding the defect rate, which is a maximum of 2%. In 2022, one of the XYZ biscuit products, namely cream-filled coconut biscuits, had an average defect rate of 3%, exceeding the company's tolerance limit. The purpose of this study is to identify the types of defects in cream-filled coconut biscuit products, identify critical factors that cause defects, and give recommendations for appropriate improvements to overcome these causal factors. The method used in this research is Six Sigma, with the Define, Measure, Analyze, and Improve stages. The analysis stage uses RCA and FMEA to determine the root cause of the problem. Furthermore, the 5W+1H method is used to determine the appropriate improvement; the improvement selected is the design of SOPs for the cleanliness of production equipment.

Keywords: Quality; Defect; Six Sigma; FMEA

1. Introduction

The food industry is one of the key sectors that significantly contributes to Indonesia's economic development. Based on data from the Ministry of Industry, the food industry sector in the first quarter of 2022, contributed 37.77% of the total GDP of the non-oil and gas industry in Indonesia [1]. The food industry sector is currently experiencing continuous development. This industry continues to grow rapidly, driven by the rising demand for food and beverages as a necessity, amid Indonesia's population of over 271 million. This causes many similar companies to emerge, leading to increasingly fierce business competition. To survive, companies must enhance the quality and productivity of their products to remain competitive globally.

One food industry company is XYZ. XYZ offers six main products: biscuits, candy, wafers, chocolate, coffee, and drinks. Biscuits are the first product of this company to achieve the highest production volume, and as a result, they have become one of the company's flagship products. At XYZ, the biscuit division has seven main products. However, the production of biscuits continues non-stop for 24 hours. In production, various problems often arise, including defects in biscuits or failed products, waiting time due to damaged machines, and other issues. As a result, the company suffers significant losses and impacts.

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Table 1 Percentage of Defects and Product Achievement Rate of XYZ

Biscuit Type	Total Defects	
	Kg	%
Rosa	9871,5	2%
Sol	42743,5	2%
Coconut	37130	2%
Malcom	15238,5	2%
Ric (cream-filled coconut biscuit)	13713	3%
Marsu	2356,5	1%
Sarum	7887	2%

In Table 1, the cream-filled coconut biscuit product has the highest defect rate among the other XYZ biscuit division products. Table 1 also shows that the defect rate for cream-filled coconut biscuits is 3%, exceeding the company's standard of 2%. The production process of cream-filled coconut biscuits involves the following stages: preparing ingredients, mixing ingredients, printing, baking, detecting for metal contamination, and cooling. The department responsible for maintaining the production process is the production department. There are several types of defects that occur in cream-filled coconut biscuits, namely: the biscuits' color is not suitable, their shape is not according to standard, and their texture is not appropriate—products with color, dimension, and shape defects. Previous researchers have investigated improving production quality across various research objects. Previous research has been conducted in the automotive industry; this study employs Six Sigma methods, including Pareto diagrams, control charts, and cause-and-effect diagrams, to reduce defective units resulting from the pin insertion process [2]. Other research on quality improvement has previously been conducted in the filter industry, aiming to reduce rejection rates using the DMAIC, VSM, and Lean Six Sigma methods [3]. Other research uses the Lean Six Sigma method, which aims to identify defects with the most significant adverse environmental, economic, and social impacts [4].

The problem XYZ faces is defects in cream-filled coconut biscuits that affect the company. The methods used are statistical methods and quality control tools, namely Six Sigma and FMEA. This study aims to enhance the quality of cream-filled biscuit production at XYZ Company. Therefore, it is necessary to identify the factors that cause defects in cream-filled coconut biscuits during production and to provide recommendations to improve product quality. Recognizing the importance of improving the quality of cream-filled coconut biscuit production, this research aims to identify the most influential factors and the most effective improvements to enhance quality and minimize defects in the production process at XYZ. Research on Six Sigma has previously been conducted in the automotive industry, aiming to improve supply chain quality using the Six Sigma method, the Pareto diagram, and the fishbone diagram [5]. Furthermore, Six Sigma research discusses the rejection rate of rubber weather. This research used the Six Sigma and DMAIC methods [6]. Other Six Sigma research was conducted at the hospital. This research uses Six Sigma to improve service quality [7].

