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# Improving Bread Quality and Production Process Using Taguchi's Loss Function, Sigma Level: Vulgarization of Composite Breads

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## ABSTRACT

Over the years, bread has become a staple food for millions of Cameroonians, with each Cameroonian consuming 33 kilograms of wheat each year. This has made bread production a highly lucrative business for manufacturers. According to Taguchi, a product does not cause a loss only when it is outside specification limit but whenever it deviates from its target value. This study measured the quality of bread already on the market with the objective of quantifying the financial losses to society and evaluated the process sigma quality level to guide efforts to improve the process. The study population consisted of 400 bread samples of two most consumed types of bread, selected using a systematic random sampling method from a total of four bakeries and five sale points in Bamenda and Bafoussam Cities of Cameroon. The results indicated that 15% of the breads from Bakery D did not meet the weight specifications, while 42% of the 600g bread presentation did not meet the specifications. The remaining bakeries had a weight deviation of between 95% and 98%. The losses for the products with presentations of 600g, 200g (Bakery A), 200g (Bakery B), 200g (Bakery C), and 200g (Bakery D) are 59.81 xaf, 44.22 xaf, 23.03xaf, 26.91xaf, and 35.14 xaf, respectively. The 600g bread presentation incurred the greatest economic loss when it deviated from the nominal value, while bakery A exhibited the best sigma quality level of the process, 5.61 sigma. It was recommended that various stakeholders throughout the country consider substituting portions of wheat flour with cassava flour in the manufacturing of composite bread. Additionally, it was suggested that the weight and quality of bread available on the market be monitored and controlled in order to minimize losses to society.

**Keywords**: loss function, six sigma, cost of quality, bread quality, composite bread

## INTRODUCTION

Bread is the most consumed food and one of the most wasted foods in the world (Dymchenko *et al.*, 2023) that was consumed by 80% of the world's population during the year 2022. Over the years bread had become a staple food for many thousands of Cameroonians, each Cameroonian consuming 33 kilograms of wheat each year which is far more than 23 kilograms of rice each Cameroonian eats annually, making bread production a very lucrative business for manufacturers. However, in an industry as precise as that of bakery, the margin of error should always be minimal, suggesting a 95% confidence interval (Ajayi & Olawale, 2007).

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The quality requirements for bread include: weight, maximum moisture content, maximum ash content, minimum sugar content, maximum fat content, protein content, maximum total microbes of 10 colonies/g, odor and normal taste, potassium bromate concentration, bread appearance, crumb structure, crust appearance, etc. (Nkwatoh *et al.*, 2023; Ulhaq *et al.*, 2022; Curic *et al.*, 2008). The bakery industry is required to implement a good and appropriate quality control system for the products it produces. With good and proper quality control, the products produced can meet the quality standards set by the regulatory authorities/company, such that consumer trust and satisfaction can be maintained.

Unfortunately, the bakery industry in Cameroon hasn't adopted standard quality control technique for checking product variability and conformity. Many bakers don't take sample measurement after baking. Nkwatoh *et al*. (2024) for example found that the concentration of potassium bromate in bread samples consumed in the North West region of Cameroon ranged from 48.50 mg/kg to 10148.50 mg/kg, exceeding the maximum acceptable limits by 9–203 times the dose (50 mg/kg) recommended by Food and Drug Administration. Moreover, bread manufacturing in Cameroon has been predominantly prepared from refined wheat flour.

The reliance of the Cameroonian bakery industry on wheat, and the wheat flour prices increase due to increased bread consumption in developing countries where climate conditions are unsuitable for wheat cultivation, wheat supply shocks caused by force majeure or man-made events, in addition to negative environmental and health consequences (Wang & Jian, 2022) has been a major challenge for bakers. In addition, factors such as salaries, taxes, additives, yeast, and fuel costs in the bread-making process are often used by bakers as justification for bread and bakery product high prices.

In Cameroon, a baguette must weigh 200 g, but most bakers produce loaves weighing less. Most bakers even fail to meet weight standards in their bread production. This discrepancy constitutes a serious violation that the authorities must address. Thus, there is an urgent need to explore other determinants of bread quality such as tracking variability and determining the conformity of bread weight to acceptable standard sizes and evaluate the loss to the society or the bakers from producing bread and other bakery product out of weight standard.

Over time, the scope of quality has shifted from just conformance to specifications and customer satisfaction to broader terms such as delighting all stakeholders and sustainable development (Dev & Jha, 2017). A method that quantifies the poor quality of a product that is already in the market and therefore causing a loss to society is that developed by quality guru Genichi Taguchi (Mateo-Díaz *et al.*, 2021), called the QLF. According to Taguchi, a product has the best quality when it meets the requirements and suffers a loss of quality when it deviates from these requirements.

Taguchi quality loss function is a critical concept in quality management that helps businesses measure the cost of poor quality (CoPQ) or the monetary losses which a customer may have to incur in terms of the repair of a poor quality product (Evans & Lindsay, 2019). Taguchi loss function allows them to evaluate the impact of these variations on the overall quality and performance of a product and process, enabling them to make informed decisions for process improvement (Batool & Bushra, 2020; Yusof & Lee, 2022).

In many product categories, weight has been found to influence how users perceive and evaluate products (Piqueras-Fiszman *et al*., 2011). The objective of this research is to use the Taguchi loss function to estimate the costs incurred by companies or the loss to society as a result of production that deviates from target specifications. Furthermore, the study aims to enhance the bread production process in Cameroon by monitoring manufactures Sigma Quality Level and the variability of bread weight in the North West region of Cameroon.

## RELATION TO EXISTING STUDIES

In today's business environment, companies are focused on increasing process capability while reducing the CoPQ, which represents the cost of delivering substandard products or services to customers. Quality costs are defined as "costs incurred for ensuring conformance to quality standards or compensating for nonconformance to quality standards" (Kim & Liao, 1994). One of the most critical and influential tools for evaluating the success of Total Quality Management programs in industrial companies is measuring the cost of quality (CoQ) (Jaju *et al*., 2009).

The most common approach to classifying quality costs is to categorize these costs into three main groups (Juran *et al.*, 1999; Durmaz, 2012; Rodchua, 2006), as illustrated in Figure 1: prevention, appraisal, and failure costs, or what Zheng & Wang (2013) calls tangible and intangible costs. Prevention and appraisal are the costs of maintaining quality, while internal failure and external failure are the CoPQ. Tangible costs are those that have an identifiable source and could be quantified. Intangible costs are those that could be identified but are difficult to quantify.

