Optimization of Impacts of Eggs from Different Birds, Oven Temperature and Oven Rack Speed on the Physicochemical Properties of Cupcakes

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Abstract- Consumers' demand for healthy snacks necessitates the need to study the impacts of eggs from different birds, oven temperature and oven rack speed on the physicochemical properties of cupcakes. A developed rotary oven with varied oven temperature (130°C, 150°C and 170°C), oven rack speed (0, 10 rpm and 20 rpm) and egg-type (Exotic chicken eggs, Turkey eggs and Local fowl eggs) were interacted using Face Centred Composite Design of Response Surface Methodology (FCCD-RSM). The physicochemical properties (baking time, product mass, product height and proximate composition) of the cupcakes produced were determined using standard procedures. The physicochemical properties were modelled using polynomial regression models and accuracy were determined using coefficient of determination (R^2). The optimizer of FCCD-RSM was used to optimize protein content of the cupcakes. The baking time ranged from 28.50 min to 52.50 min, product height (3.82 to 4.20 mm) and product mass (36 to 36.67 g). The moisture content, crude protein, crude fat, crude fibre, ash and carbohydrate content of the cupcakes ranges from 16.92 to 18.09%, 7.69 to 12.67%, 1.49% to 1.87%, 1.41% to 1.66%, 2.01% to 4.09% and 62.77 to 69.28%, respectively. The regression models were significant for product height, product mass, moisture content and crude protein content with R^2 ranging from 0.81 - 0.95. Optimum protein content (12.77%) was obtained in cupcakes produced with Turkey egg at 170ºC oven temperature and 10 rpm oven rack speed. This study provided useful information about some underutilized birds eggs that can be explored to produce healthier cupcakes.

Keywords- Birds Eggs, Cupcakes, Optimization, Oven temperature, Physicochemical properties

1 INTRODUCTION

Baking is one of the oldest and most popular techniques used in food processing industries which make use of prolonged dry heat and it involves complex simultaneous heat and mass transfer process (Sanusi et al., 2020). Nowadays, due to consumers' interest in nutritional characteristics of food products, requests for functional and health-giving foods have increased and the food industry has focused on redesigning of traditional foods to optimize nutritional value along with preserving or improving the taste of the product (Fahimeh et al., 2021). Bakery goods are one of the most extensively consumed foods on the planet.

Cake is one of these items that consumers prefer because of its strong sensory features; nevertheless, due to its high sugar and fat content, long-term use of this food leads to obesity and consequent health concerns; hence, experts advocate limiting cake consumption in diets. As a result, a healthier product can be offered by enriching and boosting the nutritional content of cake. The oven type, ingredients and preparation process in baking play an important role in determining the quality of the finished baked product. The advent of the rotary oven has received considerable attention in terms of efficiency, flexibility and durability over the last decade (Sanusi et al., 2020).

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The use of rotary oven has gained wide usage in supermarkets, pastry shops and bakeries. Cupcakes are a type of sweet cake that is high in calorie and is appreciated by consumers of all age groups due to their unique taste and texture. The growth in the consumption of baked goods remains positive due to the growing market in Africa and the positive growth rate in the cakes and pastries market. The demand for cake is driven by good taste, soft texture and affordability. The quality of a cake is highly influenced by the quality and balance of ingredients. The primary ingredients for cake are; wheat flour, sugar, fat, egg and leavening agents (Richardson et al., 2018). Eggs are highly nutritious foods and they provide the most complete protein of any food, together with fats, minerals and vitamins (Onyenweaku *et al.*, 2018).

The modern Agricultural and food systems have played a significant role in reducing the diversity of eggs to mostly the exotic chicken egg (*Gallus domesticus*) in the baking industry. The utilization of different varieties/breeds of egg could make a significant impact on the nutrition and health of baked products. However, this has not been the case because there is limited information on the use of local fowl egg (*Gallus gallus*) and Turkey egg (*Meleagris gallopavo*) in the production of cupcakes. Literature is sparse on the evaluation of the influence of egg-type, oven rack speed and oven temperature on cupcakes' physicochemical properties. The present study investigated and models the influence of egg-type, rotary oven temperature and oven rack speed on: (i) the product mass and product height of cupcakes (ii) the proximate composition of cupcakes and (iii) optimization of protein content of cupcakes.

