ISSN: 2716-9227 Algerian Journal of Engineering and Technology 07 (2022) 063–069 e-ISSN: 2716-9278

Algerian Journal of Engineering and Technology

Journal homepage: https://jetjournal.org/index.php/ajet

Original Article

Optimization of a gas-fired *gurasa* (local bread) baking oven using response surface methodology (RSM)

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ARTICLE INFO

Article history:
Received 30 April 2022
Revised 01 September 2022
Accepted 28 September 2022

Keywords:
Gas-fired;
Gurasa;
Baking oven;
Optimization.

ABSTRACT

Gurasa (local bread) is an important diet in many households in Northern parts of Nigeria for time immemorial, especially in Kano State, Nigeria. This study is to develop a *gurasa* baking oven, carry out the performance evaluation of the oven and also to optimize the baking parameters of the oven using the response surface methodology (RSM). The oven is composed of three baking compartments; these include a heat source, a control panel and the main frame. The baking compartments consist of heating rods and the *gurasa* baking trays. The heat source is a gas burner that generates the required heat to bake the products. There is a control panel that is used to set the temperature at which the gas cylinder goes off (after the preheating of the oven) and the heat in the oven is maintained for some time with the aid of the insulator in between the walls. Using the response surface method, the oven was evaluated to know its baking efficiency, baking damage, and capacity. The oven has a baking efficiency of 87.5 %, baking damage of 11.5 % and a capacity of 23.4 kg/hr with 27 loaves per batch. The RSM showed values of the responses ranged from 16 – 95 g, 5.24 – 13.6 %, 845.8 – 3684.2 N/m^2 and 0.7–8.06 cm^3/g for weight loss, moisture content, tensile strength and specific volume respectively. Quadratic models to predict weight loss, moisture content, tensile strength and specific volume of *gurasa* in terms of baking temperature, baking period and mass of dough were developed. The optimum baking process was achieved at a baking temperature of 200^{o}C, a baking period of 9 minutes and a dough mass of 130 g. These values show that the oven can be adopted for domestic and commercial baking.

1. Introduction

In Nigeria, increasing population and rapid urbanization have resulted in a preference for ready-to-eat convenient foods such as bread, biscuits, and other baked products like *gurasa* (1). *Gurasa* is an important diet in many households in some Northern parts of Nigeria especially Kano State for time immemorial. Despite its importance in the lives of people, the processing and storage of this product have received little attention it deserved from researchers.

The traditional processing of *gurasa* usually exposes the producers to the risk of fire burn and the product (*gurasa*) to contamination by charcoal, ash residue and the peels of pot wall during removal due to adhesive force between the wall and the products which eventually render the products unhygienic. Uneven baking due to uncontrolled heating and low output capacity are other problems associated with the traditional method of *gurasa* baking. Traditionally, the baking of *gurasa* is usually done by burning corn stalks (softwood) which also is a type of firewood. It has been noted that continuous receiving the emissions from burning firewood has a high negative impact on the health of an individual (2). According to (2), households using wood in an open fire as done in *gurasa* production experience particulate matter (PM) concentrations of over 3000 μg/m^3 in the air compared to households using charcoal stoves, which are only exposed to PM concentrations of around 500 μg/m^3 (3). The Global Burden of Diseases study has shown that 3.5 million premature deaths per year (in the

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Peer review under responsibility of University of El Oued.

world) are directly attributed to household air pollution from the use of solid fuels (4). Therefore, the provision of a better and healthier *gurasa* baking oven with optimum baking parameters will add value to the product and also give the people an eco-friendly environment to live in. Even though, literature has not shown much research works done on the baking oven for *gurasa*. However, many research works have been done on the design of baking ovens for bread, cake, biscuit and the like.

A gas-powered oven was designed and evaluated and the report showed that an increase in cake size leads to an increase in the baking period with an acceptable volume of cake (5). It was also found that the oven is suitable for baking cakes, cookies and most bakery products with good quality parameters like colour, texture taste and good volume in the fermented products. However, the inability to control the oven's internal temperature was a demerit.

