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Response surface methodology for the optimization of process parameters during hot-air frying of chicken sausages incorporated with corn bran

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Deep-fat frying is still a very popular food processing method among consumers of different age groups despite the negative health implications of consuming too much fat. However, the application of innovative frying techniques such as hot-air frying is on the rise to produce low-fat fried foods owing to its acceptable characteristics. Response surface methodology has been used to study the effects of hot-air frying temperature (HFT; 170–190 °C) and time (HFt; 15–25 minutes) on some critical quality attributes of chicken sausages incorporated with corn bran. HFT and HFt had significant ($p < 0.05$) effects on the moisture content, colour change, total phenolics, carotenoid contents, and chewiness of samples. Hot-air frying resulted in a significant reduction in the oil content; high retention of total phenolics, carotenoids, and dietary fiber; as well as improvement in chewiness and acceptable quality attributes. The optimum processing conditions obtained were 170 °C and 25 minutes at a desirability index of 63%. Significant ($p < 0.05$) differences were observed in some qualities of the optimized and control samples. The study concluded that the incorporation of corn bran into sausages using the hot-air frying process can improve the quality attributes of chicken sausages and serves as a means of value addition and waste valorisation; the hot-air frying technique could be an alternative method to produce healthier, fibre-rich and acceptable fried chicken sausages in a sustainable manner.

Sustainability spotlight

Conventional frying methods often yield products with high oil contents, which are not compatible with the health needs of consumers. The use of a sustainable processing technique, hot-air frying, and the incorporation of a sustainable nutrient source (corn bran-dietary fibre and antioxidants) into food products have been gaining rapid scientific attention. Corn bran, which is a waste product of the corn milling industry, is mostly used as animal feed, thus leaving a huge quantity unused. In this study, the optimization of the hot-air frying temperature and time required to achieve enhanced nutritional contents of chicken sausages is established. Therefore, the incorporation of corn bran into chicken sausages, coupled with the use of hot-air frying technique, is presented as a promising and sustainable source of dietary fibre, phenolics, and carotenoids with reduced fat content, which is in line with the UN SDG goals 2, 3, 9, 11, and 12.

1 Introduction

Snacks, especially fried ones, are widely consumed and vary in terms of the food type, time of eating, place of consumption, and quantity,[1] and their demand is increasing owing to rapid changes in lifestyle, industrialization, urbanization, *etc.*[2] Despite the desirable qualities conferred on foods during deep-fat frying, a major challenge has been the retention of excessive amounts of oil in the fried product.[3] The consumption of large amounts of such foods has been linked with many health challenges such as obesity, coronary heart diseases, cancer, hypertension, and cardiovascular diseases. Therefore, in an attempt to mitigate these challenges, several techniques are being applied. Regrettably, most of these suggested techniques do not confer on the fried products the exact sensory characteristics peculiar to conventionally fried products nor do they come with a minimal cost. According to Castro-López *et al.*,[4] frying in hot air is a technique in which food products are passed directly through contact with a small quantity of oil sprayed in streams of hot air in the frying chamber of the appliance. During this process, the food is cooked when

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superheated air circulates through it. In the cooking chamber, heat radiates from a heating element that is close to the food, resulting in an efficient and appropriate cooking process.[5] Also, included in the design of the fryer is an exhaust fan below the chamber, which provides airflow from underneath, thereby allowing the heated air to pass through the food. The appliance allows the circulation of very hot air at a high speed, similar to the movement and flow of heat currents in a vat containing boiling oil.[6] This makes the exterior of the food crispy and at the same time cooks the inside.

Poultry meat, especially chicken, is widely known and accepted globally as a major meat source due to some healthy characteristics in comparison to red meat. These include their luxurious nutritional value – digestible proteins, unsaturated lipids – and their reduced fat content.[7] Fried chicken sausage, a value-added product, is gradually becoming a very popular snack in cities of most developing countries due to its attractive golden yellow colour, good flavour, and ease of preparation, among others. Although processed meat products are nutritious, they significantly lack dietary fiber, which has been reported to lower the risk of some diseases like obesity, tumours in the colon, and heart and blood vessel-related diseases, among others.[8] The incorporation of dietary fiber into meat products is on the increase due to its benefits to human health and its numerous technological uses. The use of non-meat ingredients plays a crucial role in determining the overall quality of value-added meat products that are emulsion-based.