2 Materials and Methods

2.1 Materials

Figure 1 shows the exotic Chicken egg (*Gallus domesticus*), Turkey egg (*Meleagris gallopavo*) and local fowl egg (*Gallus gallus*) of different birds that was used for this study. The eggs were purchased at Alao Farms, Ilorin, Nigeria for proper identification. The wheat flour, milk powder (Dano skimmed milk), baking powdered, vegetable oil, sugar, sodium propionate and vanilla flavour were obtained in a grocery store in Ilorin, Nigeria.

Fig. 1: (1) The exotic Chicken egg (*Gallus domesticus*), (2) Turkey egg (*Meleagris gallopavo*) and (3) local fowl egg (*Gallus gallus*).

2.2 Experimental Design

The application of Faced Central Composite Design of Response Surface Methodology (FCCD-RSM) was used to evaluate the influence of egg-type (1,2,3), oven temperature (130°C, 150°C and 170°C) and oven rack speed (0 rpm, 10 rpm and 20 rpm) on the physicochemical properties of cupcakes as shown in Table 1. The three factors and three levels were interacted using $2^k + 2k + 2k$, where k is the factors (3) to give a total of twenty experimental runs. The RSM-FCCD was executed using Design expert version 13 software and the experimental data were analysed using Analysis of variance (ANOVA) to find the interactions between the process factors (egg-type, oven temperature and oven rack speed) and responses (baking time, product mass, product height and proximate composition) using p-values at 95% confidence level and Fischer- value (F-value).

Table 1. Response Surface Methodology experimental design (Faced Central Composite Design) of independent variables and their levels

Process Factors	Code	Unit	Low (-1)	Medium 0	High (+1)
Egg-type	A		1	2	3
Rotary oven temperature	B	°C	130	150	170
Oven rack speed	C	rpm	0	10	20

where Egg type= 1 for Exotic chicken Egg (Gallus domesticus), 2 for Turkey Egg (Meleagris gallopavo) and 3 for Local fowl Egg (Gallus gallus)

2.3 Cupcakes Preparation

Cupcake recipe containing 21.22 % of wheat flour, 16.98 % vegetable oil, 10.61 % powdered milk, 21.22 % sugar, 17.68 % whole egg (Exotic chicken egg, Turkey egg and Local fowl egg), 0.74 % vanilla flavour, 0.74 % baking powder, 0.21% preservative (sodium propionate) and 10.61% of water, respectively was used. The egg and milk powder were mixed with water and vanilla flavour and allowed to rest for 10 min for hydration. Afterwards, vegetable oil was added and mixed properly. Meanwhile, wheat flour, white sugar, baking powder and preservative were also added and blended using a planetary mixer until homogeneous batter was formed. Portions of 40 ± 0.1 g batter were filled in paper cups in metallic cupcake pans. Cupcakes were baked in groups of 6 units in a pre-heated developed rotary oven (Figure 2) at temperatures 130°C, 150°C and 170°C and oven rack speeds of 0 rpm (static), 10 rpm and 20 rpm till the cupcake was done and allowed to cool at room temperature. The cooled cupcakes were packed in Low-Density Polyethylene (LDPE) bags and tightly and properly sealed.

Fig. 2: Pictorial view of the developed rotary oven

2.4 Physicochemical Properties

2.4.1 Product Mass

The product mass was determined by weighting raw batter and baked cupcake and expressed as g/100 g of initial sample weight (6 replicates per batch were measured).

2.4.2 Product Height

The height of the cupcakes removed from their paper cups was measured from the base to the highest top using a digital Vernier calliper with 0.01 mm resolution (Model AD-5765-100, China) (6 replicates per batch were measured).

2.4.3. Proximate Composition

The proximate composition of the cupcake samples based on the experimental design was analysed using the AOAC (2000) methods.