### Tangible costs of quality in the bakery industry

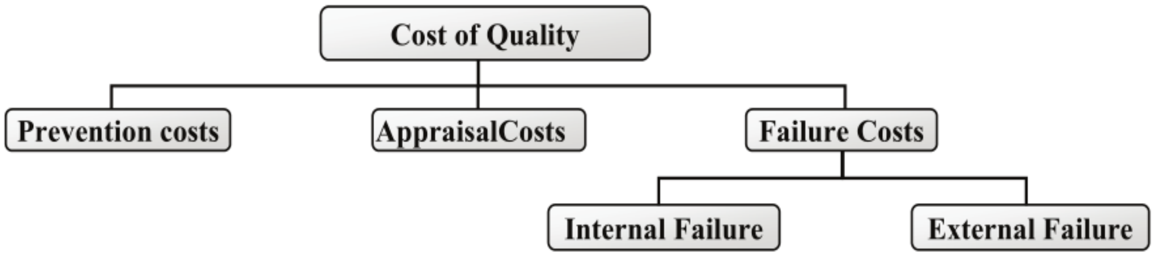



**Figure 1: Classification of Quality Costs (Rodchua, 2006)**

Currently, the Cameroonian bakery industry is facing significant financial challenges due to rising fuel and flour prices, which are beyond their control. Prevention costs in the bakery industry, like in other industries, are the preliminary activities' costs to reach quality goals for producing goods and services and avoid deviations of those goals. Table 1 provides a summary of prevention costs in the bakery industry in relation to inputs, process prevention activities, product design activities and negative feedbacks.

**Table 1: Examples of prevention activities applicable to the bakery industry**

| Activities/Costs | |
|---|---|
| Calibration and maintenance of production equipment | Quality improvement projects |
| Continuously reviewing product design and development | Quality system audits |
| Controlled storage | Predictive equipment maintenance |
| Defective production reduction | Process improvements |
| Quality control | Process prevention |
| Quality data system | Reduce wastage of time, materials, and effort |
| Quality design and planning | Supplier audit<br>Training to raise the quality level |

Appraisal costs are any activity specifically designed to measure, inspect, evaluate or audit products to assure conformance to quality requirements. Those costs are related with supplier management appraisal, operations appraisal, quality appraisal (Table 2). Appraisal cost serves management to determine which area of operation requires preventive measures.

**Table 2: Examples of Appraisal activities applicable to the bakery industry**

| Activities/Costs | |
|---|---|
| Control charts and statistical process control | Pre-production inspection and evaluation |
| Costs of final inspection of products before supplying to stores | Process monitoring and control |
| Equipment setup inspection and testing | Test samples of products after baking is completed |
| Finished goods inspection | The analysis of examination and testing results, along with the preparation of reports on them |
| Laboratory testing | The stock assessment to ensure that the stored products' value does not fall. |
| Maintenance and calibration of test equipment | Review of inspection data |
| Measurement equipment costs | |

Internal failure costs are any cost or activity related to any non-conformance detected prior to shipment to the customer.  In other words, these costs arise when the outcomes of production fail to meet stated quality specifications and are noticed before transfer of those low quality products to the customers. Examples of internal failure costs in the bakery industry are listed in Table 3. Those costs are related with in-process scrap and rework, troubleshooting and repairing, additional inventory required to support poor process yields and rejected lots, re-inspection and retest of reworked items, etc.

**Table 3: Examples of internal failure costs applicable to the bakery industry**

| Activities/Costs | |
|---|---|
| Sorting | Re-work or re-processing |
| Re-inspection or re-testing | Root cause investigation support costs |
| Extra material handling | Supplier corrective actions |
| Excess capacity needs | Internal corrective actions |
| Labor losses due to equipment downtime | Excess inventory cots |
| Rejected or downgraded raw material | Lost equipment capacity due to downtime |
| Scrap or rework due to design change | Employee turnover |

External failure costs are failure costs which are detected after   the products to the customers. Those costs take place for the reason that prevention and appraisal activities didn't detect the non-before being delivered to customers as in Table 4. It is also incurred by sales returns and allowances, service level agreement penalties, complaint handling, recall, legal claims, lost customers and opportunities etc.

**Table 4: External failure costs examples**

| Activities/Costs | |
|---|---|
| Customer returns or rejects | Loss of reputation or goodwill |
| Customer complaints and investigations | Product liability |
| Lost sales and customers | Product service calls |

The more organizations prioritize investment in prevention, the more likely it is that this will result in a gradual reduction in evaluation costs, leading to a reduction in both internal and external failure (Alsada & Kumar, 2022).

Figure 2 of Juran's Quality Handbook illustrates a model of total cost of quality. This model demonstrates that quality improvement leads to cost reduction. At the highest quality level, or 100% quality, the cost of failure is zero, as everything is fine. Prior to this, the failure cost is high and will continue to decrease until it reaches 100%. The prevention and appraisal costs will increase from zero onwards. As quality is increased, so too will be the costs of prevention and appraisal. Without investment in these areas, quality will suffer. The total cost of quality is highest when quality is lowest. However, as quality improves, the total cost of quality will decrease.

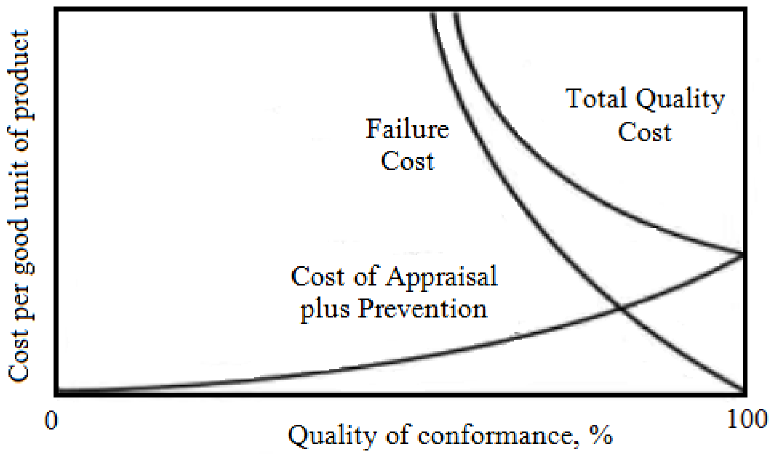



**Figure 2: Juran's model for optimal quality costs (Juran *et al.*, 1999)**

**Intangible costs of quality in the bakery industry**

Traditional accounting systems are unable to measure intangible quality costs, so these costs become hidden quality costs. Some examples of hidden quality costs are customer dissatisfaction with a product or defects in a product that result in lost sales (Kim & Liao, 1994). These hidden quality costs can be the largest factor in the total cost of quality for a product. Under intangible costs, the costs that need to be measured and quantified are the external failure cost which could be considered as the costs of loss from food product value, and the potential cost from food risks.

There are several existing methods for quantifying intangible costs, including Taguchi's QLF (Zheng & Wang, 2013). Taguchi's approach is based on the principle that any deviation from the target value causes a loss, regardless of whether the movement is within or outside the specified limits. This led to the development of the QLF, which is used to measure the associated loss in hidden quality costs. The QLF establishes a direct correlation between quality, productivity, and cost, providing engineers with a tangible means of quantifying quality. Taguchi's philosophy can be summarized with a single statement: the quality of a product is the minimum loss imparted by a product to society from the time the product is shipped.

The conventional quality metric, the so called Goal Post Method, assumes that products meeting specifications are equally good and acceptable, while those falling outside of specifications are equally bad and are rejected, resulting in a loss. Figure 3 shows the target and tolerance limits, i.e., lower specification limit (LSL) and upper specification limit (USL), for a bakery product. Both products A and B are considered equal in quality. However, product A meets the target specifications while product B falls short, despite being within the specification limit. There is no cost associated with poor quality of product B. However, product C is deemed unacceptable as it falls below the lower specification limit. Product C is rejected, resulting in a cost. Unfortunately, this mindset of product quality, as illustrated in Figure 3, hinders product improvement.