Globally, the corn market is expanding, resulting in the large production of corn bran,[9] which is reported to contain the highest amount of phenolics and dietary fiber[10] among the cereal family. Although the use of corn bran in feeding animals is well known, its inclusion in the human diet, especially fried snacks, is also on the increase.[11] It is rich in dietary fiber and the different ways in which its economic value can be enhanced are widely gaining interest industrially.[12] Phytochemicals have been discovered to be the main contributing factor to the total antioxidant activity in corn. According to Mrowicka *et al.*,[13] zeaxanthin and lutein are the two main pigments present in the macular region of the retina, which are members of the xanthophyll family of carotenoids.

Despite these numerous advantages of dietary fiber inclusion in snacks, its presence in food may disrupt the structure and subsequently affect some important quality attributes.[14] Therefore, an increase in the dietary fiber content of individuals without severely affecting the eating culture of the people would be a herculean task. Hence, the enrichment of foods with dietary fiber to develop novel food products might be the best solution. As a functional constituent, dietary fiber can be integrated into meat products so that the health status of these products can be further enhanced.[15–19] Also, as stated by Cava *et al.*[20] and Petracci *et al.*,[21] dietary fiber increases the yield and improves the texture and sensory properties of meat and poultry products with an increased shelf life.

One of the most commonly used methods for optimization in food processing is the Response Surface Methodology (RSM). It is a collection of mathematical and statistical methods effective in industrial processes as well as the improvement and/or development of nutritional products in food materials. Instances of RSM applications in food processes include the optimization of deep fat frying conditions of chicken nuggets,[22] the modelling of microwave processing parameters for coconut water,[23] and the optimization of retort processing parameters for skimmed coconut milk.[24]

Consequently, the processing of broiler chicken into sausage with the incorporation of corn bran *via* hot-air frying is a way to reduce the fat content of the product while enhancing the overall image and quality of the product. It will also promote the utilization of residues obtained during corn processing, thereby reducing cost and waste, while also developing new products with excellent and acceptable sensory characteristics that will respond to customer consciousness of health-promoting products. Herein, research was undertaken to study the effects of novel hot-air frying processing conditions (temperature and time) on some quality characteristics of chicken sausage incorporated with corn bran, using response surface methodology.

2 Materials and methods

2.1 Processing of broiler chickens

Broiler chickens (FUNAAB Alpha) aged 6 to 8 weeks were obtained from DUFARMS, Federal University of Agriculture, Abeokuta, Nigeria. Yellow corn bran, refined wheat flour, and other ingredients were purchased from a local market in Abeokuta. The slaughter and dressing of chickens were done on the farm using standard procedures. The carcasses were thoroughly washed with clean water and manually deboned using a stainless-steel knife under hygienic conditions. Connective tissues and visible fat were trimmed, and samples were utilized on the same day.

2.2 Formulation, preparation, and hot-air frying of chicken sausage

The method of Yadav *et al.*[25] was used in producing sausage with slight modification. Deboned chicken breast was minced in a food processor (Akai Multifunction Food Processor SM001A-668BG Tokyo, Japan) and ground (MG1701 Mixer Grinder, India) into a paste. Sausage seasoning (1.5%), salt (1.5%), ice water (15%), ground chicken breast (82%), and 10% replacement of the lean meat with corn bran or refined wheat flour (deep-fat fried/control) based on a preliminary study were added and then mixed. The emulsion (45 ± 1 g) was thereafter stuffed in artificial casings, precooked in boiling water in a closed container for 20 min, and allowed to cool. The stuffed chicken sausage was then fried in an air-fryer (Tower Low-fat Air fryer, T14001 United Kingdom) at varying temperatures (170–190 °C) and times (15–25 min) as shown in Table 1. Air-fried samples were left to cool at room temperature for 1 h and stored in air-tight containers for further analysis. Deep-fat fried (control) samples were also prepared using vegetable oil (King's Refined Palm Olein) at 180 °C for 8 min and compared with the optimized hot-air fried sausage.

