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Article

Analysis of Bread Production Quality at SMEs Industry using Statistical Process Control (SPC)

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A B S T R A C T

XYZ Industry is a micro-enterprise engaged in bread production. However, defects such as burnt bread, irregular shapes, and inconsistent weights are still frequently found during production, which affects customer satisfaction and production efficiency. This study aims to analyze and optimize bread production quality using the Statistical Process Control (SPC) approach. The methodology includes data collection over 20 production days, analysis using Pareto diagrams, p control charts, $\overline{X}$ and R charts, and cause and effect diagrams. The findings indicate an average defect rate of 4.79%, with burnt bread being the most prevalent defect (30%). The p control chart identified several days with assignable variation, while the $\overline{X}$ and R charts revealed that the bread weight process was statistically in control. The main causes of defects were related to human factors, machine limitations, and the absence of standardized procedures. Recommendations include establishing standard operating procedures (SOPs), conducting operator training, and procuring supporting tools. The consistent application of SPC is expected to enhance both the quality and efficiency of production.

1. Introduction

In an increasingly competitive industrial landscape, product quality plays a critical role in ensuring business sustainability, particularly for Micro, Small, and Medium Enterprises (MSMEs). Today's consumers are becoming more selective, considering not only price but also product quality and consistency (Šostar & Ristanović, 2023). Therefore, quality assurance is a strategic aspect of building customer trust and enhancing competitiveness in the market.

MSMEs are the backbone of the national economy, significantly contributing to the Gross Domestic Product (GDP) and employment. In Indonesia, MSMEs contribute over 60% of GDP and absorb more than 97% of the national workforce (Afifudin & Sudarmiatin, 2024; Kurniadi et al., 2024). However, one of the prevailing challenges in this sector is the lack of structured quality management systems, resulting in product quality inconsistency (Ezizwita et al., 2020).

The food industry, particularly home-based bread production businesses, is a growing subsector of MSMEs due to high consumer demand and easily sourced raw materials. However, maintaining and improving product quality consistently remains a major challenge amidst technological and resource limitations (Farida & Setiawan, 2022; Sudirjo, 2023). Variations in product quality can lead to customer dissatisfaction and diminished market loyalty.

Quality issues in bread production may arise from multiple factors, including raw material variability, irregular production processes, and limited quality control. Without a robust quality control system, MSMEs may struggle to detect and address the root causes of product nonconformity at an early stage (Ananda, 2022). Consequently, effective and efficient methods are required to monitor and control production quality.

One of the most practical methods for statistical quality control is Statistical Process Control (SPC). SPC is a systematic approach that utilizes statistical tools such as control charts, histograms, and cause-and-effect diagrams to monitor and analyze production processes (Nadhif & Kusumawardhani, 2021). Through SPC, business operators can detect process variations and implement corrective actions before defective products reach consumers.

Despite its potential, SPC implementation in MSMEs remains limited due to constraints in knowledge, training, and supporting tools. However, SPC is highly applicable to small-scale businesses because of its preventive nature and low investment requirement (Fitriyanti et al., 2023). Previous studies have demonstrated that SPC implementation can improve process efficiency and reduce defect rates in the food processing sector (Isniah & Purba, 2021).

SMEs Industry XYZ is a local bread producer that has been operating for more than five years. Despite increasing demand, this business continues to receive complaints regarding inconsistencies in taste, texture, and shape. Daily production records indicate significant fluctuations in bread weight and size, pointing to suboptimal quality control processes on the production line.

The primary issue faced by SMEs Industry is the absence of a structured quality control system. Current quality monitoring is conducted visually and relies on worker experience, lacking systematic data and analysis. As a result, defective products are not promptly anticipated, ultimately reducing overall productivity and product quality.

Given these conditions, this study aims to optimize bread production quality at SMEs Industry through the application of Statistical Process Control. By identifying critical points in the production process and using statistical tools, it is expected that XYZ can reduce process variability, minimize defective products, and improve operational efficiency and customer satisfaction. This study is anticipated to offer not only short term benefits for SMEs but also a replicable quality control model for other MSMEs in the food sector. Promoting data driven approaches such as SPC within MSMEs is essential to build productive, competitive, and sustainable small industries (Bálint et al., 2025).

