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Packaging Quality Control in a Small-Scale Tempeh Industry Using Pareto Analysis and Control Charts

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ABSTRACT

Tempeh is a traditional Indonesian fermented food with high economic value and is widely consumed by the public. In the tempeh industry, packaging quality is a crucial factor as it protects the product during fermentation, storage, and distribution. Packaging defects such as torn packaging or loose seals can reduce product quality and increase the risk of contamination. This study aims to analyze the level of packaging defects and evaluate the stability of the tempeh packaging process using a Statistical Quality Control (SQC) approach. The study was conducted at a tempeh industry in Yogyakarta using observation data for seven days of production. The analysis was conducted using check sheets, Pareto diagrams, and c-charts. The results showed that during the observation period, 179 packaging defects were found out of a total production of 3,670 kg. The 700 g packaging size had the highest number of defects at 71 defects (39.7%), followed by the 425 g packaging with 64 defects (35.8%), while the 150 g and 270 g packaging each contributed 14.5% and 10.0% of the total defects, respectively. Pareto analysis showed that 700g and 425g packaging contributed 75.5% to the total defects, making them a top priority in the quality improvement program. The c-chart analysis showed a CL value of 25.57, a UCL of 40.74, and a LCL of 10.40. All observation points were within the control limits, indicating that the packaging process was in statistically controlled conditions. However, the relatively high number of defects indicated the need for continuous improvement efforts, especially in large-sized packaging. This study demonstrated that the application of the SQC method can be used effectively to identify quality improvement priorities and evaluate the stability of the packaging process in small and medium-scale tempeh industries.

1. Introduction

Tempeh is a traditional Indonesian fermented food with high nutritional value and has been an important source of vegetable protein for decades. This product is produced through the fermentation of soybeans with the fungus *Rhizopus* spp., which not only improves protein digestibility but also increases the availability of bioactive compounds such as isoflavones, bioactive peptides, vitamins, and antioxidants that are beneficial for health [1]–[3]. Various studies have shown that consuming tempeh has the potential to have positive effects on health, such as reducing the risk of cardiovascular disease, improving blood lipid profiles, improving digestive tract health, and contributing to a more

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sustainable food system because it is based on vegetable protein [4]–[6]. As public awareness of healthy and sustainable food increases, the tempeh industry continues to grow from household scale to medium and large industries, making product quality a crucial factor in maintaining consumer trust and industry competitiveness [7], [8].

Packaging is a crucial component of the food system, protecting the product from physical damage, microbiological contamination, and environmental influences during storage and distribution [9]–[11]. For tempeh, packaging not only protects the product but also maintains fermentation conditions for optimal mold growth. Proper packaging maintains the product's shape, texture, and quality until it reaches consumers [2]. Conversely, packaging damage, such as tears or imperfect seals, can lead to decreased product quality, changes in the tempeh's shape, and increase the risk of contamination. Furthermore, packaging defects can reduce the product's aesthetic value and impact consumer acceptance. Therefore, quality control in the packaging process is a crucial aspect for the tempeh industry to ensure product quality and maintain consumer trust [12], [13].

Quality control is a crucial component of a food production management system, ensuring that products meet established specifications and quality standards. Effective quality control implementation can help companies identify process deviations, reduce production variation, and minimize the occurrence of defective products, which can potentially reduce customer satisfaction and increase operational costs [14], [15]. Packaging defects not only cause economic losses due to rework, repackaging, and market rejection, but can also undermine a brand's image and consumer trust [16], [17]. Therefore, a systematic quality control method is needed to monitor product defect levels, identify problem sources, and determine appropriate corrective actions to maintain consistent product quality and enhance industry competitiveness [15].

Various studies have applied Statistical Quality Control (SQC) methods to identify and control product defects in the food industry [18], [19]. The use of quality control tools such as check sheets, pareto charts, histograms, and control charts has proven effective in identifying dominant defect types, evaluating process stability, and assisting in the formulation of corrective actions for various food products and packaging [20]. Furthermore, several studies have reported that the application of SQC can reduce product defect rates and increase production process efficiency by controlling variations that occur during the manufacturing process. However, most previous research has focused more on general food product quality control, raw material quality, processing processes, or the performance of modern packaging systems in large-scale industries [21]. Studies specifically evaluating packaging defects in tempeh products, especially in small- and medium-scale tempeh industries, are still relatively limited. Existing tempeh research has more commonly addressed fermentation, nutritional quality, microbiological characteristics, and processing conditions than quantitative monitoring of packaging defects [22], [23]. This study therefore presents an applied case study of packaging quality control in a small-scale tempeh industry using basic SQC tools. The contribution of this study is not the development of a new statistical method, but the practical application of established quality-control tools to characterize packaging defects and provide preliminary information on packaging-process stability under small-scale production conditions.

