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Full Length Paper

Optimization of Bread Baking Parameters Using Taguchi Method: A Case Study of the University of Benin, Ugbowo Bakery

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Abstract

This study optimizes bread baking parameters in a bakery domiciled in the University of Benin, Ugbowo, Benin City, Edo state, using the Taguchi method of experimental design. The study focused on the problems of having breads of good quality arising from the outcomes of the process in relation to the product output. The controllable factors of product design in relation to product output corresponded considerably. After adopting the Taguchi technique with L9(3^3) orthogonal array, and signal to noise ratio, the optimum setting parameters for manufactured bread quality revealed that mixing type(high), had the most significant effect on product quality, with a baking temperature of 150^0c and a duration of 30minutes. It was also seen that temperature and time had the least significant factors respectively.

Keywords*:* *Bread, optimization, mixing type, baking duration, baking temperature, oven, signal to noise ratio.*

1. INTRODUCTION

Bread is a basic dietary item dating back to the Neolithic era, which is prepared by baking that is carried out in oven. The first bread was made around 10,000 years BC or over 12,000 years in the past, which may have been developed by deliberate experimentation with water and grain flour (Arpita et al 2008). In bread-making, baking process is one of the key steps to produce the final product qualities including texture, color and flavor, as a result of several thermal reactions such as non-enzymatic browning reaction, starch gelatinization, protein denaturalization and so on (Nantawan et al 2003). Bread making requires a deep understanding of the many complex raw material and process interactions that determine final product quality. Baking is the most important step in bread making. A series of physical, chemical and biochemical changes such as evaporation of water, formation of porous structure, volume expansion, protein denaturation, starch gelatinization, crust formation, etc., take place during bread baking (Arpita et al 2009). While the conformance to quality is related to the degree of how match between the features of a specific product (service) to its specification. This is why the customers' expectation involves the specification as a quality of product or service. And also the comparison against the competitors in the marketplace as which Prat and Tort (1989) in their study discusses why the pet food manufacturing companies need to implement the quality improvement as crucial task in order to survive in today's marketplace. Antony (2002) reported about the successful application of Taguchi method by many US and European manufacturers over the last 15 years in order to improve their product quality and process performance. This is due to Taguchi concert off-line quality control based on an understanding of the loss function, system design, parameter design and tolerance design, that enables the product development process is immediately produces a quality product or process at the lowest possible cost and thus the online quality control function during manufacturing and service after the sale effort are therefore reduced.

2. LITERATURE REVIEW

1. Taguchi method of Design of experiment (DOE).

As a researcher in Electronic Control Laboratory in Japan, Dr. Genechi Taguchi carried out significant research with DOE techniques in the late 1940's. He spent considerable effort to make this experimental technique more user-friendly (easy to apply) and applied it to improve the quality of manufactured products (Karna, et al 2012). Taguchi started to develop new methods to optimize the process of engineering experimentation. He believed that the best way to improve quality was to design and build it into the product. (Pei-Ling et al 2020) developed a new bakery product (djulis sourdough bread) using a combination of the Taguchi method coupled with grey theory. He utilized the method to optimize the baking parameters (product formulation). Five main factors, i.e djulis sourdough (A), hulled djulis (B), oil type (C), a mixture of bread flour (wet gluten content of 29.0%) and a high-gluten flour (wet gluten content of 35.5%) (D), and honey (E), (each at four levels) were chosen for the Taguchi experiment design ($L16(4)^5$). Taguchi method of design of experiment has been used to develop and evaluate the performance of a rotary oven. It was used to investigate the influence of oven temperature (160, 180, 200°C) and oven rack speed (0, 10, 20 rpm) on the physical properties (baking time, mass, surface area, specific volume and density) of bread produced from the rotary oven (Sanusi et al 2020). The method has found application in several food manufacturing industries, for example (Haeryip et al 2012) used the taguchi method to optimize the manufacturing process of the SME bread
product The study is focused on the quality problems occurred as the outcomes of the process (quality of the bun produced) related to controllable factors of products design identified (machine temperature and length duration time) for the improvement required. The orthogonal array is an arrangement of numbers in rows and columns. Taguchi method employs the signal to noise ratio (S/N) value to qualify and quantify the differences in the combination of parameters and how they significantly influence the final product. These values are basically used as a tool for measuring the effect of noise factors on performance characteristics. The S/N ratios adopts both amount of variability in the response data and closeness of the average response to the target output. There are three S/N ratios available depending on type of characteristics: smaller is better, nominal is best (NB) and larger is better. Taguchi outlined 18 basic orthogonal arrays known as the standard orthogonal arrays. Each orthogonal array uses a notation that indicates its number of rows and columns, as well as the number of level in e
ach column.