2. Literature Review

2.1 Statistical Process Control (SPC)

Statistical Process Control (SPC) is a statistics-based approach used to monitor and control process quality through the analysis of data variation. SPC focuses on distinguishing between common cause variation and special cause variation, allowing organizations to detect deviations early before producing defective products. This method functions not only as a quality control tool but also as a foundation for continuous improvement decision-making. In practice, SPC often employs various quality tools such as control charts, Pareto diagrams, and cause-and-effect diagrams, which enable companies to identify, prioritize, and analyze the causes of quality issues in a more systematic manner (Baidawih & Nugraha, 2024).

2.2 Control Chart

A control chart is the primary tool within Statistical Process Control (SPC), designed to evaluate process stability over time by distinguishing between common-cause and special-cause variations. It consists of a center line (CL), an upper control limit (UCL), and a lower control limit (LCL), which are mathematically determined from historical process data. For instance, in variable data using the $\bar{X}$-R chart, the control limits are typically calculated as:

$$UCL_{\bar{x}} = \bar{X} + A_2\bar{R} \quad (1)$$

$$LCL_{\bar{x}} = \bar{X} - A_2\bar{R} \quad (2)$$

$$UCL_{\bar{R}} = D_4\bar{R} \quad (3)$$

$$LCL_{\bar{R}} = D_3\bar{R} \quad (4)$$

while in attribute charts such as the p-chart, the limits are based on binomial distribution:

$$UCL_p = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \quad (5)$$

$$LCL_p = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \quad (6)$$

Where $\bar{p}$ is the average proportion defective and nnn is the sample size. When sample sizes vary daily, adjustments must be made to recalculate control limits dynamically, ensuring accurate detection of process instability. Beyond limit calculations, SPC also incorporates decision rules, such as the Western Electric run rules, which specify patterns (e.g., consecutive points above/below CL, trends, or cycles) that signal potential special causes even when data points remain within limits (Freitas et al., 2021; Wan & Zhu, 2022).

By integrating these principles, control charts provide a robust mechanism for food MSMEs to monitor quality, minimize process variability, and comply with food safety standards such as ISO 22000 and SNI 01-3840-1995 for bread. Recent studies have shown that applying SPC in small-scale food industries enhances product consistency and reduces defect rates, thereby strengthening competitiveness in the market (Alifka & Apriliani, 2024; Shrestha, 2021).

2.3 Pareto Diagram

The Pareto diagram is a tool used to identify and prioritize the main causes of quality problems based on the 80/20 principle, which states that most effects often stem from a small number of dominant causes. This diagram takes the form of a bar chart arranged in descending order of frequency, accompanied by a cumulative curve that illustrates the relative contribution of each cause. In this way, the Pareto diagram helps organizations focus improvement efforts on the most significant problems with the greatest impact on product or service quality. Its application enables improvement resources to be allocated more effectively, thereby achieving quality enhancement more efficiently (Saefullah et al., 2023).

2.4 Fishbone Diagram

The Fishbone Diagram, also known as the Ishikawa Diagram, is a visual analysis method used to identify the root causes of quality problems. The diagram resembles a fish skeleton, with the main problem placed at the "head" and potential causes represented as branching "bones." These causes are commonly categorized into six main groups known as the 6M: Man (human factors), Machine, Method, Material, Measurement, and Mother Nature/Environment. This structured approach allows teams to systematically identify the most influential factors affecting quality. The Fishbone Diagram is often used in conjunction with control chart analyses and the prioritization results from the Pareto diagram to ensure that corrective actions address not only the symptoms but also the underlying root causes (Aristriyana & Fauzi, 2022).