2.5 Optimization of Cupcakes' Protein Contents

The second-order polynomial regression model was used to develop predictive model equations for the physicochemical properties of the cupcake. The fitness of the models for the physicochemical properties was determined using coefficient of determination R^2 and R^2_{adj}.The egg-type, oven temperature and oven rack speed were optimized using the desirability approach to maximize the protein content of the cupcakes. The Derringer and Suich methodology was used for the optimization of the protein content and was transformed into a desirability function. For perfect optimization, the desirability value of protein content must be closer to one

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(1). The desirability function was determined using Equation 1 described by Sanusi and Akinoso (2020). The lowest acceptable and highest permissible were represented by Ai and Ci for protein content. The weight assigned to the protein content was represented by s and was chosen to be one. The individual desirability of protein content in optimization is d while yi is the targeted response.

$$d(y_i) = \begin{pmatrix} 0 & if\ y_i \leq A_i \\ \left(\frac{y_i - A_i}{C_i - A_I}\right)^s & if\ A_i \leq y_i \leq C_i \\ 1 & if\ y_i \geq C_1 \end{pmatrix} \quad (1)$$

2.6 Validation of the Optimum Condition

To validate the optimum condition obtained from the optimiser, the optimum condition for egg-type, oven temperature and oven rack speed was experimented in the laboratory to determine its effect on the protein content. The experimental values from the laboratory and predicted values from the FCCD-RSM optimiser were compared. The percentage error (PE) was then determined by the validity of the optimisation as shown in Equation 3 as described by Skara et al. (2013) and Sanusi and Akinoso (2021).

$$PE = \frac{(EV - PV)}{PV} \times 100 \quad (2)$$

Where PE is the percentage error, EV is the experimental value and PV is the predicted value

3 Results and Discussion

3.1 Baking Time

Baking time is the minimum time required for a baked product to attain doneness. It is expected that the recipe for cupcakes must have a perfect baking temperature and time, in order to ensure that baked foods does not get overcooked or not completely baked. Figure 3 shows the effect of oven temperature and egg-type on the baking time of cupcakes. The baking time ranges from 28.50 – 52.50 min. It was observed that as the baking time reduces the oven temperature increases. The differences in the baking time might be due to the temperature profile differences in the heat transfer which accelerates baking rate, therefore reduces the baking time. The result is in agreement with the findings of Sanusi *et al.* (2020) which stated that oven temperature of rotary oven influences the baking time during bread production.

Ramya and Anitha (2020) reported the baking time of 25 to 30 min at a temperature of 180°C for muffin cake which was within the range obtained. Short baking time could aid in minimizing the operational time and also preserve some heat sensitive food components in the baked product. The coefficient of regression of the second-order polynomial model for baking time (y_{time}) showed that oven temperature is the only significant factor that influences the baking time with p-value of 0.001 and F-value of 8.34. From Equation 3, the negative coefficient in oven temperature (x_1) shows that decrease in oven temperature was observed to increase the baking time. The R_2 and R_{2adj} were 0.88 and 0.78, respectively.

$$y_{time} = 79.09 - 2.34x_2 \quad (3)$$

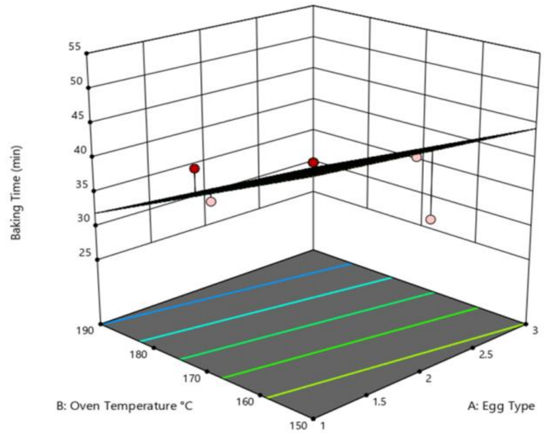

Fig. 3: Effect of oven temperature and egg type on baking time of cupcake

3.2 Product Mass

Product mass is an important characteristic in cake and it is related to the matrix–water interactions (Marchetti *et al.*, 2018). Figure 4 shows the effect of oven rack speed and oven temperature on the product mass. The products mass ranges from 36.00 to 36.67 g. It was observed that the highest product mass occurred when the oven rack speed (0 rpm) was static. Baking at lower temperature and the use of local fowl egg was also observed to favour product mass. During baking process, water is the principal component released at higher temperature that could lead to weight loss.