A charcoal bread baking oven was developed and tested with functional efficiencies of 91.2% and 92.1% for the baking dough of mass 0.5 kg and 1.5 kg of bread at a baking period (BP) of 27.7 minutes, 35.9 minutes with the baking temperature (BT) of 153.8^{o}C and 165.9 ^{o}C respectively (6). The oven was essentially made of mild steel, angle iron, flat bars and square pipes while the source of heat was charcoal the dependent variables used were baking time, colour, texture and moisture content. The oven has bread baking capacities of 56, 36, 28, 22 and 18 pieces of bread per batch operation using dough mass of 0.5 kg, 0.75 kg, 1.00 kg, 1.250 kg and 1.500 kg respectively. According to this research work, there is a strong relationship between baking temperature, baking period and mass. This is because the oven is sensitive to the baking time and baking temperature in relation to dough mass with a resolution value of 0.22.

Research on the development and optimization of operational parameters of a gas-fired baking oven using galvanized steel sheets, still pipes, fiberglass angle iron, thermocouple and regulator was carried out (1). The oven has a capacity of 0.036 m^3 (20 loaves per batch) and each loaf has a surface area of 0.018 m^2. It was concluded that baking temperature and baking period influence the rate of weight loss during the baking process, where bread quality (volume, weight loss, and moisture content) was the dependent variable while loaf size (mass), baking temperature and baking periods were the independent variables.

A mini dual-powered baking oven using galvanized sheet metal (outer body) and aluminum (inner body) was designed, the oven was capable of baking 12 loaves of bread (area of 0.022 m^2 per loaf) for bread (7). The oven was mainly made up of the electric coil, the lagging material, temperature control and the gas burner. According to this research, the maximum temperature recorded in the oven was 220 ^{o}C and it was established that baking temperature is inversely proportional to the baking time. In this research, the performance indicator used was the quality of the final product whilst the independent variables are baking duration, baking temperature, size of loaf and loaf geometry.

A domestic gas oven was designed, fabricated and evaluated (8). The oven has an outer dimension of 860 × 660 × 1150 mm. The oven was designed from mild steel and fiberglass 40 mm thick was used as an insulator to reduce heat loss. The oven capacity was 12 loaves of 0.5 kg bread per batch. Quality parameters like volume, weight, texture and colour of loaves were considered the dependent factors while baking temperature, baking period and mass of dough were the dependent factors. When the oven was operated on a maximum baking temperature of 210 °C, maximum efficiency of 90.7% was recorded and it took approximately 43 minutes to bake a batch of dough to the desired quality. The study showed that an increase in baking temperature and baking period reduces the moisture content of the dough. Substantial research has been done on the design and performance evaluation of the conventional oven for bread and cake but the optimization of baking parameters is not common and the ovens are not specifically designed for *gurasa* production which is a specialized kind of bread. Therefore, this research work is intended to develop and fabricate a *gurasa* baking oven, carry out a performance evaluation of the oven and determine the optimum baking temperature and baking period using the response surface methodology (RSM). It is aimed at producing a better, more acceptable *gurasa* more safely and efficiently. The oven will have a higher baking capacity as compared to a typical *Tanderu*, and the product will be hygienic and retain its sensory qualities.

2. Materials and Methods

2.1 Sample preparation

The ingredients for the *gurasa* consisting of wheat flour, yeast, sugar and salt were purchased from Abubakar Rimi market in Fagge Local Government Area, Sabon Gari Kano State, Nigeria. With aid of a professional *gurasa* producer, the ingredients were mixed in the right proportion of 10 kg, 500 g, 250 g and 4 litres for flour, yeast, sugar and water respectively until a homogenous mixture was achieved. After mixing, the dough was covered and allowed to stay for 15-20 minutes. The dough was then cut and weighed into the required mass using a digital weighing balance (SF – 400) and molded into a flat round shape. The oven was preheated at the baking temperature of 220°C for 9 minutes. The dough was then transferred into the preheated oven for baking.

2.2 Oven Description

The oven (Plate 1) is made from galvanized steel metals with fibre glass insulator in between the walls to minimize heat loss. The baking chamber consists of heating rods and baking trays. The gas burner generated the required heat to bake the products. During baking, the heat collector (mild steel) received the heat and transfers the heat by conduction to the heating rods.

Plate 1. Gas fired *gurasa* oven

The rods also transfer the heat through conduction to the galvanized baking trays and finally the tray transfer the heat to the product by conduction for baking to occur. The exploded view of the oven is presented in Figure 1.