2. Method

2.1. Study Design

This study employed a quantitative descriptive design to characterize packaging defects in a small-scale tempeh production process. The study was conducted at a tempeh industry in the Special Region of Yogyakarta, Indonesia. The dataset consisted of observational records collected over seven consecutive production days.

The available dataset included daily production volume in kilograms, total packaging defects per day, and the distribution of observed defects among four package sizes: 150 g, 270 g, 425 g, and 700 g. The packaging defects recorded in the production records consisted of torn packages and incomplete or loose seals.

The original production records were used as the primary data source. Quality inspection was performed during the packaging stage before the products entered fermentation, and defective packages were removed for resealing or replacement. However, the available records did not document the exact inspection fraction (e.g., 100% inspection or sampling), the identity or number of inspectors, or a formal written operational definition for each defect category. These aspects are therefore recognized as methodological limitations of the present dataset.

For future replication, a torn package should be recorded according to a predefined criterion describing visible rupture or opening of the plastic film, whereas an incomplete or loose seal should be recorded when the sealed edge is visibly incomplete or can be opened without damaging the film outside the sealing region. These definitions should be confirmed against the actual inspection criteria used by the production facility before implementation in subsequent studies.

2.2. Tempeh Packaging Process

The packaging process is a crucial stage in tempeh production, aiming to shape the product, protect the ingredients during fermentation, and maintain product quality until distribution to consumers [24]. At one tempeh factory in Yogyakarta, packaging takes place after the cooling and fermentation processes are complete. Boiled and cooled soybeans are mixed with tempeh yeast (Raprima) at a ratio of approximately 20 g of yeast for every 10 kg of soybeans. Once the yeast is thoroughly mixed, the soybeans are ready to be packaged [25].

Packaging is carried out using polyethylene (PE) plastic bags with a thickness of approximately 0.3 mm. Before use, the plastic is perforated with a piercer to provide air circulation necessary for the fermentation process of Rhizopus sp. mold. The small holes in the packaging allow for oxygen exchange, which allows for optimal growth of the mold mycelium.

The fermented soybeans are then weighed according to the company's product sizes: 150 g, 270 g, 425 g, and 700 g. Weighing is performed using a digital scale to ensure uniform product weight. After the filling process is complete, the edges of the plastic are sealed using a hand sealer to form a tight package ready for fermentation.

The sealed packages are then arranged on racks or fermentation platforms with the labels facing downwards. The product is then fermented for 2–3 days, until the tempeh has a compact texture and a surface covered with white mycelium. During the packaging stage, packages showing physical damage or incomplete sealing were identified and separated for resealing or replacement. The observed defects were subsequently recorded in the production check sheet.

Based on observations during seven days of production, packaging defects found during the packaging process include tears and incomplete seals. These defects have the potential to impact product quality, hinder the fermentation process, and increase the risk of contamination, necessitating continuous quality control during the packaging stage.

2.3. Data Analysis

The research phase began with data collection using a check sheet to record the number of packaging defects occurring during the observation period. Descriptive statistical analysis was then conducted to determine the total number of defects, the average number of defects, the percentage contribution of defects to each packaging size, and the distribution of defects throughout the production period.

Pareto analysis was used to identify the packaging categories that contributed the most to the total number of defects, allowing for quality improvement priorities [26]. Furthermore, the stability of the packaging process was evaluated using a c-Chart (control chart for defects) by calculating the center line (CL) (equation (1)), upper control limit (UCL) (equation (2)), and lower control limit (LCL) (equation (3)), where c_i was number of defects in each observation [27].