In addition, local fowl egg could be assumed to have higher water content and oil absorption capabilities with respect to exotic egg and turkey egg. Therefore, the difference in the product mass could be related to the matrix–water interactions at the varying temperatures and the egg-type. The coefficient of regression model for product mass ($y_{product\ mass}$) is shown in Equation 4 and it indicates that oven rack speed is the only significant factor that influences the product mass. The p-value and F-value of the model were 0.007 and 5.47, respectively. The negative coefficient in oven rack speed (x_3) indicated that decrease in oven rack speed, increases the product mass. The R^2 and R^2_{adj} for the model was 0.83 and 0.68, respectively.

$$y_{product\ mass} = 40.56 - 0.055x_3 \quad (4)$$

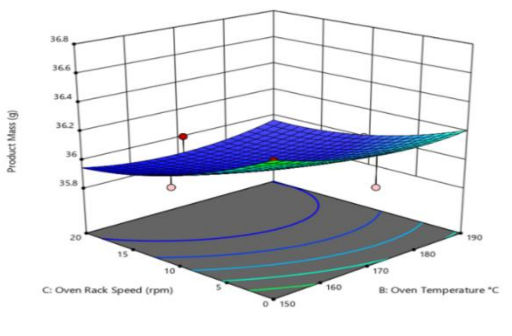

Fig. 4: Effect of oven rack speed and temperature on product mass

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3.3 Product Height

Volume development can be judged during baking process by using height profile method (HadiNezhad and Butler, 2010). Figure 5 shows the effect of egg-type, rotary oven temperature and oven rack speed on the product height. The product height observed ranges from 3.82 to 4.20 mm. It was observed that the height of cupcakes obtained at oven temperature of 170°C were the highest among other samples. The increase in the height of the cupcake at higher temperature (170°C) could be due to higher porosity and lower density at higher temperature.

As reported by Sadiqeh et al. (2018) cupcakes expand with temperature due to its internal vaporization of water and air expansion that is incorporated during the mixing of the batter. When the cupcakes temperatures exceed 85°C, expansion stops and evaporation continues. This evidence shows that significant increase in temperature affect the height of the cupcakes. The difference in the product height of the samples could also be attributed to the oven-spring that occurred at high temperature. Morakinyo et al. (2017) reported that for every 10°C increase in baking temperature, the rate of oven-spring doubles and this could influence the height of the cupcakes. The model for product height ($y_{product\ height}$) showed that p-value was 0.000 while F-value is 11.24. Equation 5 shows that oven temperature and double interaction of oven temperature only had influence on product height. The R_2 and R_{2adj} were 0.91 and 0.82, respectively.