2.5 Research Gap

There remains a research gap regarding the application of Statistical Process Control (SPC) in micro, small, and medium enterprises (MSMEs), particularly in the bakery industry in Indonesia. Most prior studies have focused on the implementation of SPC in large-scale manufacturing sectors or medium-scale food processing industries, such as refined sugar and coffee (Aulia & Winursito, 2025; Ripandi et al., 2025), while in-depth studies on micro-enterprises, especially home-based bakeries, remain limited. Furthermore, existing research has predominantly emphasized the technical aspects of process control and control charts, but has not yet comprehensively integrated root cause analysis (Fishbone Diagram) with Pareto-based prioritization to formulate sustainable improvement strategies (Aristriyana & Fauzi, 2022). In fact, MSMEs face unique challenges such as resource limitations, variability of raw materials, and the absence of standardized operating procedures, which differentiate them from large-scale industries (Sitanggang et al., 2022). Therefore, this study contributes by filling the gap through the holistic application of SPC in bakery MSMEs, combining control charts, Pareto diagrams, and Fishbone analysis to identify root causes and provide practical recommendations tailored to small business conditions.

3. Research Methodology

This study employed a descriptive quantitative approach aimed at identifying, analyzing, and optimizing the production quality of bread at SMEs through the implementation of Statistical Process Control (SPC). Data were collected directly from the production process and analyzed using various statistical tools.

3.1 Research Location and Object

The research was conducted at SMEs, a local bread production enterprise located in Bengkulu City, Indonesia. The study focused on the entire bread production process, with particular attention to the critical stages that significantly influence product quality, such as dough weighing, baking, and packaging.

3.2 Data Collection and Techniques

Data were collected through direct observation of the production process over 20 consecutive working days, review of production reports and defect records, and structured interviews with the business owner and employees. The observed parameters included the daily number of defective products, types of defects, and variable data such as bread weight and size.

3.3 Data Analysis Technique

The data were analyzed using the Statistical Process Control (SPC) method through the following stages:

1. Product Defect Identification, classifying and documenting the types of product nonconformities found during production.
2. Pareto Diagram, used to identify the most frequent types of defects, following the 80/20 principle (Statsenko et al., 2021).
3. Control Charts:
   a. *p-chart*, used to monitor the proportion of defective products per day (Aulia & Winursito, 2025).
   b. $\overline{X}$ *and R* chart, used to evaluate the stability of variable attributes, specifically bread weight (Ashasry et al., 2021).
4. Cause-and-Effect Diagram (Fishbone Diagram), utilized to trace potential root causes of defects, categorized into Man, Machine, Method, Material, and Environment (Kumah et al., 2024).

All statistical analyses were performed using Microsoft Excel and Minitab software.

3.4 Success Indicators

The success of SPC implementation was measured by a reduction in the number of defective products and improved process stability as evidenced by control charts. The results of the analysis were then used to formulate recommendations for continuous quality improvement in the production process.

4. Results and Discussion

4.1 Production Data Description

Data were collected over a span of 20 consecutive working days, focusing on the total number of bread units produced and the corresponding number of defective products. Table 1 summarizes the production and defect data.

Table 1. Bread Production and Defective Products Over 20 Days

Days	Total Production	Product Defect	Defect Proportion
1	200	10	0.050
2	210	8	0.038
3	205	12	0.059
4	200	7	0.035
5	215	15	0.070
6	190	11	0.058
7	195	9	0.046
8	205	13	0.063
9	200	10	0.050
10	210	6	0.029
11	200	9	0.045
12	205	14	0.068
13	210	7	0.033
14	190	12	0.063
15	195	8	0.041
16	200	10	0.050
17	205	9	0.044
18	200	13	0.065
19	210	7	0.033
20	215	12	0.056

4.2 Defect Analysis

The types of defects identified were classified and their frequencies calculated as follows Fig.1:

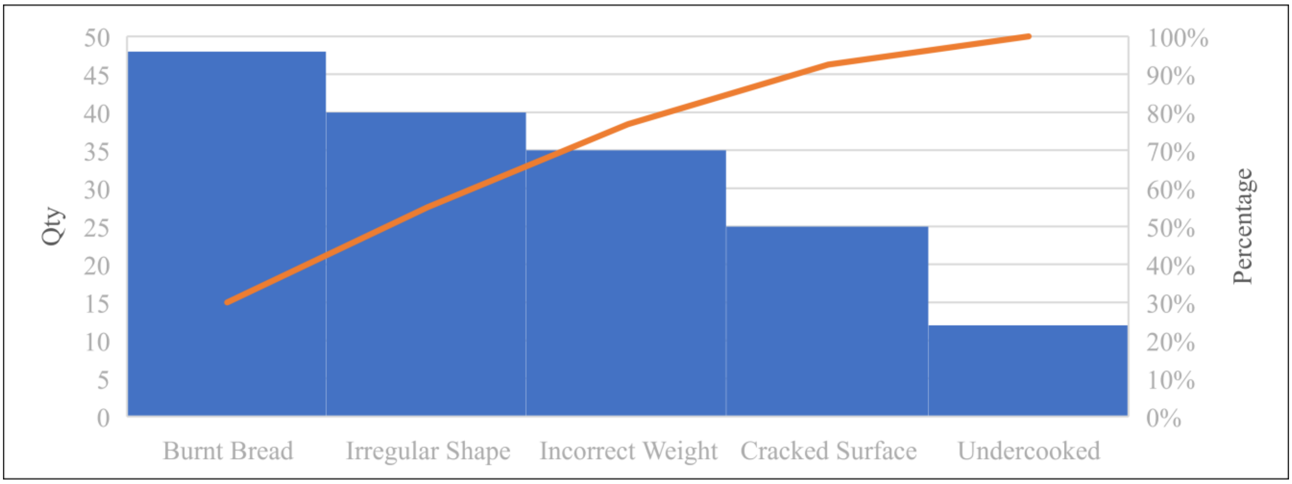

Figure 1. Pareto Product Defect Types

Fig 1. illustrates the frequency and cumulative percentage of defect types in the bread products. The defect type "Burnt Bread" was the most dominant (30%) and falls within the priority improvement group according to the 80/20 principle. The top three defect types (burnt bread, uneven shape, and incorrect weight) contributed to nearly 77% of the total defects.

4.3 Defect Control Chart

The initial step in implementing Statistical Process Control (SPC) at SMEs Industry was to analyze the daily proportion of defective products using the p Control Chart. This chart monitors the stability of the production process in terms of the number of defective products relative to total daily output (Nadhif & Kusumawardhani, 2021). During the 20-day observation period, daily production ranged from 190 to 215 units. The calculation results showed an average defect proportion ($\bar{p}$) of 0.0479 or 4.79%. Most data points on the control chart fell within the upper control limit (UCL) and lower control limit (LCL), indicating the production process was statistically stable. However, some points approached the UCL, notably on days 5 and 12 as shown Fig 2, indicating potential assignable causes requiring further investigation. These findings suggest that although the process remains controlled, operational and human factors must be addressed to prevent defect trends from increasing (Hasanain, 2024).