In creating good quality, of course, there must be control of that quality. Quality control can generally be defined as a system that maintains the desired level of quality through feedback on product/service characteristics and the implementation of corrective actions, thereby achieving the set standards [8]. One method for improving process quality and reducing the number of defective products in the company is Six Sigma. The Six Sigma concept can be used to minimize product variance, improve process capability along the existing value stream, and strive for zero-defect products [9]. Six Sigma is a method that focuses on developing the company's production quality [10]. Additionally, Six Sigma prioritizes increasing the company's profits by taking corrective actions [11]. In Six Sigma, the target for defects or process failures is set at 3.4 DPMO (Defects per Million Opportunities), meaning that 1 million units of product have only 3.4 defective units [12]. Six Sigma can deliver improvements, including cost reduction, productivity gains, market share growth, customer retention, cycle time reduction, defect reduction, and product/service development [13]. In this research, the object of study is the production process of cream-filled coconut biscuits, which has not been studied previously. With this research, it is hoped that the factory can leverage novelty to identify defects in the biscuit production process and design improvements to reduce defects in the production of cream-filled coconut biscuits.

Six Sigma can be implemented using the DMAIC method (Define, Measure, Analyze, Improve, Control). DMAIC is used to control the production process of a company that has not met the customer specifications [14]. The tools used to run the Six Sigma concept to make improvements are DMAIC Six Sigma, Big Picture Mapping, Failure Mode and Effects Analysis (FMEA), and Root Cause Analysis (RCA). Root cause analysis is the source that causes the problem, as the cause of the symptoms that affect the appearance of the problem. Root cause analysis is carried out to determine the source of the problem, to eliminate and anticipate the emergence of the source of the cause of the period. One tool for root cause analysis is the Fishbone Diagram. Failure Mode and Effect Analysis (FMEA) is a systematic approach that helps technicians identify potential failure modes and their effects. This FMEA procedure calculates the RPN (Risk Priority Number) to minimize the risk of failure by reducing Severity and Occurrence and increasing Detection capability [9].

2. Research Methods

Industries have adopted the Six Sigma methodology as a business management tool to enhance operational performance and minimize defects across various processes. To prepare this study, the necessary information and primary data were collected following discussions with the production and quality control departments. This research utilizes both qualitative and quantitative approaches. The qualitative approach employed in this study is illustrated through the observations and interviews conducted to gather descriptive data [15]. Secondary data relating to the research problem has been collected from the company's data. With expert input, a literature review, and primary and secondary data, this study presents a case study of the application of the Six Sigma DMAIC methodology to reducing the defect rate of cream-filled coconut biscuits at XYZ Biscuit Division. DMAIC analysis was conducted to reduce the rejection rate of cream-filled coconut biscuit defects at XYZ Biscuit Division. This research employs Six Sigma methods, Pareto diagrams, and FMEA to identify the root causes of critical defects. The initial stage of this research begins with preliminary studies and literature reviews [16]. Preliminary studies are conducted through literature reviews and field observations. Literature reviews are conducted to examine the theories that underpin a research study. In addition to literature and field studies, which aim to understand the real situation, researchers also conduct field interviews and observations. This study uses purposive sampling, selecting respondents based on the criterion of having worked at the same company for at least 1 year.

This is because it takes approximately 1 year to develop the skills and sensitivity required to produce cream-filled coconut biscuits [17]. Interviews were conducted with respondents who are experts in their fields, understand the problems, and can provide an assessment of the research object [18]. Based on these criteria, the respondent in this study was the Department Head of the Production Department at XYZ Biscuit Division. Researchers observed the company's production activities. This observation was conducted to identify discrepancies. In this study, observations were made of the production process at XYZ Biscuit Division, particularly the activities involved in the production of cream-filled coconut biscuits. The data obtained from these observations will be used to understand the production flow of cream-filled coconut biscuits. Observations are also made to observe defects that may occur in production activities. Research variables are the characteristics or values of the research object that are the focus of research implementation [19]. The variables of this study are biscuit color, biscuit shape, and biscuit dimensions [20].