2. Manufacturing process

There are several stages in the bread manufacturing process ranging from dough formation to fermentation and then to the final stage of baking.

The stages involve mixing of flour, water, yeast, salt and other ingredients. In this process, the changes are associated with the formation of gluten, which requires both the hydration of the proteins in the flour and the application of energy through the process of kneading.

3. MATERIALS AND METHODS

This study is conducted on the current food manufacturing system against the characteristic behavior of the selected controllable parameters applied in the food manufacturing production line process. The flow process and the steps of manufacturing as described in table 1 below

Table 1: Process flow of bread production. (Source Haeryip et al 2012)

STEPS	PROCESS
1. The first step is the mixing of the ingredients to make the dough of the bread	Mixing bread This process evenly distributes the ingredients, develops the gluten and to initiate fermentation • The machine has 3 alternative speeds scale. • To change the speeds, first turn off the motor, then move the shifter handle to the desired speed. • Speed number 1 for slow speed is for heavy mixtures. In many mixing operation, it is customary to start on speed number 1 and then change to a higher speed as the work progresses. • Speed number 3 for fast speed is for light work as whipping cream, beating eggs and mixing thin batters.
2. Then, the prepared dough is divided into several amounts by using dough cutter machine.	Dough cutter • This process is continued from the first process which divide the dough to several quantity that needed with set up at the machine button. • The capacity for one cycle process is 80pcs. per min.
3. The dough are then will arranged on the tray. The composition of the dough is properly arranged to make sure the dough will baked completely later.	
4. The dough which has been prepared on the tray will then on hold in the fermenting box to ensure the dough is steamed to maintain the dough.	Bread fermenting box • The prepared dough is transferred to the fermenting box. This is required to keep the bun in good condition, fresh before transfer to oven
5. Next, the bread is baking in infrared food oven at several times according to the setting.	Oven • This gas oven provide platform type revolving hot air oven for cook process. The surround hot air in the oven is support the cook process for several trays of buns in the oven.
6. The bread is allowed to cool in room temperature and packaging for sell	

Fig. 1: Cake bread

Fig. 2: Medium sized bread

Fig. 3: Big sized bread

3.1. Bread Inspection

Figure 1, 2 and 3 shows the Cake bread, Medium sized bread and Big sized bread. Bread inspection is done based on the visual inspection on the surface of the bread. The inspection is done manually for the appearance of the final product to confirm the acceptable lot that can pass through the next process of packaging. The color of the bread and surface peak of final product are the measurable quality characteristics of this study

4. RESULTS AND DISCUSSION

Table 2: Control Factors and Levels of the experimental Design

	LEVELS		
FACTORS	**1**	**2**	**3**
Baking temperature(^{0}c) (A)	150	200	250
Mixing type (B)	Low	Medium	High
Baking Duration(min) (C)	30	35	40

After a run of the nine experiments from the L9(3^3) orthogonal array, it was observed that some bread had defects, some were burnt, some not properly baked, while others were overcooked. The following results were obtained and recorded from a sample of 10 small loaves each

Table 3: Summarized results of manufactured bread quality

Experimental trial	Total accepted	Rejected			Total Rejected(y)
		Burnt	Half Done	Overcooked	
1	8	2	0	0	2
2	7	0	2	1	3
3	1	6	2	1	9
4	8	0	1	1	2
5	8	1	0	1	2
6	6	2	0	2	4
7	8	0	2	0	2
8	5	1	3	1	5
9	7	2	1	0	3

4.1 Signal to noise ratio

The Taguchi's method provides the orthogonal array as a mathematical tool that allows the analysis of the relationship between a large numbers of design parameters by using only a limited number of experimental run. The target is based on the conditions identified which results the optimal process or product performance. Here, the S/N ratio is what the Taguchi method advocates for measuring the quality through orthogonal array based experiments. The S/N ratio is used to convert the trial result data into a value for the evaluation characteristics as the optimum setting analysis. In this study, the visual inspection against the output is to determine the quality characteristics considered of the bread product. To determine the optimal parameter factors for the bread manufacturing process, the reject should be in minimum as the acceptable of output. For the nine experiments the signal to noise ratio values were obtained as follows The S/N ratio selected for this study is the larger-the-better quality characteristics. The calculation and equation for S/N ratio is as follows;

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{yi^2}\right)\right]$$

where n = number of samples or repetitions/trial in a row in this experiment, n=1

y_i = Response value of each repetition/trial.

The results from the signal to noise ratio for the Larger the better quality characteristics is shown below.