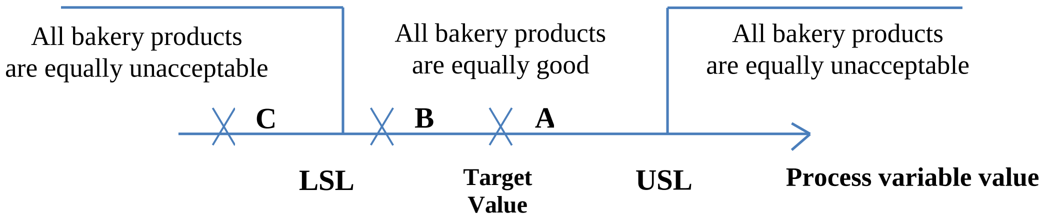



**Figure 3: Goal post approach: Product Performance Levels**

In Taguchi's view, quality is not defined by specific limits, but rather by the extent to which it creates a financial loss to society (consumer, producer, etc.). Taguchi's concept is to replace the traditional concept of "quality" with the concept of "quality loss." This means that parts of acceptable quality have the lowest quality loss, particularly zero (Vacarescu & Vacarescu, 2010). He defined and quantified "quality loss" via his QLF, which unites the financial loss with the functional specification, as an average amount of total loss that society is compelled to bear as a result of deviating from the ideal point and variability in responses. This implies that the quality characteristic of bakery products (weight, concentration of potassium bromate, etc.), must be closer and closer to ideal value, and everything that deviates from the target is considered a loss for society.

Even if a product is performing within its specifications, a quality loss occurs if its parameter value is not at the ideal performance target. This loss is quantified in financial terms so that it can be compared to the product's manufacturing cost (Vacarescu & Vacarescu, 2010). The QLF attempts to make a trade-off between the mean and variance of each type of quality characteristics (Park & Antony, 2008). Figure 4 depicts the graphical concepts of expected loss function considering three different types of quality characteristics such as of Nominal The Best (NTB), Smaller The Better (STB), and Larger The Better (LTB).

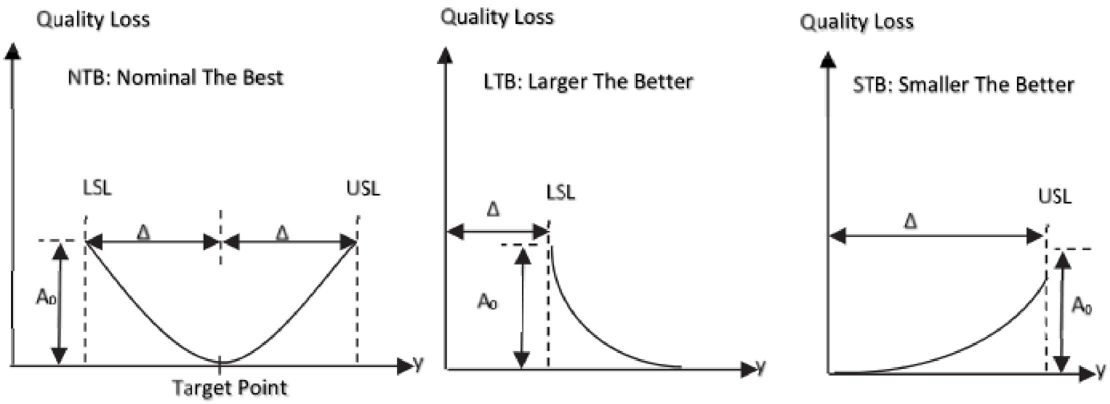



**Figure 4: The expected loss function for three types of quality characteristics (a) NTB, (b) STB, (c) LTB (Parnianifard *et al.*, 2019)**

**Nominal is better (NTB)**

For some quality characteristics, such as product weight, closer to the target is better, and any deviation from the target is a loss of quality. This is the case when the upper and lower specifications are on either side of the target. The loss varies quadratic as the distance from the target, and the average quality loss and mean square deviation (MSD) for NTB case are respectively:

$$L_{NTB}(y) = \frac{1}{n}\sum_{i=1}^{n} L(y_i) \approx k[(\bar{y} - T)^2 + s^2] \quad (1)$$

$$MSD_{NTB} = \frac{1}{n}\sum_{i=1}^{n}(y_i - T)^2 = (\bar{y} - T)^2 + s^2 \quad (2)$$

Where, $L(y_i) = k(y_i - T)^2$ is the NTB quality loss function. $MSD$ is the average of all values of $(y_i - T)^2$. $k(\bar{y} - T)^2$ is the loss due to the deviation of the mean from the target, $T$, while $ks^2$ is the loss due to the average square deviation from the mean variance of y. $\bar{y}, s$ are the average and standard deviation from $n$ samples. $s^2$ represents the variance of the quality characteristic.

$k = \frac{A_0}{\Delta^2}$ is the quality loss coefficient, a proportionality constant dependent upon the organization's failure cost structure (Kim & Liao, 1994). $\Delta$ is defined as the point of intolerance or loss associated with the specification limit, while $A_0$ is also defined as the cost of a corrective action as shown in Figure 4. For a manufactured batch with $m$ produced parts, the global financial loss can be expressed as:

$$L_{NTB} = m \times k[(\bar{y} - T)^2 + s^2] \quad (3)$$

**Smaller is better (STB)**

For some quality characteristics of bakery products, such as potassium bromate concentration, delivery time, as their values decrease, the quality becomes better and the loss decreases. The average quality losses and MSD for the STB case are:

$$L_{STB}(y) = \frac{k}{n}\sum_{i=1}^{n} L(y_i) \approx k[\bar{y}^2 + s^2] \quad (4)$$

$$MSD_{STB} = \frac{1}{n}\sum_{i=1}^{n} y_i^2 \approx \bar{y}^2 + s^2 \quad (5)$$

Where $L(y_i) = k{y_i}^2$ is the STB quality loss function, $k = \frac{A_0}{\Delta^2}$.

**Larger is better (LTB)**

For some quality characteristics, as their values become larger, the performance becomes better that is, the quality loss become smaller. The average quality loos and MSD for larger the better case are:

$$L_{LTB}(y) = \frac{1}{n}\sum_{i=1}^{n} L(y_i) = \left(\frac{k}{\bar{y}^2}\right)(1 + 3s^2/\bar{y}^2) \quad (6)$$

$$MSD_{LTB} = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{y_i^2}\right) = \frac{1}{\bar{y}^2}(1 + 3s^2/\bar{y}^2) \quad (7)$$

Where $L(y_i) = \frac{k}{{y_i}^2}$ is the STB quality loss function, $k = A_0\Delta^2$.