The data processing stage is carried out with the DMAI phase. The first phase of definition involves researching the company's existing conditions, identifying the products with the most defects, and determining the percentage of production at each achievement level. This phase also entails identifying Critical to Quality (CTQ) attributes for each type of Defect to understand the output attributes produced by each defect. After the Define phase, the next phase is Measure. This phase measures the impact of the problems found on the company. At this stage, calculations are performed to assess the current conditions of the cream-filled coconut biscuit production process. In the measurement phase, the production process flow is depicted using a flowchart, followed by a Pareto chart that shows the contribution of each defect type to the overall process. The goal is to identify critical defects to enable improvements. Then, calculate the initial performance value using DPMO and the sigma value [13].

After the Define and Measure stages, the next step is to analyze and provide recommendations for improvement for the company. After the analysis, conduct a root cause analysis to identify the cause of the defect that often occurs. The output of this step will serve as input to the following process, namely, building a failure mode and effects analysis (FMEA). After analyzing the causes of defects, examine the effects produced by each type of defect. This FMEA helps determine the critical causes of defects.

In the improvement stage. The purpose of this stage is to develop suitable improvement proposals based on the existing critical variables and to determine the most effective improvement effort from the proposed alternatives using the 5W+1H approach. At this stage, recommendations for improving the production process are provided based on the analysis conducted in the previous stage. Furthermore, conclusions from this research will address the predetermined objectives [12].

3. Results and Discussion

The defect rate of cream-filled coconut biscuits produced by XYZ Biscuit Division is exceptionally high, with an average defect rate of more than 2% in 2020, resulting in significant financial losses for the industry. To be able to minimize the high defect rate of cream-filled coconut biscuits using the Six Sigma DMAIC approach. The DMAIC methodology used in this project is categorized into the following four basic phases:

- Define, to determine the problem and project objectives.
- Measure, to check the current status of the problem.
- Analyze, analyze the current situation and find solutions to achieve the goal.
- Improve, implement the solution to achieve the goal.

3.1. Define phase

At this stage, understanding the problems being faced involves identifying them in detail. The things that are done at this defining stage include:

- Identification of products with the most defects and the percentage level.

The products of XYZ Biscuit Division include various types of biscuits. The product that is used as an observation is a cream-filled coconut biscuit product, also called RKC, for the following reasons:

- The defect rate far exceeds the KPI set by the company.
- The number of defects is the largest compared to other products 2.
- Has the lowest level of achievement of production targets compared to other products.
- The comparison of the production achievements of several products produced by XYZ biscuit division is depicted in the graph in Figure 1.

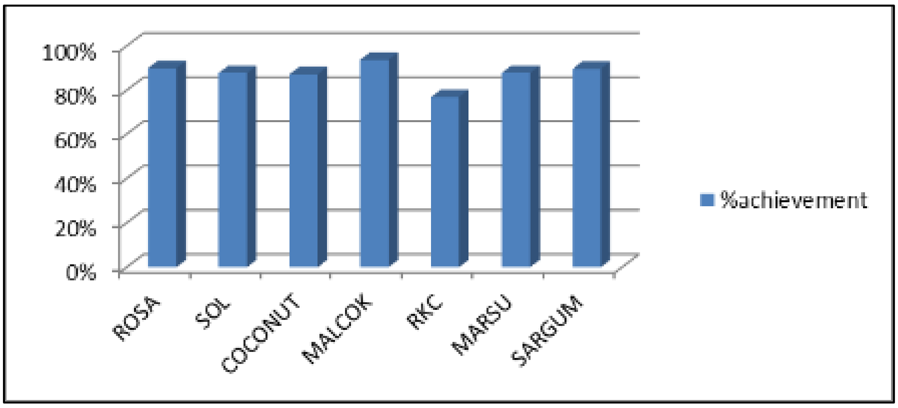

Figure 1 Percentage chart of XYZ production target achievement

The following defects observed in the production process of cream-filled coconut biscuits from the production department at XYZ are shown in Figure 2.