Table 4: Calculation for Signal to noise ratio values (The larger the better)

n	y	y^2	S/N ratio
1	2	4	6.0206
2	3	9	9.5424
3	9	81	19.0849
4	2	4	6.0206
5	2	4	6.0206
6	4	16	12.0412
7	2	4	6.0206
8	5	25	13.979
9	3	9	9.546

4.2 Main effect of signal-to-noise ratio (s/n) response and Means.

Figure 4 shows S/N graphs for the bread manufactured experiment. Basically, the larger the value of S/N, the better the quality. Based on this graph, it reveals that the trend of the mixing type is more significant than other factors. The S/N ratio is slightly increased from low setting to medium setting, but the S/N ratio is slightly increased and approach to the maximum for high type of mixing setting. For baking duration, the graph trend begins with a sharp decrease between 30 minute and 35 minute and increase before 40mins of baking process. The S/N ratio value between 30 minutes and 35 minutes is equally decreased and approach to the minimum of the S/N ratio value. For baking temperature, the S/N ratio trend is smoothly decreased between 150^0C and 200^0C and approaches to the minimum of S/N ratio which then is followed by a slight increase of baking temperature from 200^0C to 250^0C. Based on the Figure 4 and Table 5, it can be said that the mixing type is the main factor influenced to the quality of the output of the bread manufacturing process. It shows that the mixing type is the control factor that has the most significant effect. The effect of the other factors (A and C) is of less significance. Table 5 shows the average S/N ratio values for the experiment at the three levels setting of each factor and the effect of each main effect on the S/N ratio in respectively. The mean of S/N ratio for percentage of the mixing type at level 1, level 2 and level 3 is 15.59, 19.37 and 22.27 respectively. Clearly, the S/N ratio of mixing type at level 3 appears to be the best choice since it corresponds to the highest average S/N ratio. The mean S/N ratio of baking duration is 20.04, 18.26 and 18.93 at level 1, level 2 and level 3 respectively. The S/N ratio for baking duration suggests that parameter at level 1 is better than at level

3 and level 2. Level 1 shows the highest average of S/N ratio and is considered as the best choice. For S/N ratio of baking temperature, same as previous, level with highest S/N ratio will be chosen so; the best choice is at level 1 with 20.27. From the analysis above, the optimum parameters selected to optimize the quality of bread manufactured are A1B3C1. The maximum-minimum value is equal to the range of S/N ratio variance due to the change in the level setting. The larger the range, the more powerful impact the control factor has on quality. The ranking in Table 4.4 shows that S/N ratio of mixing type, which has ranking 1, has relatively strong impacts and influence on the quality of bread. S/N ratio of baking temperature and baking time which has ranking 2 and 3 respectively have relatively weak impacts. So, S/N ratio of mixing type should be strictly controlled for high quality of bread during the manufacturing process. Therefore, Table 5 shows that the most significant factor for the output of the product is the control factor toward B (mixing type). The effect of the other factors (A and C) is of less significance. Since the objective of this study is to optimize the bread product process, the S/N ratio should be maximal in order to minimize variability. Thus, factor B should be to set at level 3 in order to get the maximum result

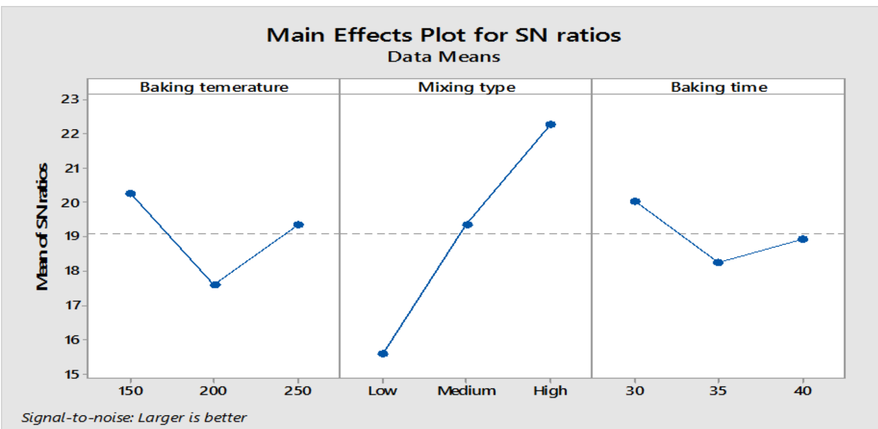

Fig 4: Signal to noise ratio graph

Figure 5 shows the mean graphs for the bread manufactured experiment. Basically, the larger of the S/N ratio values suggests the better quality. Figure6 shows the best levels for each control factors to obtain the optimal values accepted of the bread product. From the graph, it is obvious that the trend of the mixing type is more significant compared to other factors. The mean is slightly increased from low setting to medium setting, and then slightly increased by approaching the largest high type of mixing setting. For baking duration, the graph trend begins with a