The MSD is used to compare product manufacturing quality. A product with smaller MSD can satisfy optimum performance goal $\bar{y}$ for NTB, STB, and LTB. Optimum performance minimizes performance deviation, $s^2$. The QLF can be expressed mathematically by the process capability index. But the former has dollars as a unit and the latter has no unit. Using the Eq. (1) it is possible to determine the financial losses based on the process capability indices as in Eq. (8) (Vacarescu & Vacarescu, 2010). For example, the process capability index of last month was 0.9, and it is 0.92 this month. This fact does not explain the difference from the economic or productivity point of view. Using the loss function, monetary expression can be made and productivity can be compared (Taguchi *et al.*, 2005).

$$L(y) = A\left(1 + \frac{1}{9C_p^2} + \left(\frac{C_{pk}}{C_p}\right)^2 - 2\frac{C_{pk}}{C_p}\right) \quad (8)$$

$$C_p = \frac{USL - LSL}{6\sigma} \quad (9)$$

$$C_{pk} = min\left\{\frac{USL - Mean}{3\sigma}; \frac{Mean - LSL}{3\sigma}\right\} \quad (10)$$

Where $C_p$ is the process capability, while $C_{pk}$ is the capability index, which measures the best the processes is capable of in terms of short term variation. Table 5 shows the relationship between sigma level, defects per million opportunities (DPMO), and CoPQ (Kumar & Muthukumaar, 2018).

**Table 5: Six Sigma level comparison**

| Sigma Level | $C_{pk}$ | DPMO | Competitive Level | CoPQ |
|---|---|---|---|---|
| 6- Sigma | 3.000 | 3.400 (99.99%) | World-Class | 0% - 10% of sales |
| 5- Sigma | 1.667 | 233.000 (99.97%) | Significantly higher than average | 10% - 15% of sales |
| 4- Sigma | 1.333 | 6.210 (99.38%) | Industry average | 15% - 20% of sales |
| 3- Sigma | 1.000 | 66.807 (93.32%) | Industry average | 20% - 30% of sales |
| 2- Sigma | 0.667 | 308.500 (69.15%) | Below industry average | 30% - 40% of sales |
| 1- Sigma | 0.333 | 691.500 (30.85%) | Uncompetitive | 40% - 69% of sales |

Taguchi definition of quality is one of the most comprehensive, as it aims far beyond the traditional concept of conformance to specifications. But one of the main limitations of Taguchi's approach is that his concept of loss to society is limited only to the useful life cycle of the product and further in a certain situation this loss can even be zero (Pan & Pan, 2006). Dev and Jha (2017) proposed that the scope of quality of a product shall be further enhanced by considering the losses imparted by a poor quality product to society at large, due to associated environmental and safety related factors, over the complete life cycle of the product.

## MATERIALS AND METHODS

The purpose of this research was to estimate the hidden quality costs of bakery bread products that do not meet weight specifications. Estimates of hidden quality costs are needed to estimate the loss to society and to enable managers to understand and control these hidden costs.

### Study Area

A survey was conducted in Bafoussam and Bamenda, two major cities in the West and Northwest Regions of Cameroon. One hundred bread samples were collected from 4 bakeries and 5 sales points between January and April 2024 to observe the deviations that occurred in bread weight. Two bread presentations were considered: 200g for which samples were collected from Bakery A, B, C and D. For the 600g presentation, samples were randomly collected from 5 sales points.

### Materials

The study involved the collection of different samples of bread from two cities in the Republic of Cameroon. All samples were produced in 2024. To ensure accurate weight measurement, an electronic kitchen scale (SF-400) with a high-precision strain gauge sensor and LCD display was employed.

### Methods of Analysis

Taguchi loss function was applied to quantify the poor quality of two most consumed bread types already on the market so as to quantify the financial loss for both the consumer and the company by deviating a quality characteristic from its nominal value (product weight) as illustrated in Figure 5. Moreover, we identified the methods used in the companies to address deviations from the target quality specifications. Data for two commonly consumed bread presentations specified to have nominal values of 200g (French bread) and 600g (local bread) content respectively were analyzed. Data analysis were performed using, Minitab 17, DATAtab online statistics calculator.

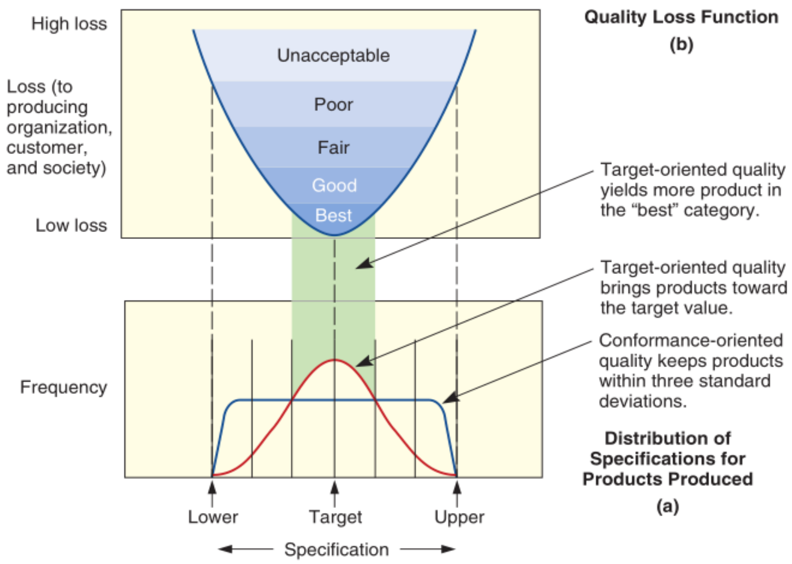



**Figure 5: Quality loss function and quality target (Heizer *et al.*, 2019)**

## DATA RESULTS AND ANALYSIS

### Data Results

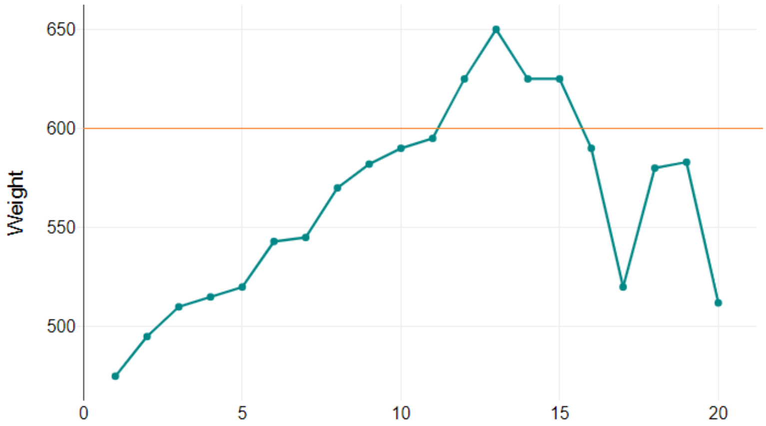
Table 6 presents the data on the number of loaves per weight interval for a random sample of 100 for five bread presentations. Table 7 presents the results of some descriptive statistics of interest. Figures 6a and 6b demonstrate the discrepancy between the measured characteristics (bread weight) and their target values for each product presentation. In Figure 7, each bar represents a range in the values of the bread for the different presentations.