$$y_{product\ height} = 8.51 + 0.065x_2 + 0.0002x_2^2 \quad (5)$$

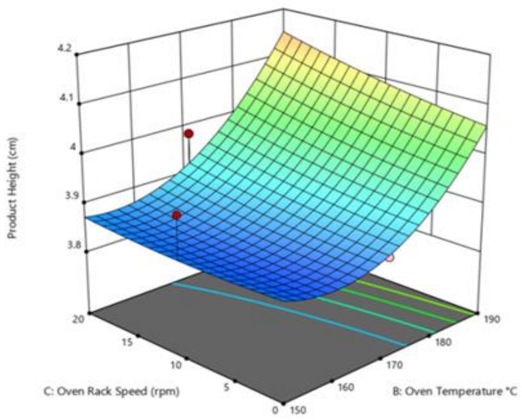

Fig. 5: Effect of oven temperature and rack speed on product height

3.4 Proximate Composition of Cupcakes

The effect of oven temperature, oven rack speed and egg-type on the proximate composition of cupcakes shows that moisture content, crude protein, crude fat, crude fibre, ash and carbohydrate content of the cupcakes ranges from 16.92 to 18.09%, 7.69 to 12.67%, 1.49% to 1.87%,1.41% to 1.66%, 2.01% to 4.09% and 62.77 to 69.28%, respectively. The p-values of the models for crude fat, crude fibre, ash and carbohydrate content were higher than 0.0500 and thus indicate that there are no significant model terms. However, the models for moisture content and crude protein content were significant with p-values and F-values of 0.000 and 0.013, and 22.20 and 4.58, respectively. For moisture content; egg-type, oven rack speed, double interaction of egg-type and oven temperature, and interaction of egg type and oven rack speed, and interaction of oven temperature and oven rack speed are the significant model terms as shown in Equation 6.

For crude protein content, egg-type is the only significant model term as shown in Equation 7. The R^2 and R^2_{adj} for moisture content and protein content were 0.95 and 0.91 and 0.81 and 0.63, respectively. The cupcakes had the highest moisture content when produced at 130°C oven temperature, 10 rpm oven rack speed and turkey egg was used while the lowest moisture content occurred when produced at 170°C oven temperature, 0 rpm oven rack speed and when local fowl egg was used. The difference in the moisture content of the cupcakes could be attributed to the difference in rotary oven temperature which had a significant influence on the moisture content. This may be attributed to the increase in thermal energy due to higher oven temperature, which may have resulted in the vaporization of moisture in cakes. Patel et al. (2019) reported similar findings while studying the effect of baking temperature on the moisture content of biscuit.

The cupcakes had the highest ash content when produced at 130°C oven temperature, 0 rpm oven rack speed and when local fowl egg was used while the lowest ash content occurred when produced at 150°C oven temperature, 20 rpm oven rack speed and when turkey egg was used. The highest ash content observed in the cupcakes could be traced to the local fowl egg used. According to Shahrazad (2020), the ash content of local fowl egg is higher than other poultry eggs. The ash content of the egg could constitute to the mineral content of the cupcakes since heat applications does not affect the ash content of foods. The cupcakes had the highest crude fibre content when produced at 150°C oven temperature, 0 rpm oven rack speed and when turkey egg was used while the lowest crude fibre content occurred when produced at 130°C oven temperature, 10 rpm oven rack speed and when exotic egg was used. Fibre ensures smooth bowel movements and thus helps in easy flushing out of waste products from the body, increase satiety and its effect also enhances some degree of weight management (Edima-Nyah et al., 2019). The cupcakes had the highest crude fat content when produced at 130°C oven temperature and when local fowl egg was used but with different oven rack speed of 0 rpm and 20 rpm while the lowest crude fat content occurred when produced at 130°C oven temperature, 20 rpm oven rack speed and when exotic egg was used. The difference in the crude fat content could be due to the composition of the fat that is present in the types of egg used.

Onyenweaku et al. (2018) observed variation in fat content of five raw eggs of different bird species. This shows that the fortification of cupcakes with exotic chicken egg is a welcome development for reducing the fat content of cupcakes. The cupcakes had the highest crude protein content (12.67%) when produced at 150°C oven temperature, 10 rpm oven rack speed and when local fowl egg was used while the lowest crude protein content occurred when produced at oven temperature 130°C, 20

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rpm oven rack speed and when exotic egg was used. The differences in the protein content of the samples could be attributed to the oven temperature and the type of egg used. It is worthy to note that the highest protein content can be due to high oven temperature which resulted in protein denaturation thus increases the availability and solubility of protein in foods. Vincenzo et al. (2020) reported similar findings.