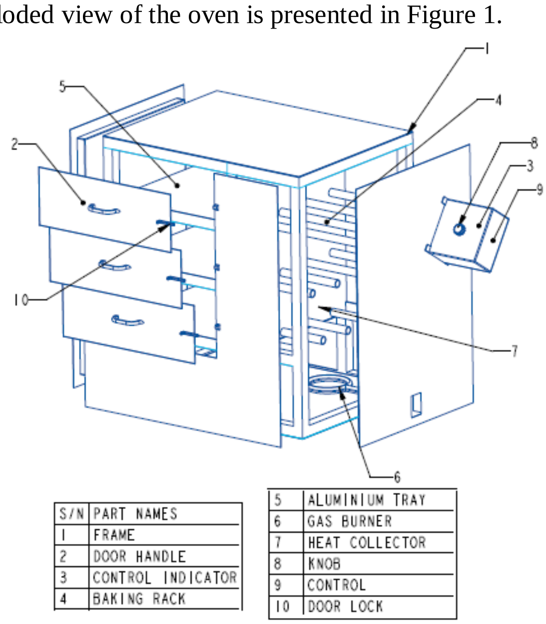

Fig 1. Exploded view of the gas-fired *gurasa* oven

2.3 Oven Performance and Evaluation Parameters

The oven generally operates on the principles of simultaneous heat and mass transfer in which the heat generated by the burning gas evaporates moisture from the dough and bake-cook the dough to the taste of its consumers. The oven is preheated to the required temperature of 220 °C, the *gurasa* dough is mixed and prepared into the required sizes, the pre-heated oven is opened and the doughs are placed on the baking trays. The control panel is set to the required baking temperature and the control turn-off the gas cylinder once the required baking temperature is reached and the product is allowed to bake at this temperature for 5-9 minutes.

2.4 Experimental Design and Statistical Analysis

The experiment design was done using the Box-Behnken design of Response Surface Methodology (RSM) due to its uniqueness in generating a higher-order response with few required runs to maintain the higher-order surface response. An experimental design was carried out at three (3) levels of independent variables (Table 1) selected based on traditional methods of *gurasa* processing; baking temperatures (A) baking periods (B) and mass of dough (C). Each run was replicated three (3) times. The outline of the Box-Behnken design generated using the design expert software (Design-Expert v13, Stat-Ease Inc., Minneapolis, USA) is given in Table 2.

The quadratic models developed in this study were used to optimize process conditions for the performance of the oven. The optimization result shows that the best baking temperature ranges from 200°C - 240°C for a baking period of 5 - 9 minutes and dough mass of 40 - 220 g. This study is aimed at maximizing weight loss and specific volume while the moisture content and tensile strength are to be kept minimum. Optimization of the process conditions was carried out to get the optimum solutions using Design Expert Software and the desirability function by setting the software to the minimize or maximize criteria as required for each of the responses.

Table 1: Experimental design variables

S/N	Factors	Units	Levels		
1	Baking Temp. (A)	°C	200	220	240
2	Baking period (B)	Minutes	5	7	9
3	Dough mass (C)	G	40	130	220

For model validation, a different independent performance tests were conducted for each of the model. The recommended optimum input variables of baking temperature, baking period and mass of dough were substituted into each of the model equations for weight loss, moisture content, tensile strength and specific volume. The performance test results correspond to the predicted optimum responses were presented.

3. Results and Discussions

A total of 17 runs of Box-Behnken design and observed response data for the performance evaluation of the oven are presented in Table 2. These observed response data were statistically analysed to generate the best-predicted quadratic models that define the correlation between the experimental variables which include: baking temperature (A), baking period (B) and dough mass (C)) and the responses (weight loss, moisture content, tensile strength and specific volume).

3.1 Mathematical Models

The developed models in terms of actual factors are given in Equations 1 - 4.

$$Weight\ loss = +4590.03434 - 36.97569A - 164.67361B + 1.06373C + 0.156250AB - 0.000139AC - 0.009722BC + 0.081562A^2 + 9.40625B^2 - 0.003627C^2 \quad (1)$$

$$Moisture\ content = -209.00519 + 2.04750A - 0.625139B + 0.077620C - 0.016625AB + 0.000150AC - 0.001778BC - 0.004575A^2 + 0.303750B^2 - 0.000319C^2 \quad (2)$$

$$Tensile\ strength = +11238.18302 - 41.33944A - 849.96667B - 28.06762C + 3.28938AB - 0.027639AC - 0.694583BC + 0.054438A^2 + 18.05000B^2 + 0.097404C^2 \quad (3)$$

$$Specific\ volume = 188.55540 - 1.36132A - 8.69929B - 0.045143C + 0.015625AB - 0.000049AC - 0.002708BC + 0.002830A^2 + 0.399250B^2 + 0.000160C^2 \quad (4)$$