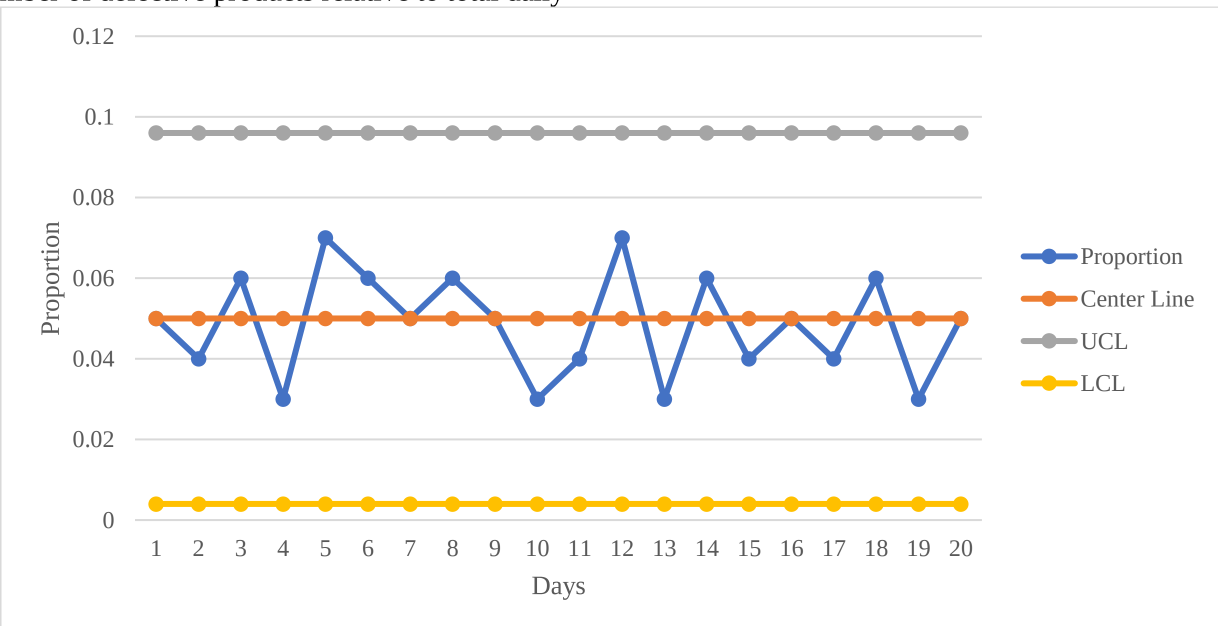

Figure 2. Proportion Defect Products

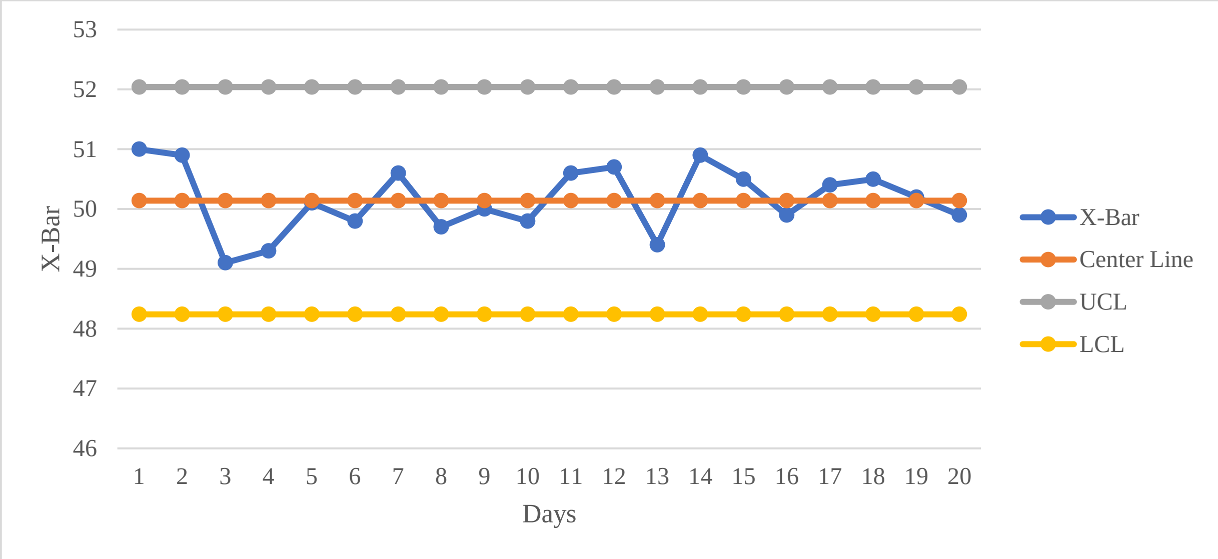

Figure 3. X-Bar Defect Product

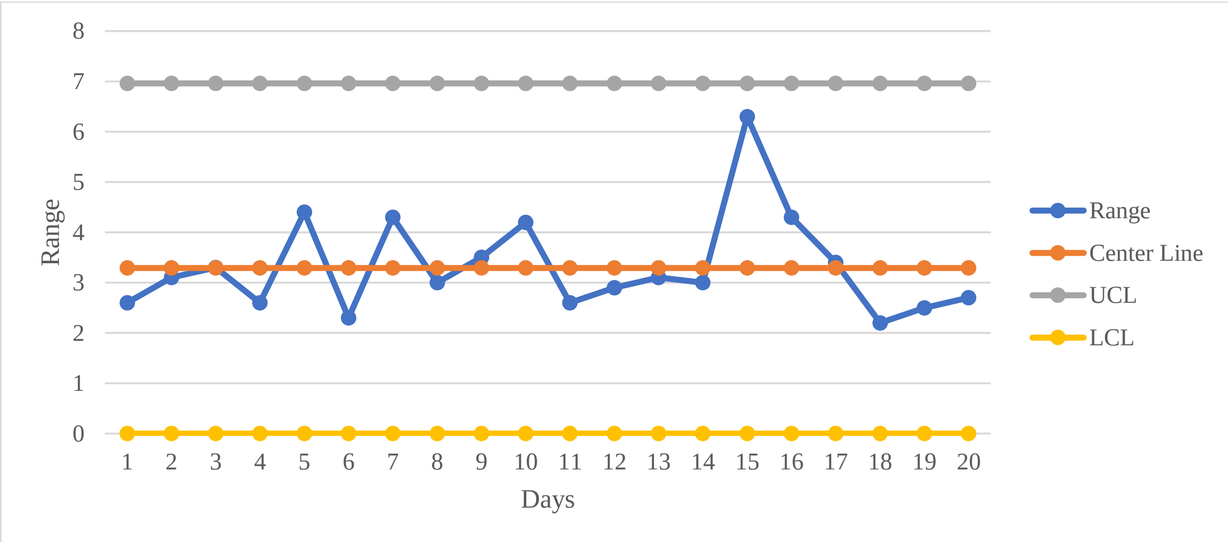

Figure 4. Range Defect Product

After confirming the overall stability of the defect proportion, the analysis continued with quality characteristics measured by variables, specifically bread weight. The $\overline{X}$ and R Control Charts were applied to monitor daily average and range variations from samples of five bread units, as shown in Fig 3 and 4. The analysis indicated that the average bread weight ($\overline{X}$) was approximately 50.3 grams, with relatively small daily variation. The $\overline{X}$ chart showed all observations within control limits, indicating no significant special cause variation affecting the mean weight (Shrestha, 2021). Similarly, the R chart showed stable sample range values within control limits, signifying normal within-group variability that does not affect quality. Collectively, the p, $\overline{X}$, and R control charts provide comprehensive evidence that the production process at SME Industry is statistically under control, although systemic defect causes especially related to human factors and work methods still require improvement.

4.4 Fishbone Analysis

To identify the root causes of product defects during production, a Cause-and-Effect analysis (Fishbone Diagram) was conducted (Kusuma et al., 2024). This method categorizes potential major causes systematically, serving as a basis for formulating process improvement strategies, as illustrated in Fig 5.