**Table 6: Measured bread weight ($\sum n_i = 100$)**

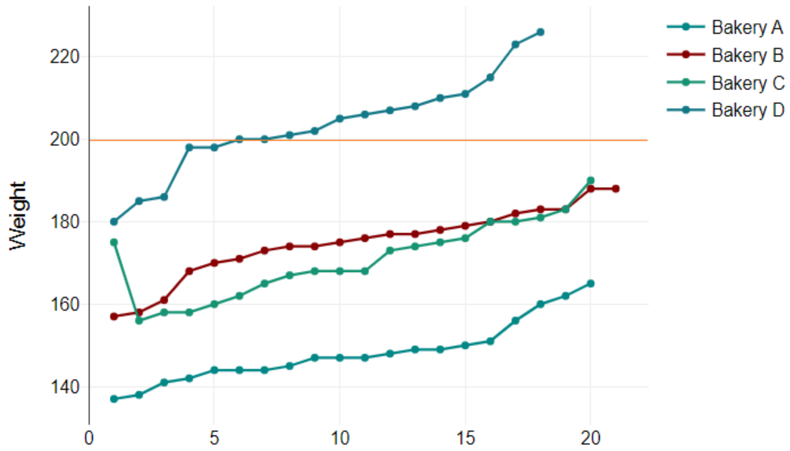
| Bread presentations | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **5 sale points (600g)** | | **Bakery A (200g)** | | **Bakery B (200g)** | | **Bakery C (200g)** | | **Bakery D (200g)** | |
| Weight Interval (g) | $n_i$ | Weight Interval (g) | $n_i$ | Weight Interval (g) | $n_i$ | Weight Interval (g) | $n_i$ | Weight Interval (g) | $n_i$ |
| 475-485 | 4 | 135-140 | 10 | 155-160 | 9 | 155-160 | 20 | 180-185 | 11 |
| 486-495 | 6 | 141-145 | 30 | 161-165 | 5 | 161-165 | 10 | 186-190 | 5 |
| 496-505 | 3 | 146-150 | 35 | 166-170 | 9 | 166-170 | 20 | 191-195 | 2 |
| 506-515 | 7 | 151-155 | 5 | 171-175 | 25 | 171-175 | 20 | 196-200 | 21 |
| 516-525 | 10 | 156-160 | 10 | 176-180 | 29 | 176-180 | 15 | 201-205 | 15 |
| 526-535 | 5 | 161-165 | 10 | 181-185 | 14 | 181-185 | 10 | 206-210 | 22 |
| 536-545 | 6 | | | 186-190 | 9 | 186-190 | 5 | 211-215 | 10 |
| 546-555 | 3 | | | | | | | 216-220 | 3 |
| 556-565 | 3 | | | | | | | 221-225 | 11 |
| 566-575 | 10 | | | | | | | | |
| 576-585 | 8 | | | | | | | | |
| 586-595 | 12 | | | | | | | | |
| 596-605 | 4 | | | | | | | | |
| 606-615 | 5 | | | | | | | | |
| 616-625 | 4 | | | | | | | | |
| 626-635 | 3 | | | | | | | | |
| 636-645 | 2 | | | | | | | | |
| 646-650 | 5 | | | | | | | | |

**Table 7: Descriptive statistics by type of product presentation**

| Product presentation (g) | **600 g** | **200g (Bakery A)** | **200g (Bakery B)** | **200g (Bakery C)** | **200g (Bakery D)** |
|---|---|---|---|---|---|
| Mean deviated weight (g) | 47.32 | 51.20 | 24.90 | 29.52 | 4.04 |
| Total lost for the company (g) | 525 | 0 | 0 | 0 | 695 |
| Total lost to society (g) | 4207 | 5120 | 2490 | 2952 | 290 |
| Average product weight (g) | 563.18 | 148.30 | 175.10 | 170.48 | 204.04 |
| Variance | 2054.23 | 55.10 | 70.82 | 85.79 | 154.73 |
| Total breads with defect | 42 | 95 | 96 | 98 | 15 |