Table 1 Frying conditions for enriched hot-air fried chicken sausages

Experimental runs	Frying temperature (°C)	Frying time (minutes)
1	170.00	15.00
2	180.00	20.00
3	180.00	20.00
4	194.14	20.00
5	170.00	25.00
6	180.00	20.00
7	180.00	20.00
8	190.00	25.00
9	180.00	20.00
10	180.00	27.07
11	180.00	12.93
12	190.00	15.00
13	165.86	20.00

2.3 Determination of the quality characteristics of fried chicken sausage

2.3.1 Determination of moisture, fat, and protein contents. The moisture content of fried chicken sausages incorporated with corn bran was determined using the oven-drying method of AOAC.[26] Five grams of the sample were put into an oven set at 80 °C for 2 h and at 100 °C for 3 h, respectively, until a constant weight was reached. The difference in weight between the initial weight and the constant weight gained represents the moisture content. The fat content was determined using the Soxhlet extraction method while the Kjeldahl method was used to determine the protein content.[26]

2.3.2 Determination of total carotenoid content. The method described by Lucia *et al.*[27] was employed. The air-fried sausage incorporated with corn bran was crushed and 5 g were weighed out. The carotenoid was extracted by continuously adding 15 ml of acetone until a paste was formed. The paste was then placed in a sintered glass funnel, which was fixed to a 150 ml Buchner flask and filtered under vacuum. This process was repeated thrice. The extract acquired was conveyed to a 200 ml sieve funnel containing 20 ml of petroleum ether and the removal of the acetone was done by adding distilled water. The extract was then conveyed through a funnel to a 50 ml volumetric flask that contained 10 g of anhydrous sodium sulphate. The volume was made up using petroleum ether, and the absorbance was read at 450 nm with a UV-Visible spectrophotometer (752 N Searchtech, USA).

2.3.3 Determination of total phenolic content. The total phenolic content was determined using the Folin–Ciocalteau method, as described by Rizvi *et al.*[28] About 0.5 g of the crushed chicken sausage was extracted with 20 ml methanol (80%). The aliquot of the extract (0.2 ml) was mixed with 0.2 ml of the Folin–Ciocalteau phenol reagent (1 : 1) and water (0.6 ml). The test tubes were well shaken. After 5 min, 1 ml of saturated Na_2CO_3 solution (8% w/v in water) was added to the mixture and made up to 3 ml with distilled water. The mixture was kept in the dark for 30 min. After centrifugation, the absorbance of the colour developed from the samples was measured at 765 nm with a UV-Visible spectrophotometer (752 N Searchtech, USA). Using gallic acid monohydrate, a standard curve was prepared and the total phenolic content was estimated and expressed as the gallic acid equivalent in mg/100 g (dry basis) of extract.

2.3.4 Determination of the total dietary fiber (TDF) content. The TDF of the hot-air fried chicken sausages was determined using the enzymatic-gravimetric method as modified by Odunlami *et al.*[11] The samples were dried and de-oiled using petroleum ether. Fat-free samples were initially gelatinized with termamyl (heat stable α-amylase) and thereafter digested enzymatically with amyloglucosidase and protease to eliminate starch and protein, respectively. Ethyl alcohol was added to precipitate the soluble dietary fiber. The resultant residue was filtered using a fritted crucible and washed with 78% ethanol, 95% ethanol, and acetone. The residue was thereafter dried and weighed. The residue was divided into two equal portions, with a portion analysed for total protein content using the Kjeldahl method, while the other half was analysed for ash in a muffle furnace. The total dietary fiber assay kit was supplied by SIGMA, Missouri, USA.

$$\text{Total dietary fiber} = \text{Weight of residue} - (\text{Weight of protein} + \text{Weight of ash}) \quad (1)$$

2.3.5 Colour analyses. The colour intensity of the raw and hot-air fried chicken sausages was determined according to the method described by Faloye *et al.*[22] using a Konica Minolta Colour Measuring System (Chroma meter CR-410, Minolta Ltd, Japan). The colour difference (ΔE^*) between the raw (L_0^*, a_0^*, and b_0^*) and the fried samples (L^*, a^*, and b^*) was obtained.

$$\Delta E = \sqrt{\left[\left(L_0^* - L^*\right)^2 + \left(a_0^* - a^*\right)^2 + \left(b_0^* - b^*\right)^2\right]^2} \quad (2)$$

2.3.6 Textural profile analysis (TPA). The textural properties of the hot-air fried chicken sausage were determined using a universal testing machine (Model: M500-100AT Capacity: 100 kN, Stable Micro Systems Ltd, Godalming, Surrey, UK) as described by Faloye *et al.*[22] The textural features of fried chicken sausages were determined by compressing them with a 75 mm diameter probe. The samples were compressed twice to 50% of the sample height at a crosshead speed of 50 mm min^{-1} and the parameter determined was chewiness, which is a product of hardness, springiness, and cohesiveness.