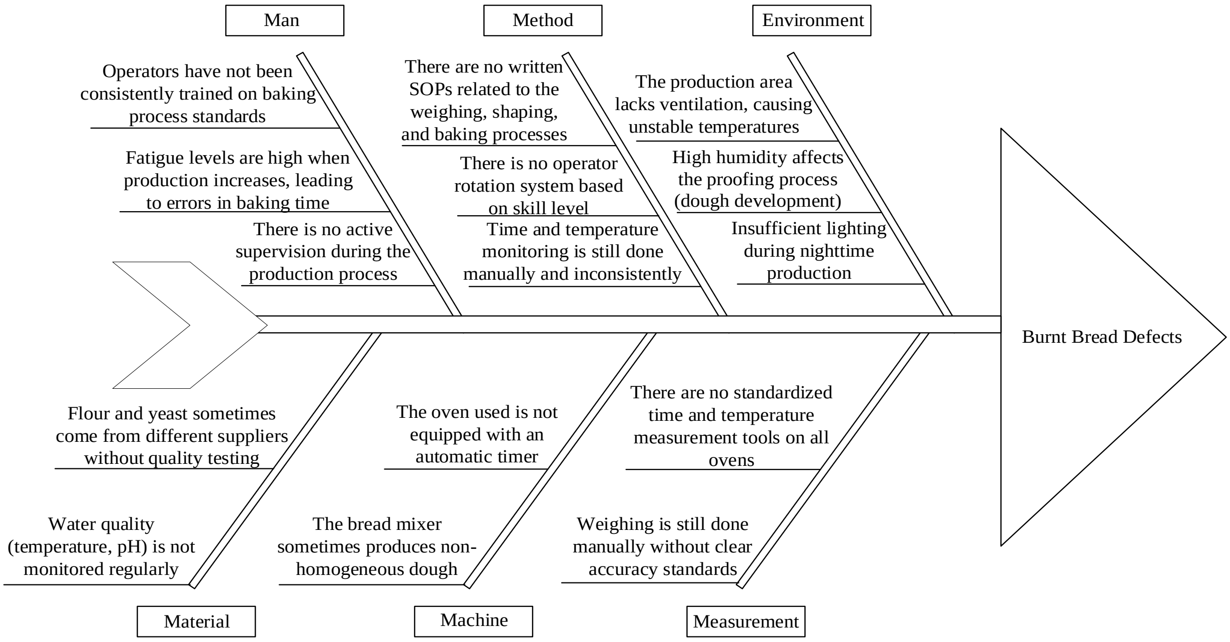

Figure 5. Fishbone Diagram Burnt Bread Defect

In this study, the dominant defects identified by the Pareto analysis were burnt bread, uneven shape, and incorrect weight. Therefore, the Fishbone Diagram focused on potential causes of these defects based on the six main categories (6Ms): Man (human), Machine (equipment), Method (process), Material (raw materials), Measurement, and Environment (work environment).

The first category, Man, revealed that most production operators lacked structured training on process standards, including baking techniques and ingredient weighing. Additionally, absence of direct supervision during production increased operator variability, contributing to defects such as burnt bread and inconsistent shapes. The second category, Machine, showed SMEs Industry used conventional ovens without automatic timers, causing baking durations to rely on manual estimates. Also, weighing scales were not regularly calibrated, resulting in inconsistent bread weight. Mixers showed non-uniform results during peak production periods.

The third category, Method, identified a lack of documented Standard Operating Procedures (SOP), leading to inconsistent production processes. Practices such as weighing sequence, kneading techniques, and baking temperature control varied by operator experience. This lack of standardization was a major source of process variation. Fourth, Material quality was inconsistent due to changes in suppliers of flour and yeast without standard quality evaluations, affecting dough consistency and bread baking.

Fifth, Measurement issues were present, as time and temperature were manually measured without standardized instruments, causing inconsistencies in baking duration and final product weight, ultimately affecting bread quality visually and sensorily. Lastly, the Environment was suboptimal, with inadequate ventilation causing unstable temperature and humidity, negatively impacting dough fermentation. Poor lighting during night shifts hindered operators' ability to control bread color and doneness.

In summary, the root causes of product defects primarily relate to human factors, equipment, and work methods. These factors interact and constitute the main sources of process variation. Systematic improvements should focus on developing SOPs, enhancing operator competence through training, and providing more reliable production tools.

4.5 Discussion

Control charts indicate most processes remained within statistical control limits; however, some points approached the upper control limit (UCL), particularly on days 5, 8, and 12, suggesting the presence of assignable causes that require attention. The dominant defect was burnt bread (30%), attributable to the lack of baking SOPs and absence of automatic temperature controllers, as revealed by the cause-effect analysis. Recommended improvements include:

1. Establishing standardized baking time,
2. Conducting operator retraining, and
3. Procuring simple timers.

Implementing these recommendations is expected to reduce defect rates by at least 20% and maintain process control.

5. Conclusion

5.1 Conclusion

Based on the research and data analysis, the following conclusions were drawn: Bread production quality at SMEs Industry is not yet optimal, with an average defect rate of 4.79%. The most dominant defect is burnt bread (30%), followed by uneven shape and incorrect weight. The p Control Chart shows several points nearing the upper control limit, indicating assignable causes requiring further investigation. The $\overline{X}$ and R Control Charts demonstrate that bread weight control is relatively stable within statistical limits, suggesting no major parameter adjustments are necessary. Key defect causes relate to human factors (lack of operator training), machinery (ovens without automatic timers), and work methods (absence of SOPs). SPC implementation effectively identifies priority improvement areas and serves as an effective quality control tool for SMEs, particularly in managing recurring production challenges.

5.2 Suggestions

SME Industry is advised to implement standard production SOPs, conduct regular operator training, and consider investing in simple equipment such as timers or digital thermometers to minimize recurrent errors.

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