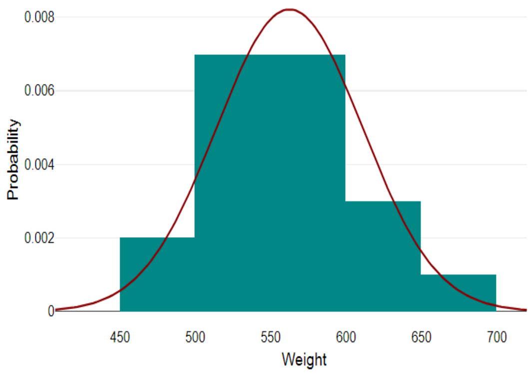


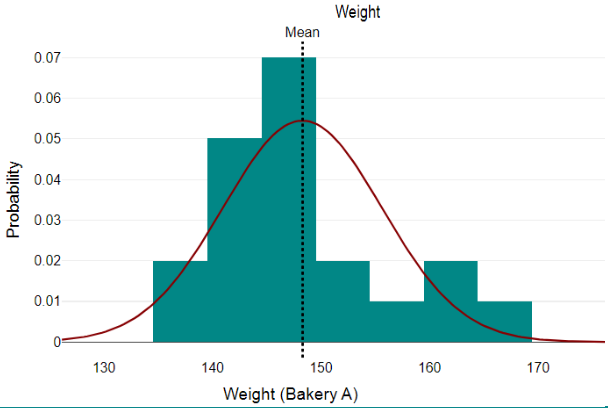

(a) Deviation of bread weight in presentation of 600g




(b) Deviation of bread weight in presentation of 200g

**Figure 6: One week averages of the product weights**



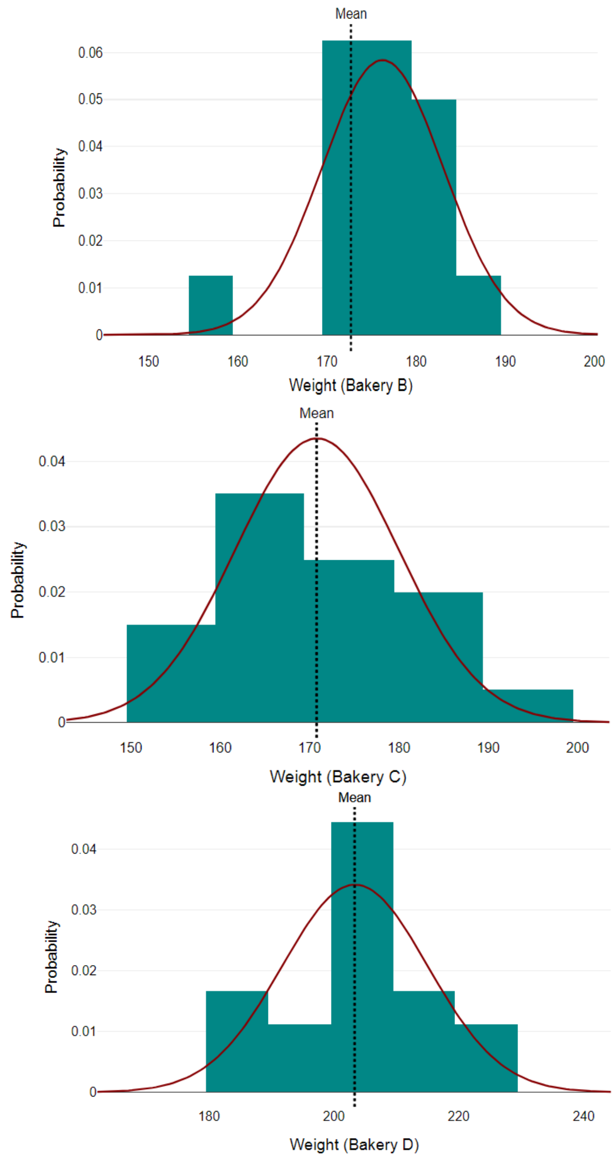



**Figure 7: One week histogram for product weight**

According to the calculated averages presented in Table 7, the weight of the presentations of the product of 600g and 200g (Bakery A, B, C) are below the nominal values, indicating that the product causes loss to society (Fig. 6a, b). While the average of the presentation of 200g from bakery D, is slightly above the nominal value, which represents an economic loss for the company (Fig. 6b). Figure 8 shows the box diagram for the breads, in which individual values of the product weights are observed; outliers are not shown.

A Boxplot is a very good way to get a picture of Variation. In Figure 8, the IQR box represents the Inter Quartile Range, which is a useful measure of Variation. Figure 8a shows that 50% of the data points (those between the 25th and 75th Percentiles) were within the range of 518.75–591.25 g. 25% were below 518.75g and 25% were above 591.25g. The median, denoted by the vertical line in the box is about 575g while the mean denoted by the dashed line is at 563.2g. Data points outside 1.5 box lengths from the box as in Figure 8b are called outliers. Outlier with values of 160g, 162g and 165g for Bakery A and 180g for Bakery D are shown by circles in Figure 8b. In bakeries A, B, C and D, 50% of the data points were respectively within the range of 144.00–150.25 g; 171.00–180.00 g; 164.00–177.00 g; 198.50–209.50 g.

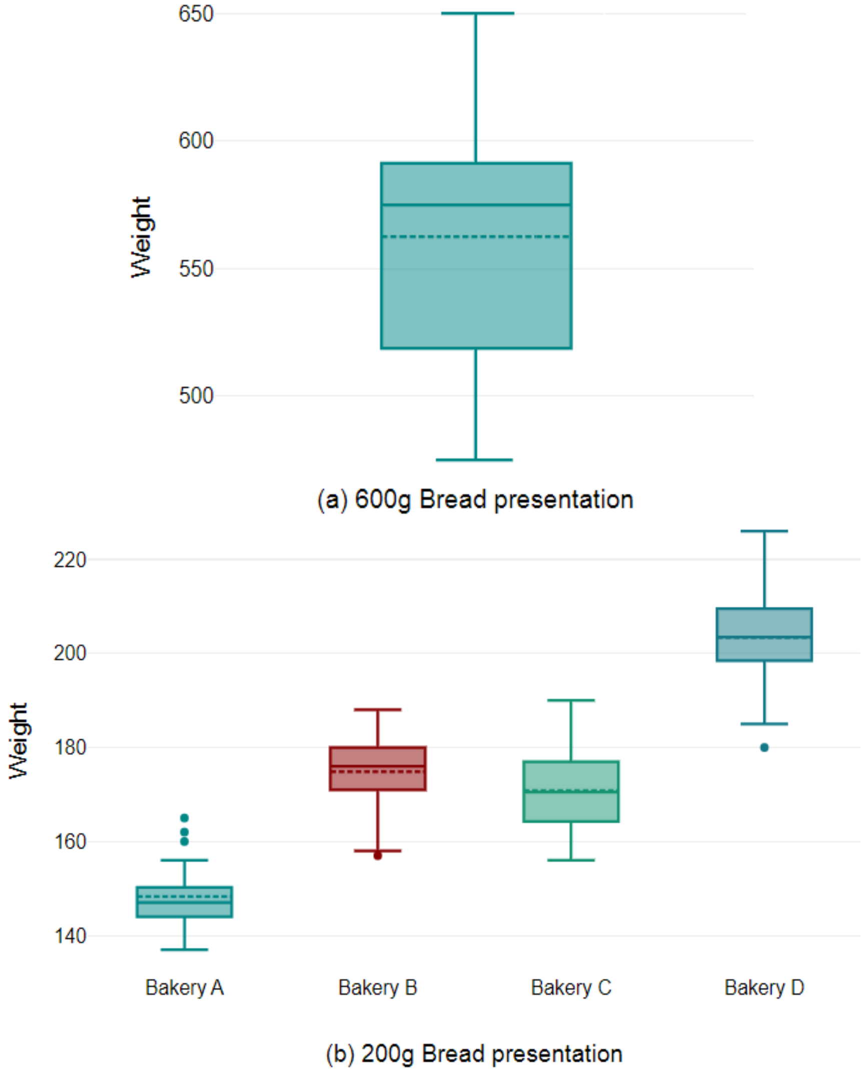



**Figure 8: Box plot for product weight**

In Figure 8b, we can see that the medians are fairly near for bakery B and C and quite low for bakery A and high for bakery D which had the highest top–end results. However, both the Box and the Whiskers for bakeries C and D are quite spread out, indicating a comparatively large amount of variability – a lack of consistency. Bakery A, on the other hand, has much less variability.

## Products Loss Function Analysis

**Table 8: Costs for weight deviations in each type of product presentation**

| Product presentation (g) | Sample size | Deviation to the nominal value (Δ) | Cost of compensating the 1g (xaf) | Cost to deviate the weight, $A_0$ (xaf) |
|---|---|---|---|---|
| 600 g | 100 | 47.32 | 0.83 | 39.28 |
| 200g (Bakery A) | 100 | 51.20 | 0.75 | 38.40 |
| 200g (Bakery B) | 100 | 24.9 | 0.75 | 18.68 |
| 200g (Bakery C) | 100 | 29.52 | 0.75 | 22.14 |
| 200g (Bakery D) | 100 | 3.35 | 0.675 | 2.26 |

Parameters $\Delta$ and $A_0$ whose data allows us to calculate the loss function respectively represents the deviation from the target that causes an average customer to take an action ($\Delta$) and corresponding monetary loss caused due to a defective component ($A_0$) (Sharma *et al.*, 2007). The listed deviations to the nominal value in Table 10 correspond to the sample analysis carried out as in Table 9. The cost to compensate the missing quantity of bread results from the division of the cost of a presentation of bread by the weight in g, depending on the presentation of the bread. The monetary loss to deviate the weight of each bread is obtained from the multiplication of the deviation of the nominal value of the bread by the cost of compensating one gram of bread in Central African CFA Franc (xaf)