The c-chart is interpreted by comparing the number of defects in each observation period against the established control limits. The process is considered to be in statistical control if all observation points fall between the UCL and LCL [28]. The results of the pareto analysis and c-chart are used as a basis for evaluating the performance of the packaging process and formulating recommendations for quality improvement in small and medium-scale tempeh industries.

$$CL = \frac{\sum c_i}{n} \tag{1}$$

$$UCL = CL + 3\sqrt{CL} \tag{2}$$

$$LCL = CL - 3\sqrt{CL} \tag{3}$$

3. Results and Discussion

3.1. Reject Level of Tempeh Packaging

As can be seen on Table 1, observations of tempeh packaging defects during seven days of production revealed 179 defective packages, consisting of torn packages or loose seals. Total production during the observation period reached 3,670 kg, with an average daily production of 524.28 kg. Based on the distribution of defects across package sizes, the 700 g package had the highest number of defects, with 71 packages, followed by the 425 g package with 64 packages, the 150 g package with 26 packages, and the 270 g package with 18 packages. These results indicate that the majority of packaging defects originated in the two largest package sizes, 700 g and 425 g. This indicates that larger package sizes have a higher potential for damage than smaller package sizes.

Table 1. The Data of Tempeh Packaging Defect

Data	Total production (kg)	Total defect per batch (piece)				Total defect (piece)
		Packaging A	Packaging B	Packaging C	Packaging D	
1	500	5	5	13	8	31
2	500	2	3	7	9	21
3	520	5	1	10	6	22
4	550	3	3	11	13	30
5	500	3	2	8	11	24
6	550	5	3	11	15	34
7	550	3	1	4	9	17
Total	3,670	26	18	64	71	179

Note: A) 150 g packaging; B) 270 g packaging; C) 425 g packaging; D) 700 g packaging.

The high number of defects in the 700g and 425g packages indicates that package size is a factor that requires greater attention in quality control. Larger packages contain more soybeans, placing greater pressure on the packaging material and sealing area. This situation potentially increases the risk of tears or imperfect seals. Therefore, quality control needs to focus on package sizes that contribute the most defects to reduce the number of defective products and improve packaging process efficiency.

When viewed based on the observation time, the number of daily defects fluctuated throughout the production period (Fig. 1). The highest number of defects occurred on day 6 with a total of 34 defective packages, while the lowest number occurred on day 7 with a total of 17 defective packages. The average number of defects observed during the observation period was 25.57 packages per day. This variation in the number of defects indicates uneven packaging process performance, which could be influenced by operational conditions during production. However, no extreme spikes in defects were observed, indicating a relatively stable pattern in the packaging process.

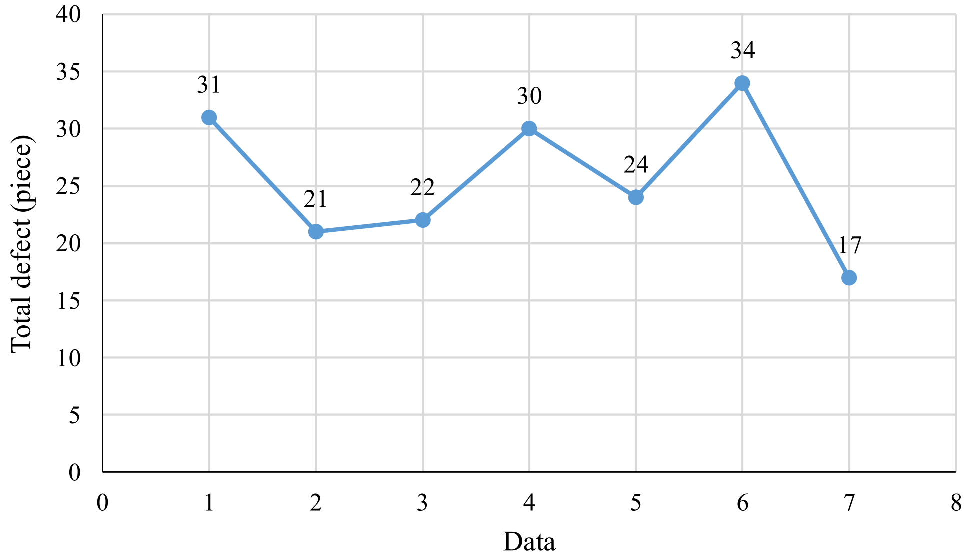

Fig. 1. Daily Trend Analysis of Tempeh Packaging Defect

3.2. Pareto Diagram of Tempeh Packaging Defect

The pareto analysis results presented in Table 2 and Fig. 2 show that packaging defects are not evenly distributed across all observed package sizes. The 700g package had the highest number of defects, with 71 packages, or 39.7% of the total defects during the observation period. Furthermore, the 425g package contributed 64 defects, or 35.8% of the total. Meanwhile, the 150g and 270g packages only contributed 14.5% and 10.0% of the total defects, respectively. These results indicate that most packaging quality issues are concentrated in large-sized packages.