Table 2: Results of experimental layout for performance evaluation

		Factors			Responses			
		1	2	3	1	2	3	4
Std	Run	A: Temp	B: Period	C: Dough Mass	Weight loss	Moisture Content	Tensile Strength	Specific Volume
		°C	Mins.	G	G	%	N/m²	cm³/g
5	1	200	7	40	20	8.14	3333.3	7.5
15	2	220	7	130	16	12.3	1353.4	1.75
16	3	220	7	130	16	12.3	1353.4	1.75
9	4	220	5	40	20	9.83	3333.3	7.6
14	5	220	7	130	16	12.3	1353.4	1.75
10	6	220	9	40	22	8.91	3684.2	8.06
2	7	240	5	130	80	11.3	1353.4	3.8
7	8	200	7	220	22	10	1094.5	2.12
4	9	240	9	130	95	9.44	1804.5	5.37
6	10	240	7	40	17	5.24	3333.3	6.43
12	11	220	9	220	25	11.4	845.8	0.73
11	12	220	5	220	30	13.6	995	2.22
3	13	200	9	130	80	13.4	1278.2	3.92
1	14	200	5	130	90	12.6	1353.4	4.85
13	15	220	7	130	16	12.3	1353.4	1.77
8	16	240	7	220	18	8.18	895.5	0.7
17	17	220	7	130	16	12.3	1353.4	1.76

Analysis of variance data (Appendix 1) used to fit the models showed that all the quadratic models were significant ($p < 0.0001$) as evident from the p-values in Appendix 1, the coefficient of determination (R^2) which explains the precision of the developed models were 0.9973, 0.9898, 0.9933 and 0.9831 for weight loss, moisture content, tensile strength and specific volume respectively. A high R^2 value closer to 1 indicates a good correlation between the input variables and response variables (9). This means the model R^2 values are good for the models. The adjusted R^2 value for the models were all greater than 0.9 which is also an indication of the model validity. The predicted R^2 of weight loss (0.9560), moisture content (0.8365), and tensile strength (0.8934) were all in reasonable agreement with their respective adjusted R^2 values since their differences are less than 0.2. A Predicted R^2 of 0.7304 (for specific volume) is not as close to the Adjusted R^2 of 0.9615 as seen in Appendix 1. The difference is more than 0.2. This may indicate a large block effect or a possible problem with the model and/or data. Coefficient of variation (CV) which explains the extent of deviation of the actual data from the predicted data are all less than 10% (Appendix 1) for all the models except for the specific volume which is 13.55%. A CV of less than 10% shows good reliability of the model (10).

The plot of predicted and experimental values of the responses are presented in Appendix 2. As shown in the appendix the plot of predicted against the actual values are scattered along the line for all the responses. This indicates the closeness of the values and fitness of the models representing the responses.

3.1 Interactive Effects of Independent Variables on the responses

3.1.1 Weight loss

Weight loss in baked foods is the amount of weight reduction in food that is principally due to moisture removal from the food. Moisture in baked foods is to be kept minimum to reduce the activities of microorganisms such as mould and bacteria thereby increasing the shelf life of baked foods. The weight loss ranged from 16 to 95 g (Figure 2). The minimum weight loss was recorded with a baking temperature of 220 ^{o}C, a baking period of 7 minutes and 130 g mass of dough while the maximum weight loss was recorded with a baking temperature of 240 ^{o}C and a baking period of 9 minutes as established in Figure 2. The weight loss of the bread increased with an increase in baking temperature and baking period, a similar trend was reported (1). At high baking temperatures, more heat is supplied to the dough which facilitates more moisture evaporation from the dough during baking. A similar report was also recorded using cake (11).

3.1.2 Moisture content

Moisture content is the amount of moisture contained in a product. The moisture content of baked food is to be kept very minimal as possible to keep the product stable and fresh for long period. The moisture content ranged from 5.24 to 13.6 % (Figure 3). The minimum moisture content was observed with the maximum baking temperature of 240 ^{o}C, baking period of 7 minutes and minimum dough mass of 40 g, whereas the maximum moisture content was observed at a baking temperature of 220 ^{o}C, baking period of 5 minutes and dough mass of 220 g. It was observed in Figure 4 that moisture content decreased with an increase in the baking period (B) and baking temperature (A) at a constant mass of dough, this trend is in agreement with the findings (1).