**Table 9: Costs for weight deviations in each type of product**

| Product presentation | QLF (xaf) | MSD | Loss function |
|---|---|---|---|
| 600 g | 59.81 | 3409.94 | $L(\bar{y}) = 1.75 \times 10^{-2}[(\bar{y} - 600)^2 + 2054.23]$ |
| 200g (Bakery A) | 44.22 | 2727.99 | $L(\bar{y}) = 1.62 \times 10^{-2}[(\bar{y} - 200)^2 + 55.10]$ |
| 200g (Bakery B) | 23.03 | 690.83 | $L(\bar{y}) = 3.33 \times 10^{-2}[(\bar{y} - 200)^2 + 70.82]$ |
| 200g (Bakery C) | 26.91 | 957.22 | $L(\bar{y}) = 2.81 \times 10^{-4}[(\bar{y} - 200)^2 + 85.79]$ |
| 200g (Bakery D) | 35.14 | 171.05 | $L(\bar{y}) = 2.01 \times 10^{-1}[(\bar{y} - 200)^2 + 154.73]$ |

It is possible to observe the losses caused by deviations from the specifications set which the company must overcome by taking a set of procedures that reduces the percentage of defects and deviations and try to reach zero defects. Therefore, a reduction rate of 5%, 10% and 15% % to indicate the savings that the company will achieve, as shown in Table 11. For example, the total annual savings that will be achieved if the company followed the reduction procedures by 55% will be equal to 345800 xaf (600g), 54600 xaf (200g Bakery B), 18200 xaf (200g Bakery C) and 3239600 xaf (200g Bakery D).

**Table 10: Proposed reduction of deviations in the companies and society loss savings**

| | Product presentation | QLF (xaf) | $s^2$ Suggest | New QLF (xaf) | Saving suggested (xaf) | saving suggested for 1Million breads (xaf) |
|---|---|---|---|---|---|---|
| 5% reduction of deviations | 600 g | 59.81 | 1951.52 | 58.01 | 1.8 | 1800000 |
| | 200g Bakery A | 44.22 | 52.35 | 44.18 | 0.04 | 40000 |
| | 200g Bakery B | 23.03 | 67.28 | 22.91 | 0.12 | 120000 |
| | 200g Bakery C | 26.91 | 81.50 | 26.79 | 0.12 | 120000 |
| | 200g Bakery D | 35.14 | 146.99 | 33.55 | 1.59 | 1590000 |
| 15% reduction of deviations | 600 g | 59.81 | 1746.10 | 54.41 | 5.4 | 5400000 |
| | 200g Bakery A | 44.22 | 46.84 | 44.09 | 0.13 | 130000 |
| | 200g Bakery B | 23.03 | 60.20 | 22.67 | 0.36 | 360000 |
| | 200g Bakery C | 26.91 | 72.92 | 26.55 | 0.36 | 360000 |
| | 200g Bakery D | 35.14 | 131.52 | 30.37 | 4.77 | 4770000 |
| 25% reduction of deviations | 600 g | 59.81 | 1540.67 | 50.80 | 9.01 | 9010000 |
| | 200g Bakery A | 44.22 | 41.33 | 44.00 | 0.22 | 220000 |
| | 200g Bakery B | 23.03 | 53.12 | 22.44 | 0.59 | 590000 |
| | 200g Bakery C | 26.91 | 64.34 | 26.31 | 0.6 | 600000 |
| | 200g Bakery D | 35.14 | 116.05 | 27.19 | 7.95 | 7950000 |

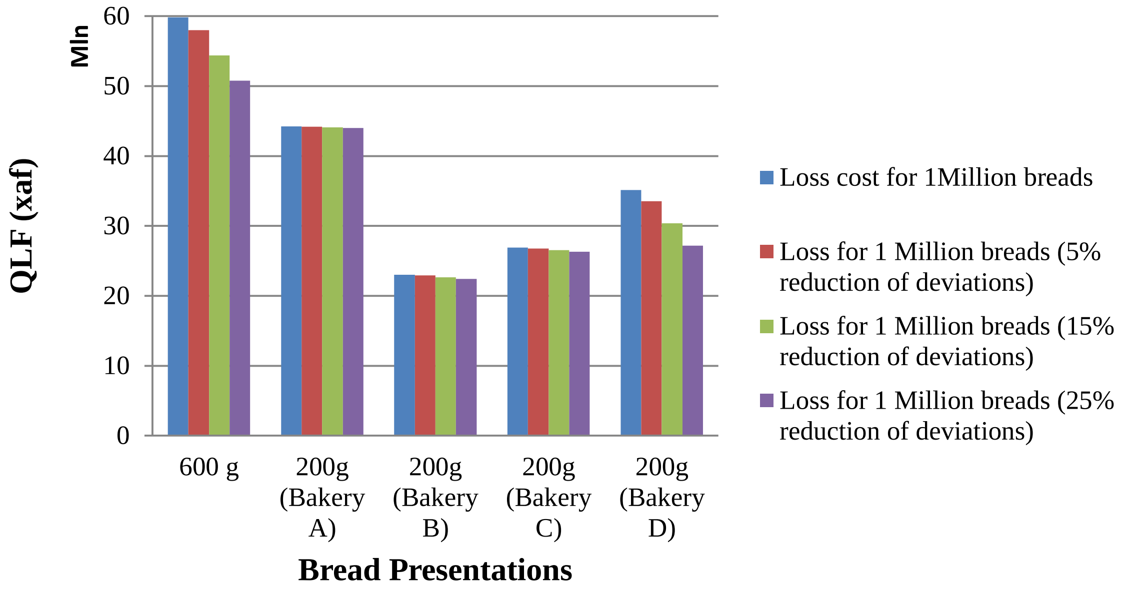



**Figure 9: Estimated quality loss to the society for 1 Million breads of each product to deviate from the nominal value**

**Process Sigma Quality Level Analysis**

The capability index ($C_{pk}$), on the two key metrics that allow us to describe the variation we experience in the bread manufacturing processes. This was done assuming normally distributed data and stable processes around the mean defined by the bakers. Results are presented in Table 11. The capability index relates the observed mean of our bread weight data to the design nominal dimension, in effect telling us how close to the center of the specification we are.

If we improve our processes only until all of them meet Industry average, corresponding to a $C_{pk}$ of 1.33 (Sigma level of 4) or greater (implying that 99.73% of our process output meets 75% of the spec tolerance), we will fall into the trap of goalpost thinking (Noltemeyer, 1994). This suggest that as our products meet the engineering specifications, we are making quality products and need do nothing more.

**Table 11: Process Sigma quality level calculation**

| | Product presentation | Initial $\sigma$ level | 5% reduction of deviations | 15% reduction of deviations | 25% reduction of deviations |
|---|---|---|---|---|---|
| Sigma Level | 600 g | 0.15 | 0.15 | 0.15 | 0.18 |
| | 200g Bakery A | 5.61 | 5.76 | 6.09 | 6.48 |
| | 200g Bakery B | 1.77 | 1.83 | 1.92 | 2.04 |
| | 200g Bakery C | 2.1 | 2.16 | 2.28 | 2.43 |
| | 200g Bakery D | 0.48 | 0.48 | 0.51 | 0.54 |

The results of the analysis, presented in Figure 10, indicate that six factors influence the variation in bread weight. These include the quality of the raw materials (flour, salt, yeast, and fuel costs) and their quantity. The quality of the raw material (flour) may be affected by the length of storage. The cost of wheat flour was identified as the primary factor influencing the production of loaves below standard weight by many bakers. The worker factor was influenced by the qualifications of the workers, fatigue, and the number of staff available.