A cumulative percentage analysis shows that the 700g and 425g packages together contributed 75.5% of the total packaging defects. This finding aligns with the Pareto principle, which states that most quality problems are generally caused by a small number of categories of causes or sources of problems. Therefore, focusing improvements on these two package sizes has the potential to significantly reduce the overall number of defects compared to improvements applied evenly across all package sizes.

Table 2. The Percentage of Tempeh Packaging Defect

Packaging size	Defect frequency (piece)	Defect percentage (%)	Cumulative percentage (%)
D	71	39.7	39.7
C	64	35.8	75.5
A	26	14.5	90.0
B	18	10.0	100.0
Total	179		

Note: A) 150 g packaging; B) 270 g packaging; C) 425 g packaging; D) 700 g packaging.

The high number of defects in the 700g and 425g packages is thought to be related to the physical characteristics of the packaged product. Larger packages contain a larger mass of soybeans, placing greater pressure on the packaging material and sealing area. This can increase the risk of damage, such as tears or imperfect seals. Furthermore, the larger product load also potentially increases mechanical stress during the transfer, stacking, and fermentation processes, increasing the likelihood of packaging damage compared to smaller packages [29], [30].

The pareto diagram in Fig. 2 provides visual information that clarifies the priority areas for improvement in the packaging process. Based on these results, quality control should be focused on the 700g and 425g packages through increased packaging inspection, evaluation of plastic material thickness, adjustment of sealing parameters, and increased operator accuracy during the packaging process. This approach is expected to more effectively reduce the number of defects and increase production efficiency. Therefore, the pareto analysis indicates that the 700g and 425g packages are critical points that should be prioritized in the continuous quality improvement program in the tempeh industry.

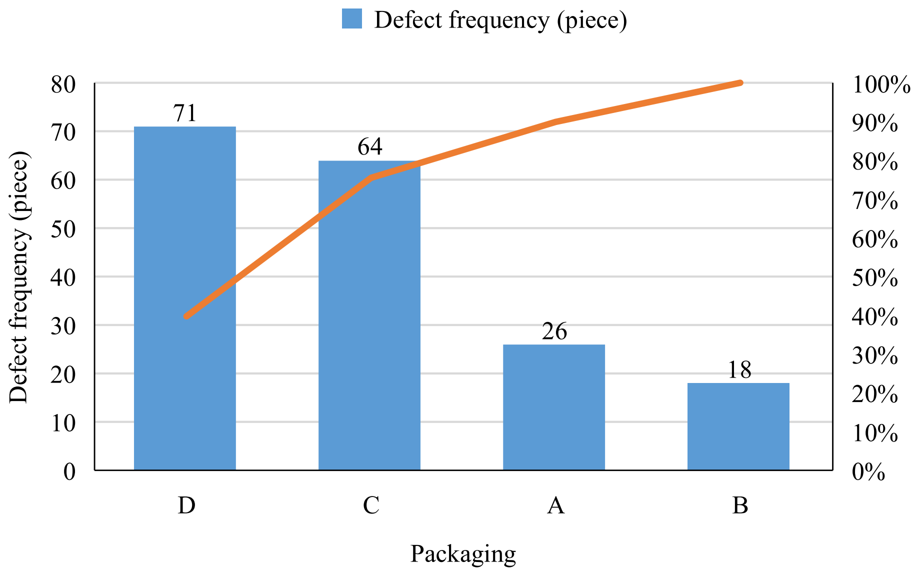

Fig. 2. Pareto Diagram of Tempeh Packaging Defect

According to the Pareto principle, categories that contribute approximately 70–80% of the total defects should be prioritized in a quality improvement program. In this study, the 700g and 425g packages contributed 75.5% of the total defects, so these two package sizes can be categorized as critical defect sources that require immediate corrective action.

3.3. Control chart of Tempeh Packaging Defect

The results of the SPC analysis using a c-chart are presented in Table 3 and Fig. 3. This analysis was conducted to evaluate the stability of the tempeh packaging process based on the number of defects that occurred during seven days of production. The calculation results showed an average number of defects (CL) of 25.57 defects per day. Meanwhile, the UCL and LCL were 40.74 and 10.40 defects, respectively. These values were used as a reference to determine whether the variation in the number of defects was within statistical control limits or indicated a process deviation.