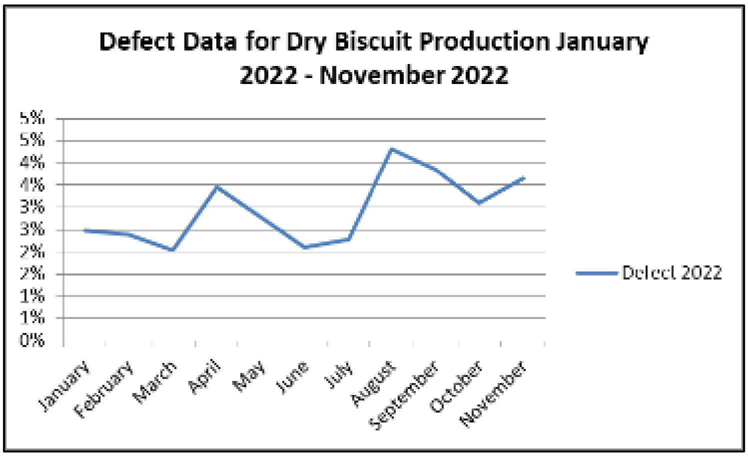

Figure 2 Percentage chart of cream-filled coconut biscuit defects

The data shows that the cream-filled coconut biscuit product has a much lower achievement rate than other XYZ products. Additionally, the defect rate for this product remains very high, averaging 3%, whereas the company has set a maximum per-product defect limit of 2%.

3.2. Identification of Critical to Quality

The Critical-to-Quality (CTQ) of each defect must be known to determine the output attributes resulting from each defect, where the purpose of this study is to provide recommendations for solutions to reduce the percentage of cream-filled coconut biscuit defects.

Table 2 Critical to Quality

CTQ (Critical to Quality) issues	Defect Type	Quality needs
The percentage of defects in cream-filled coconut biscuits is 3% which exceeds the company's standard requirement of 2%	The colour of the biscuit is too dark (burnt) or too pale	The colour of the biscuits is in accordance with the company's colour standard
	Grippy or broken biscuit shape	Whole biscuit shape
	Biscuit dimensions are not in accordance with company standards	Biscuit weight between 3.8 – 4.0 g, biscuit thickness between 4.9 – 5.5 mm, and biscuit diameter between 43 – 46 mm.

3.3. Measure Phase

After the define phase, the next phase is Measure. This phase measures the impact of the problems found on the company. At this stage, calculations are performed to assess the existing conditions of the cream-filled coconut biscuit production process [14]. In the Measure phase, the following activities are carried out:

3.3.1. Describing the production process flow

At this stage, the production process flow is identified as a step to understand the complete process better, using a flowchart of the cream-filled coconut biscuit production process. The flowchart of the production process for cream-filled coconut biscuits is shown in Figure 3.