The skills of the workers are highly correlated with their experience and the training they have received (Ulhaq *et al.*, 2022).

In terms of management, product weight can be affected by a lack of post-batch inspection, inadequate training, and poor work organization. The bread manufacturing process is susceptible to inconsistencies between shifts, and there is inadequate accounting for the weight loss during baking, which is approximately 10% to 20% of dough weight. A 200-grams dough sample, prior to baking, is estimated to weigh approximately 160 to 180 grams after baking. This is a rough range and is based on several factors, including hydration, loaf shape (surface area to volume ratio), oven temperature, baking time, and formula (flour type and other ingredients). Based on this analysis, improvement actions should have twofold goals: to adjust the mean of the response to hit the target value and to reduce the variance around this mean.

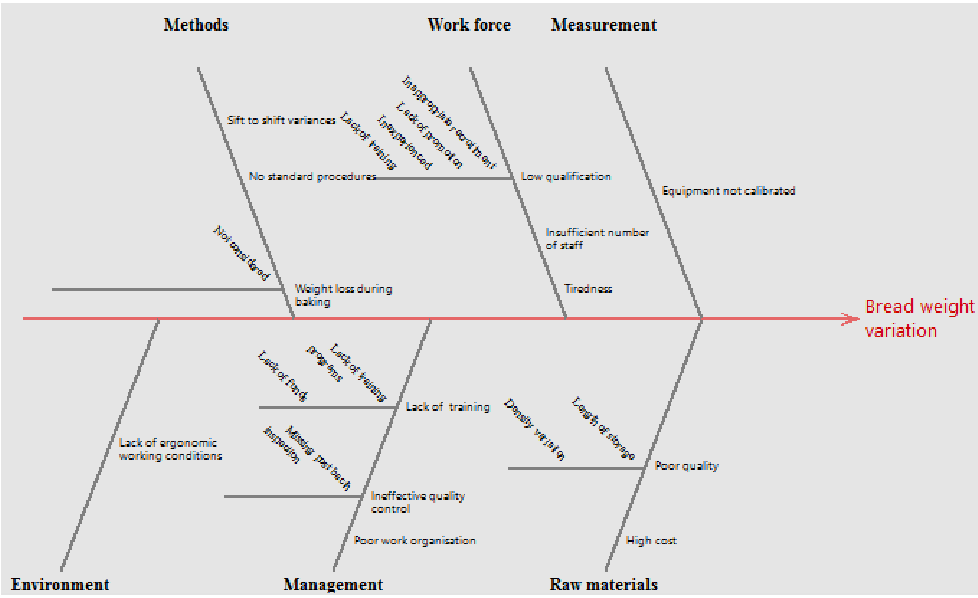



**Figure 10: Ishikawa diagram for the analysis of the causes of bread weight variation**

## DISCUSSION

The losses for the products with presentations of 600g, 200g (Bakery A), 200g (Bakery B), 200g (Bakery C), and 200g (Bakery D) are 59.81 xaf, 44.22 xaf, 23.03xaf, 26.91xaf, and 35.14 xaf, respectively. The loss of 44.22 xaf for the 600-g bread means that a randomly selected product shipped from the bakery is, on average, presenting a loss of 44.22 xaf, indicating that of 1million pieces produced from that product presentation, 59,810 000 xaf is lost by a customer, the bakery itself, or an indirect consumer as illustrated in Figure 9.

Improvement project should focus on obtaining high quality at a low cost, reducing the MSD (Mateo-Díaz *et al.*, 2021). This can be accomplished using parameter design and tolerance design. That means that whenever the company seeks to reduce the deviation from the specifications, it will be able to achieve significant savings, such as achieved by reducing deviations by 5%, 15% and 25% as reported in Table 11. The savings would represent customer satisfaction, reduced lost to the society, future market share, etc. In quality assurance settings, loss functions are used to reflect the economic loss associated with variation and deviations from the ideal value of a process characteristic (Sun *et al.*, 1996).

Cassava and corn flours offer a promising alternative to wheat flour in bread production, given that Cameroon was producing less than one-quarter of the 1.6 million tons of wheat it requires annually in 2022. These products offer both economic and sustainability benefits, making them an attractive option for businesses. The onset of the Russian-Ukrainian conflict has led to a sharp increase in the price and scarcity of wheat flour in several African countries. In March 2022, the government of Cameroon authorized an increase in the price of a 200g baguette, raising the price from the longstanding price of 125xaf set in 2008. Prior to the Russian Black Sea blockade, Cameroon imported approximately 60% of its wheat from Ukraine. The cutoff has led to a nearly 50 percent increase in the price of bread.

The growing food insecurity in Sub-Saharan Africa presents an opportunity for the promotion of locally available crops, such as corn, sorghum, cowpea, and cassava flours, in staple foods like bread. This could reduce wheat imports and stimulate the local economy through the creation of new value chains (Jesulagba *et al.*, 2024; Renzetti *et al.*, 2023; Shilliea *et al.*, 2022). In Cameroon, young entrepreneurs have begun producing composite flour for use in bakery and pastry products. The use of cassava flour in bread making represents a convenient alternative for promoting the use of a local crop, reducing imports of wheat flour, and developing high-quality cassava flour, gluten-free products, and biofortified foods (Aristizábal, 2017).

Comparative studies were conducted to investigate the effect of substituting portions of wheat flour with cassava flour in several studies. The results indicated that, depending on the type of cassava flour, up to 30% of the wheat flour could be replaced without any significant differences from control bread (Jensen *et al.*, 2015; Nadir *et al.*, 2020). In 2020, a study found that substituting wheat with 30% cassava resulted in the highest carbohydrate content, did not change any of the rheological properties, and did not significantly differ from wheat flour in all sensory tests. The substitution of wheat with 40% cassava resulted in elevated protein, fat, and fiber percentages compared to other samples (Nadir *et al.*, 2020). Similar results were obtained from composite bread formulations with a 90% wheat flour to 10% sample ratio (Jesulagba *et al.*, 2024).

## CONCLUSION

The primary objective of this study was to assess the financial impact of weight deviations in bread production. To accurately measure quality before implementing improvements, this paper employs Taguchi’s quality loss function to calculate the financial loss incurred by customers, bakeries, and society. By employing the loss function, we were able to quantify the financial loss incurred by consumers and manufacturers when bakery products deviate from their nominal weight. We were able to identify areas for improvement within the production process, such as the further development of composite breads. To remain competitive in cost and quality, all product and process designs in the bakery industry must be optimized to improve both cost and quality.

The Taguchi loss function will benefit bread manufacturers by providing a rationale for investments in quality improvements and reducing the losses caused by lack of quality. There is sufficient scientific evidence to demonstrate the efficacy of utilizing composite flour, such as cassava flour, to produce a diverse range of breads that will meet the needs of bakers for cost-effective flour while maintaining a high level of quality and dependability. The potential benefits of using composite cassava flour in bread making include cost savings, customer satisfaction, reduced dependence on wheat flour imports, foreign exchange savings, increased farming incomes, reduced food insecurity, and the promotion of rural development through cassava production.

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