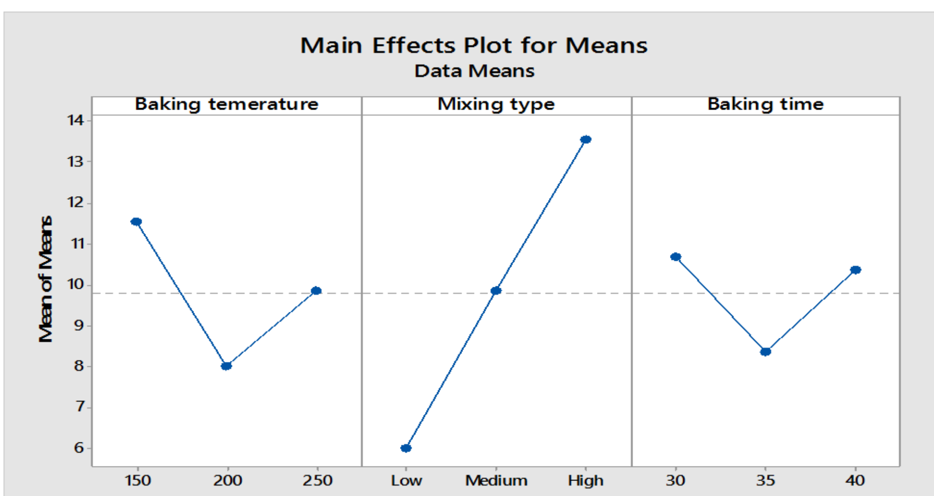

Fig 5: Main effect plot for means

decrease between 30 minute and 35 minute of baking process. The mean value between 35 minute and 40 minute is then increased. For baking temperature, the mean is smoothly decreased between 150^{0}C and 200^{0}C by approaching the minimum of mean and followed by a slight increase for baking temperature between 200^{0}C to 250^{0}C. From the Figure 6 and Table 6, it can be described that the mixing type is the main factor that influence the quality of the output of the bread manufacturing process. It shows that the mixing type is the control factor that has the most significant effect. The effect of the other factors (A and C) is of less significance. Table 6 shows the average mean values for the experiment respectively at three levels setting of each factor and the effect of each factor on the mean. The mean of mean values for the mixing type at level 1, level 2 and level 3 6.021, 9.849 and 13.557 respectively. Clearly, the mean of mixing type at level 3 appears to be the best choice since it corresponds to the highest average mean. The mean of baking duration is 10.680, 8.370 and 10.375 at level 1, level 2 and level 3 respectively. This means that for the baking duration, the parameter at level 1 is better than at level 2 and level 3. Same as previously, the level with highest mean will be chosen as the best choice, which is 10.680. Based the analysis above, the optimum parameters selected to optimize the quality of bread manufactured is A1B3C1. Since the maximum-minimum value is equal to the range of mean variance due to the change in the level setting, the larger the range, the more powerful impact the control factor has on quality. The ranking in Table 6 shows that the mixing type has ranking 1 and relatively strong impacts and influence on the quality of bread. Thus, the baking temperature and baking duration are at ranking 2 and 3 where they relatively give the weak impacts.

Table 5: Response Table for Signal to Noise Ratios

Level	**Baking temperature**	**Mixing type**	**Baking Time**
1	20.27	15.59	20.04
2	17.60	19.37	18.26
3	19.37	22.27	18.93
Delta	**2.67**	**6.68**	**1.78**
Rank	2	1	3

Table 6: Response Table for Means

Level	**Baking temperature**	**Mixing type**	**Baking Time**
1	11.549	6.021	10.680
2	8.027	9.847	8.370
3	9.849	13.557	10.375
Delta	**3.522**	**7.537**	**2.311**
Rank	2	1	3

5. CONCLUSION

The optimization has been carried out to study the parameters that greatly influences the production of bread at the University of Benin Bakery. Generally the higher the signal to noise ratio values, the better the product quality, and defects such as burnt and overcooked samples are eliminated. Therefore the basic idea is to provide a decision tool for setting optimum parameters such that defects are reduced. Validation experiment was done for the set of optimum parameters obtained, and it was observed that the product quality was better of than the previous products under the non-optimized conditions, proving that the Taguchi method of design of experiments is a an efficient tool for maximizing product quality. In addition, the further study required is against the heat transfer distribution of the oven that is influenced by location of heat generator (microwave) towards the objects. The outcome of this study was useful for finding an optimal solution to manufacturing defects that occur due to incorrect process parameters in bread baking.

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