Table 3. The Control Chart Data of Tempeh Packaging Defect

Batch	Total defect (piece)	CL	UCL	LCL
1	31			
2	21			
3	22			
4	30	25.57	40.74	10.40
5	24			
6	34			
7	17			
Total	179			

According to Fig. 3, the daily number of defects ranged from 17 to 34 defects. The highest number of defects occurred on day 6 with a total of 34 defects, while the lowest number occurred on day 7 with a total of 17 defects. Despite fluctuations in the number of defects during the observation period, all data points remained within the established upper and lower control limits. No observation points exceeded the UCL or fell below the LCL. These results indicate that the packaging process is in statistical control, meaning that the variations occurring are within the natural variation (common cause variation) originating from the process system itself.

Process conditions within the control limits indicate that there are no special cause variations significantly influencing the increase in the number of defects during the observation period. In other words, fluctuations in the number of defects are part of the normal variation of the production process. However, despite the process being under control, the relatively high number of defects, averaging 25.57 defects per day, indicates that the process is not necessarily optimal. In the concept of quality control, a statistically stable process does not necessarily have a high level of performance if the number of defects is still quite high.

The c-chart results also indicate that quality improvement efforts need to focus not only on controlling process variation but also on reducing the overall defect rate. Therefore, corrective actions should be directed at factors contributing to the high number of defects, particularly in the 700g and 425g packaging sizes, which have been identified as the main contributors to defects based on Pareto analysis. Improvements can be made through evaluating packaging materials, optimizing sealing parameters, increasing supervision during the packaging process, and training operators to enhance process consistency. Thus, even if the packaging process is under control, there is still room for quality improvement by reducing the number of defects.

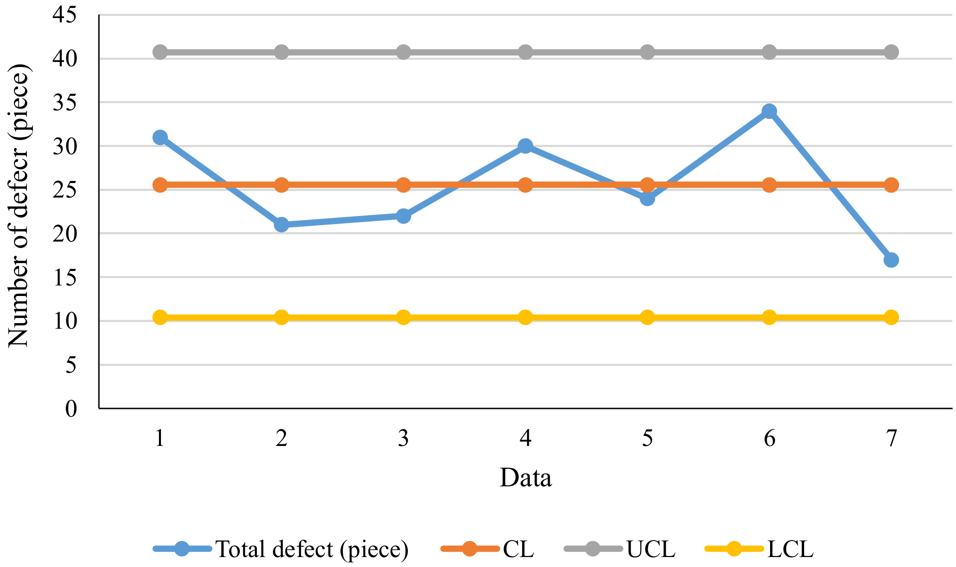

Fig. 3. C-Chart Diagram of Tempeh Packaging Defect

4. Conclusion

This study demonstrates that the application of SQC is capable of identifying the characteristics of packaging defects and evaluating the stability of the tempeh packaging process in small and medium-scale industries. A total of 179 packaging defects were found during seven days of observation, with 700 g and 425 g packages being the main contributors to defects, accounting for 75.5% of the total defects. The results of the c-chart analysis indicate that all observation data are within the statistical control limits (CL = 25.57; UCL = 40.74; LCL = 10.40), so that the packaging process can be categorized as stable and under control. However, the relatively high number of defects indicates the need for continuous improvement efforts, especially in large-sized packages, through optimization of the sealing process, evaluation of the thickness and quality of packaging materials, increased supervision during the packaging process, and operator training to improve work consistency. This study still has limitations because it only uses observation data for seven days of production and does not include root cause analysis of defects or data on the number of packaging units produced in each package size. Therefore, further research is recommended to use a longer observation period, collect production data in packaging units, and combine the SQC method with root cause analysis or other methods so that the factors causing defects and improvement strategies can be identified more comprehensively.

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