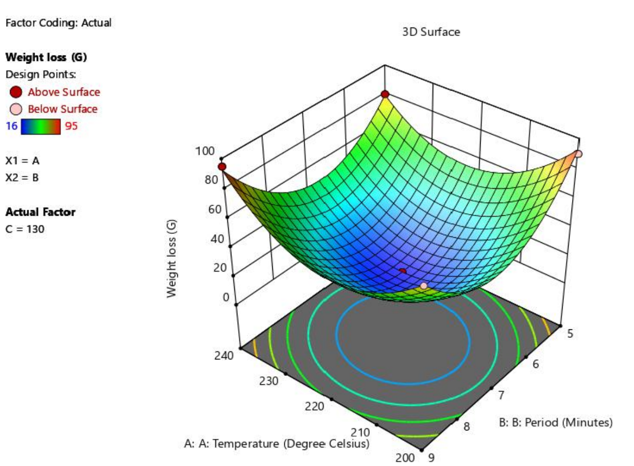

Fig 2. 3D surface for the effect of baking temperature and baking period on the weight loss

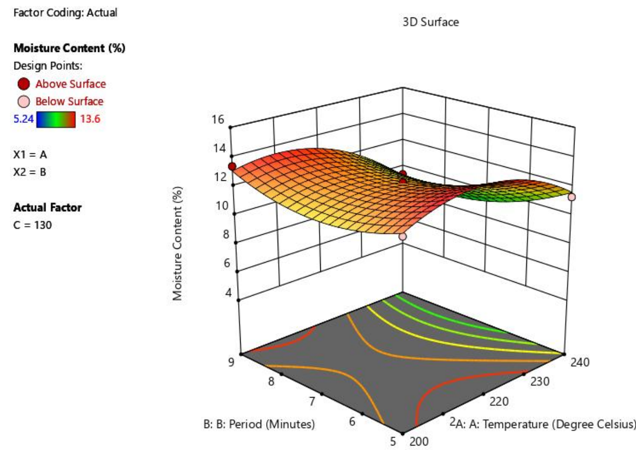

Fig 3. 3D surface for the effect of baking temperature and baking period on the moisture content

3.1.3 Tensile strength

Tensile strength in this context is a measure of the stress (tearing force) required to break apart *gurasa* before mastication for easy digestion. This force is to be kept minimal to prevent pain in the jaw when chewing the bread. Tensile strength ranged from 845.8 to 3684.2 N/m^2 (Figure 4). Minimum tensile strength was observed at a baking temperature of 220 ^{o}C, baking period of 9 minutes and 220 g mass of dough while the maximum tensile strength was observed at a baking temperature of 220 ^{o}C, baking period of 9 minutes and dough mass of 40 g. It was observed from Figure 5 that tensile strength increase with a reduction in baking temperature, baking period and mass of dough. This increase in tensile strength could be due to the presence of hot air in the oven which reduces the moisture content of the dough when placed inside the oven which is in line with the report given by (1).

3.1.4 Specific volume

Specific volume is a measure of the space occupied per unit mass by the *gurasa*. The specific volume of baked food is to be maximized for good and increased acceptability by the consumers. Specific volume ranged from 0.7 to 8.06 cm^3/g (Figure 5). The minimum specific volume was recorded at a baking temperature of 240 ^{o}C, 7 minutes baking period and a dough mass of 220 g while the maximum specific volume was observed at a baking temperature of 220 ^{o}C, a baking period of 9 minutes and a minimum dough mass of 40 g. Specific volume increase with reduction in baking temperature (A), baking period (B) and mass of dough (C) as established in Figure 5. This trend of decreasing specific volume is supported by the work of (1) in which an increase in the mass of dough, baking period and baking temperature causes a decrease in specific volume. It can therefore be concluded that increasing the baking period, baking temperature and mass of dough leads to a decrease in specific volume.