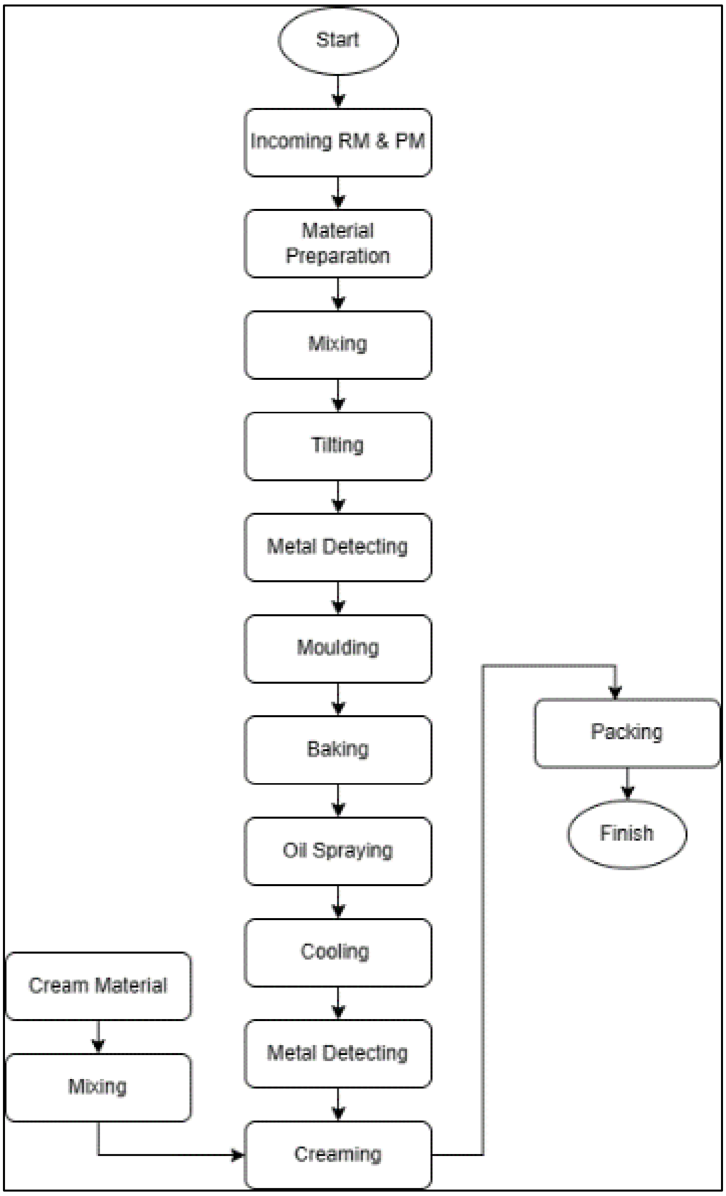

Figure 3 Flowchart of the biscuit production process

3.4. Identification of critical defect types

Based on primary data obtained from the company, the following are the types of defects that occur in the production process of cream-filled coconut biscuits

- Biscuit Color Not Up to Standard. Defects in biscuit color not up to standard occur because the biscuit color is too dark (burnt) and the biscuit color is too pale.
- The biscuit shape is not up to standard. Several factors can cause this shape defect in biscuits, including a dirty mold and an unsuitable shape.
- Biscuit dimensions are not up to standard. This defect is a biscuit defect characterized by the weight, dimensions, and thickness of the cream-filled coconut biscuits not meeting the company's specifications. The standard specifications for biscuit weight set by the company are between 3.8 g and 4 g, the standard biscuit diameter set is between 43 mm and 46 mm, and the standard biscuit thickness set by the company is between 4.9 mm and 5.5 mm.

3.5. Calculation of initial performance values (DPMO, Sigma Value)

The purpose of calculating the initial performance value is to assess the company's existing process capability. The data used comes from the company's production achievement report. The data is achievement data per shift for eleven months. In the calculation of process capability for the cream-filled coconut biscuit production section, it was observed that at the time of observation, the DPMO value of the cream-filled biscuit production process was 457,100, and the sigma value was 3.83, with three CTQs. Based on the Cost of Poor-Quality table [9], the sigma level can be converted into its corresponding cost of poor quality. XYZ suffered losses due to poor quality (Cost of Poor Quality) of 25%-40% of its total sales of cream-filled biscuits. The analysis phase of DMAIC focuses on identifying the causes of nonconformities that affect the company's productivity [14].

After it is known which defects exist and which are most critical, the analysis phase analyzes the causes of these defects (Analyze). The things that are done at this analysis stage include:

- Building RCA (Root Cause Analysis) and making a Fault Tree Diagram (FTA)

At this stage, an analysis of the causes of non-standard biscuit shape defects is conducted to better identify the underlying causes. RCA of non-standard biscuit shapes. In Figure 4 below, a cause-and-effect diagram of a non-standard biscuit shape defect.