The low protein content could be as a result of low oven temperature and egg-type used. The cupcakes had the highest amount of carbohydrate content when produced at 130°C oven temperature, 10 rpm oven rack speed and when turkey egg was used while the lowest carbohydrate content occurred when produced at oven temperature 170°C, 10 rpm oven rack speed and when turkey egg was used. This implies that cupcakes containing turkey egg has the highest carbohydrate content. Onyenweaku et al. (2018) reported that turkey egg contains more carbohydrate than local eggs. The overall variation in the proximate composition of the cupcakes produced corroborates with the findings of Oyeyinka et al. (2017) who also reported a noticeable difference in the proximate composition of Chin-chin produced from exotic eggs and indigenous eggs.

$$y_m = 36.48 + 2.48x_1 - 0.267x_2 - 0.114x_3 - 0.397x_1^2 + 0.0009x_2^2 - 0.0016x_2^2 - 0.0056x_1x_2 + 0.0163x_1x_3 + 0.007x_2x_3 \quad (6)$$

$$y_{crude\ protein} = -81.21 + 1.10x_2 \quad (7)$$

3.5 Optimization of Protein Content of Cupcakes

Figures 6 and 7 show numerical optimization plot for protein content. The optimum processing conditions were attained at 170°C oven temperature, 10 rpm oven rack speed and when Turkey egg was used. The desirability value obtained for protein content was 1.00 with optimum protein content of 12.77%. At optimum condition, the was found that the moisture content, ash, crude fat, crude fibre, carbohydrate, baking time, product mass and product height were 17.822, 2.475, 1.767, 1.553, 63.976, 37.482, 36.241 and 3.897, respectively. Sanusi and Akinoso (2020) reported that the closer the desirability to unity the more reliable the proposed optimum condition. From the validation of the optimum condition, it can be adduced that there is a good agreement between the optimum predicted values and experimental values with minimum error deviation of 0.08%, respectively. This validates the reliability of the proposed optimum condition for cupcake with maximum protein content.

4 Conclusion

Cupcakes were produced successfully using a developed rotary oven and were baked using different oven temperature, oven rack speed and birds' egg-types. The Baking time, product mass, product height and proximate composition of the cupcakes produced differs based on the processing conditions used. Baking time, product mass and product height, moisture content and crude protein content have regression models that were significant. Birds egg-type influences the crude protein content of cupcakes. Cupcakes produced with Turkey eggs at 170°C oven temperature and 10 rpm oven rack speed gave the optimum protein content.

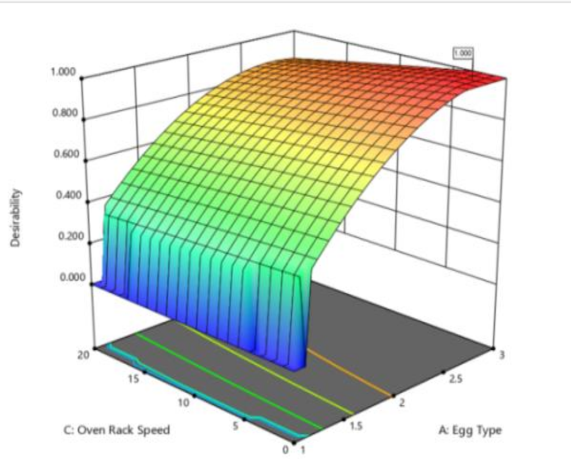

Fig. 6: Numerical optimization of protein content of cupcakes under the influence of oven rack speed and egg type

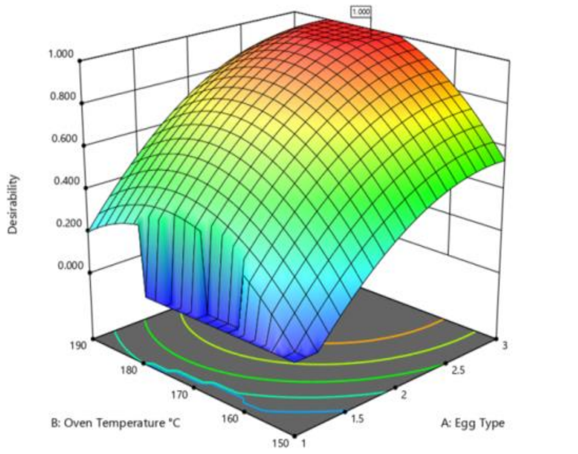

Fig. 7. Numerical optimization of protein content of cupcakes under the influence of oven temperature and egg-type

This information would be useful for food manufacturers when increasing the diversity of eggs that could be explored for product formulation. In addition, when planning to enhance the nutritional composition of cupcakes or other baked products using underutilized egg.

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