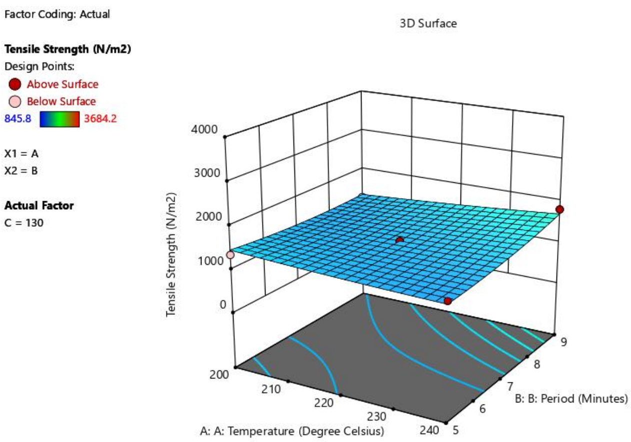

Fig 4. 3D surface for the effect of baking temperature and baking period on the tensile strength

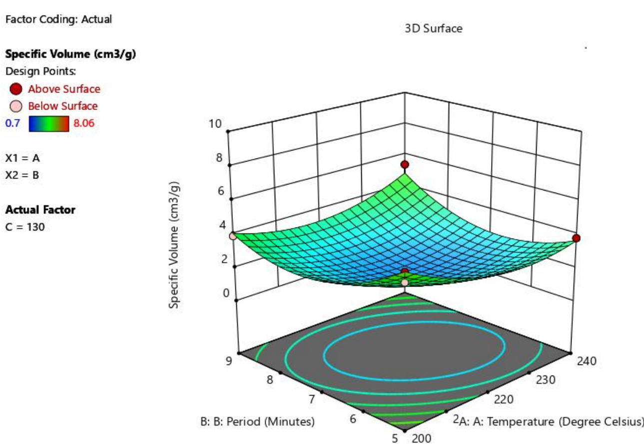

Fig 5. 3D surface for the effect of baking temperature and baking period on the specific volume

3.2 Optimization of the oven performance

The predicted optimum input variables were 220 ^{o}C baking temperature, 7 minutes baking period and 130 g mass of dough. Optimum performance responses for the predicted input variables are presented in Table 3. The closeness of the predicted and experimental values presented in Table 3 shows the developed model's suitability. Muhammed et al. (2021) recorded similar conformity between the predicted and experimental values after the performance optimization of a groundnut sheller.

Table 3: Predicted and experimental values of performance responses at the optimum conditions of the oven

Performance responses	Comparison	
	Predicted values	Experimental (Actual) values
Weight loss (g)	92.50	95
Moisture content (%)	4.99	5.24
Tensile strength (N/m^2)	930.09	845.8
Specific volume (cm^3/g)	8.07	8.06

Model validation

From the performance test conducted for models validation, the recommended optimum input variables of baking temperature (220^{o}C), baking period (7 minutes) and mass of dough (130 g) were substituted into each of the model equations for weight loss, moisture content, tensile strength and specific volume. The model R^2 values for weight loss (0.9973), moisture content (0.9898), tensile strength (0.9933) and specific volume (0.9831) as presented in Appendix 1 were obtained and they are all very close to unity. The results in Table 3 and that of the R^2 values in Appendix 1 indicate a strong agreement between the observed and predicted values. These indicate the models fitness. The optimum performance indices recorded for this study were 92.50 g for weight loss, 4.99 % for moisture content, 930.09 N/m^2 for tensile strength and 8.07 cm^3/g for specific volume.

4. Conclusion

The gas-fired *gurasa* oven was developed and response surface methodology was used to optimize the input parameters (baking temperature, baking period and mass of dough) for optimum performance of the oven in terms of the responses (weight loss, moisture content, tensile strength and specific volume). It was revealed that the baking temperature, baking period and mass of dough all have a significant influence on the baking efficiency and output capacity of the oven. Quadratic models that can be used to predict weight loss, moisture content, tensile strength and specific volume in terms of baking temperature, baking period and mass of dough were developed. The optimum baking processes were achieved at a baking temperature of 200^{o}C, a baking period of 9 minutes and a dough mass of 130 g. The optimum performance indices were 92.50 g for weight loss, 4.99 % for moisture content, 930.09 N/m^2 for tensile strength and 8.07 cm^3/g for specific volume. However, the oven can be improved by adding another burner to the right corner of the oven to increase heat generation and distribution across the racks. A solar rechargeable battery can be used as the source of power for producing the spark needed to light the burner. In addition, a fan can also be introduced for better and even distribution of heat.

Conflict of Interest

The authors declare that they have no conflict of interest

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Recommended Citation
Shittu SK, Suleiman AO, Muhammad AI. Optimization of a gas-fired *gurasa* (local bread) baking oven using response surface methodology (RSM). *Alger. J. Eng. Technol. 2022*, 7:63-69.