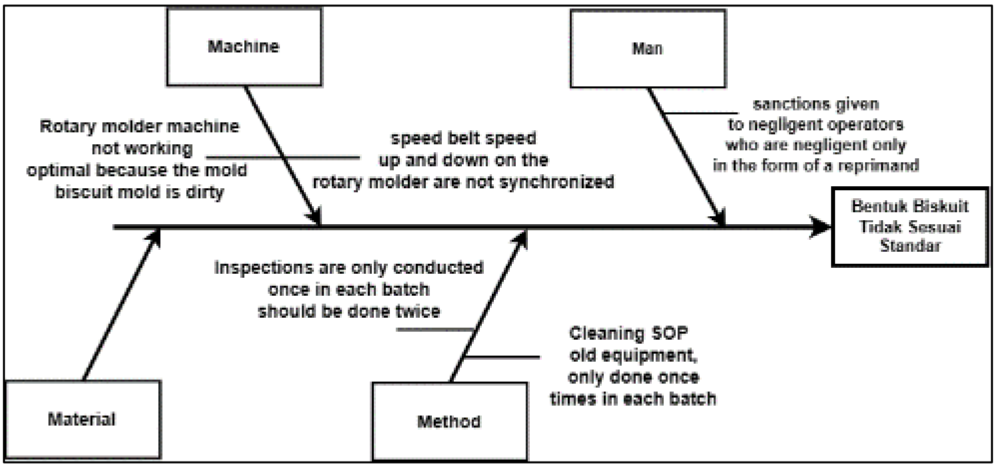

Figure 4 Fishbone diagram of biscuit shape defect

RCA of Non-Standard Biscuit dimensions, in Figure 5 below, is a causal diagram of the defect of non-standard biscuit dimensions.

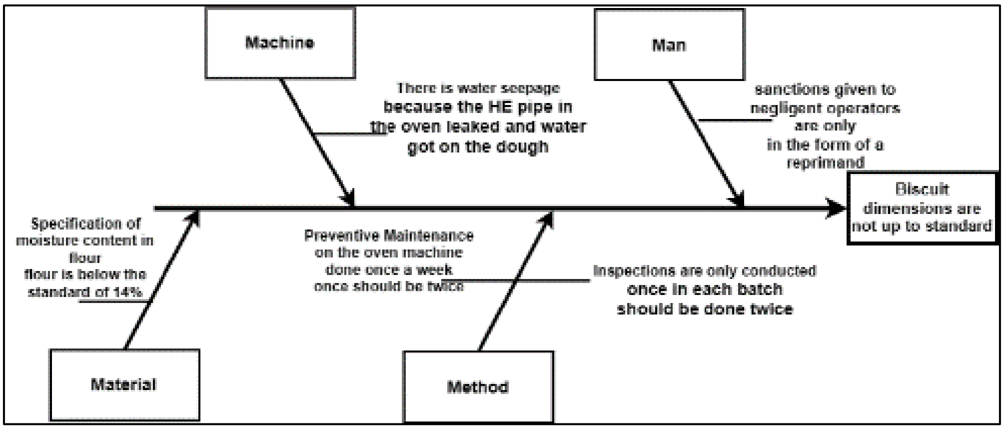

Figure 5 Fishbone diagram of biscuit dimension defect

RCA of biscuit color not according to the standard. Figure 6 below illustrates a cause-and-effect diagram that shows the defect in biscuit color that does not meet the standard.

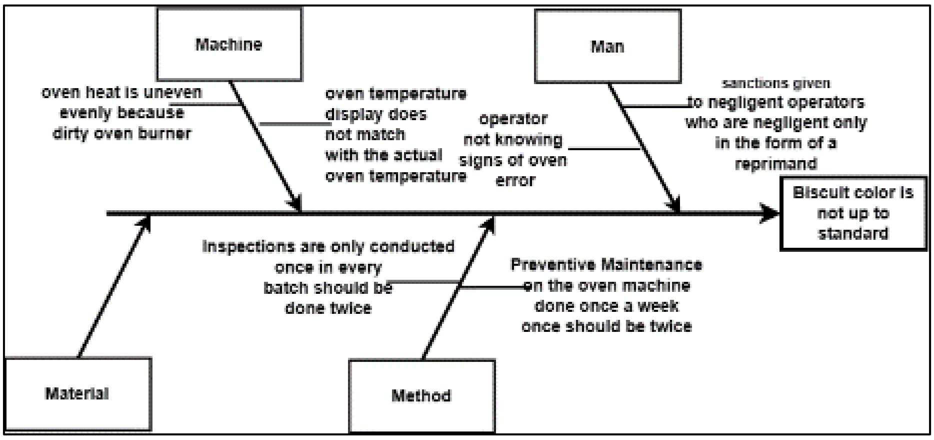

Figure 6 Fishbone diagram of biscuit color defect

The next stage is to conduct an FMEA (Failure Mode and Effects Analysis). The most critical root causes of this type of non-standard biscuit shape defect are shown in Table 3.

Table 3 The highest RPN value of the biscuit shape defect type

Defect Type	Causes of Failure	Effect	RPN
Non-standard biscuit shape	The speed belt on the rotary molder machine is not synchronized	The biscuit mold is not neat	160
	SOP for equipment cleanliness is only done once per batch	The rotary molder machine does not work optimally because of dirty biscuit printing	168
	The sanction given by the operator is only a warning	Inspection is only carried out once in each batch should be twice	96

The most critical root causes of this type of non-standard biscuit dimension defect are shown in Table 4.

Table 4 Highest RPN Value of Biscuit Dimension Defect Type

Defect Type	Causes of Failure	Effect	RPN
Non-standard biscuit dimension	Water seepage due to a leaking HE pipes in the oven	Water gets into the biscuit dough, so that the moisture content of the biscuits is more than the standard of 10%	192
	The composition of wheat flour moisture content is below the standard of 14%	High dough moisture content	42
	Inspection is only done once	The machine error sign is unknown to the worker	168
	Preventive maintenance is only done once a week	Machine errors during production often occur	150
	The sanction given by the operator is only a warning	Operators are negligent in conducting inspections	80

In the defect of non-standard biscuit shapes, the main contributing factor is that the equipment cleaning SOP is only carried out once per batch. Production equipment, specifically biscuit molds, requires regular cleaning and inspection.

The accumulation of dirt on the biscuit mold can cause the bottom of the mold to become uneven, creating a place for bacteria to spread. The first step in equipment maintenance is to understand the company's equipment in depth and prioritize their use in the production process [21]. Production equipment maintenance methods that can increase production effectiveness and efficiency are 5S, SMED, and cleaning SOPs [22]. In the absence of non-standard biscuit dimensions, the primary causal factor is water seepage due to a leaking HE pipe in the oven. The problem of non-standard dimensions is mainly caused by seeping HE fluid pipes, which have the highest RPN value, namely 192. Seeping HE fluid pipes can cause excess liquid in the biscuit dough, resulting in significant changes in biscuit dimensions.

3.6. Improve Phase

The objective in this phase is to develop suitable improvement proposals based on the existing critical variables and to determine the most effective improvement effort from the proposed alternatives using the 5W+1H approach. In this improvement phase, recommendations are provided to enhance the production process based on the analysis conducted in the previous phase. In the biscuit shape defect, the main contributing factor is that the equipment-cleaning SOP is performed only once per batch. Recommendations for improvements include rearranging SOPs related to equipment cleanliness in the curing section and establishing operational standards for preventive maintenance based on machine downtime data.

In the event of biscuit dimensions not conforming to standard, the primary causal factor is water seepage due to a leaking HE pipe in the oven. Recommendations for improvements include installing the Inverter on the panel by welding, then setting the pump speed.

In the biscuit color defect, the primary causal factor is that the oven temperature display does not accurately reflect the actual oven temperature. Recommendations for improvement include establishing operational standards for preventive maintenance based on machine downtime data, pausing production according to the scheduled preventive maintenance, and conducting intensive machine maintenance according to the planned maintenance schedule. Additionally, creating maintenance schedules for oven machines is recommended.

4. Conclusion

The results of the Critical to Quality (CTQ) indicate that three main types of defects are problems in the production process of cream-filled coconut biscuits: non-standard biscuit shapes, non-standard biscuit dimensions, and non-standard biscuit colors.

The most critical cause of each defect is the type of non-standard biscuit shape defect; the highest RPN is for the HE fluid pipe error, with an RPN of 192. For the non-standard biscuit dimension defect, the highest RPN is for the dirty or damaged biscuit mold base, with an RPN of 168. At the same time, the highest RPN value for the non-standard biscuit color defect type is the burner setting error on the oven machine, with an RPN value of 120.

The three alternative solutions chosen for handling the three types of critical defects are of the kind of non-standard biscuit shape defect, the SOP can be rearranged related to the cleanliness of the equipment in the curing section used for a specific period time, then for the type of non-standard biscuit dimension defect, the Inverter is installed on the panel by welding, then setting the pump speed is controlled, and for the type of non-standard biscuit color defect, it can be handled by making standard operation preventive maintenance according to machine downtime data. Providing recommendations for companies on how to develop SOPs for the cleanliness of production equipment, to reduce biscuit defects in the form of non-standard biscuit shape defects.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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