2.3.7 Sensory assessment: overall acceptability. Thirty panellists (made up of both graduate and undergraduate students, ages ranging from 18 to 40 years, 12 males and 18 females) were used to evaluate their preference for each of the chicken sausage samples based on overall acceptance, taking the guidelines of the standard norm into account.[29] The panellists constituted persons normally familiar with the quality of chicken sausage as they are regular consumers of this product. Prior to performing the examination, the evaluators were informed and approved to assess the fried sausage as an ethical operation and were informed of the nature of the fried sample being evaluated and then invited to evaluate the overall acceptance. A 9-point hedonic scale for food preference (1 = dislike extremely and 9 = like extremely) as described by Alugwu *et al.*[30]

was used. The sensory assessment was immediately performed after the frying process, and the outputs were recorded as averages with standard deviations.

2.3.8 Experimental design, optimization procedure, and data analysis. The central composite design of the Response Surface Methodology (Design Expert v 11.0. version, Stat-Ease Inc., Minneapolis, MN, USA) was used to investigate the effects of the processing conditions (hot-air frying temperature and frying time; Table 1) on the quality characteristics of the sausages. The experimental conditions of hot-air frying temperature (170–190 °C) and frying time (15–25 min) with five centre points were as shown in Table 1. A numerical optimization technique, which seeks a point that maximizes the desirability function was employed for the simultaneous optimization of the multiple responses. Data obtained were analysed and quadratic models were used to model the responses:

$$Y = a_0 + a_1X_1 + a_2X_2 + a_{11}{X_1}^2 + a_{22}{X_2}^2 + a_{12}X_1X_2 \quad (3)$$

where Y is a predicted dependent variable, X_1 and X_2 are the hot-air frying conditions (temperature and time, respectively), and a_0, a_1-a_2, a_{11}-a_{22}, and a_{12} are equation regression coefficients for the intercept, linear, quadratic, and interaction parameters. Sensory experimental data were subjected to the Analysis of Variance (ANOVA) test, means were separated, and significant differences at the 5% level were determined using Duncan's Multiple Range Test of SPSS version 21.0.

2.3.9 Descriptive analysis of chicken sausage. A ten-member panel (made up of graduate students, ages ranging from 25 to 40 years, 3 males and 7 females) with experiences in sensory analyses of various food products was asked to describe the hot-air and deep-fat fried chicken sausages. Prior to the analyses, the panellists were trained and relevant information related to the formulated chicken sausage was given to them. The panellists assessed the fried sausages and terms generated freely to describe the characteristics that were recorded. Once finalized, definitions for each characteristic were established. The samples were then evaluated using a 15 point scale for the intensity of attributes generated, which included crust colour (0 = light brown, 15 = dark brown), surface texture (0 = very rough, 15 = very smooth), chewiness (0 = less chewy, 15 = very chewy), mouth feel (0 = coarse, 15 = fine), taste (0 = not salty, very salty), juiciness (0 = dry, 15 = juicy) and aroma (0 = pungent, 15 = pleasant). The training and evaluation were done in two sessions to prevent carry-over effects.[31] In between the samples, water was used for palate cleansing.[11]

2.3.10 Comparison of the optimized hot-air fried sausage with deep-fat fried sausage. The optimized hot-air fried sausage was compared with deep-fat fried sausage with respect to moisture, fat, protein, total dietary fiber, total phenolic, total carotenoids, total dietary fiber, chewiness, and descriptive sensory analysis. To obtain deep-fat fried chicken sausage, a deep-fat frying process was conducted using a kitchen deep-fat fryer. Prior to submerging the samples into cooking oil, the heating temperature (180 °C for 8 min) of oil was ensured. After frying, paper towels were used to remove the excess surface oil.

3 Results and discussion

3.1 Chemical properties of yellow corn bran

The mean values for the moisture, fat, protein, and carbohydrate contents, as well as the calorific value of the yellow corn bran, were 6.22%, 5.05%, 8.30%, 76.86%, and 1662.61 kJ/100 g, respectively. The total phenolics, carotenoids, and dietary fiber contents were 107.16 mg/100 g, 4.05 μg g^{-1}, and 50.48%, respectively. These values were low as compared to the findings of Smuda *et al.*,[32] which could be a result of the differences in the corn varieties and growing conditions.

3.2 Moisture, fat, and protein contents of fried chicken sausage

The moisture content of fried foods is a vital quality attribute that determines not only the textural attributes of the food product but also its microbial stability and shelf life.[33] The mean value of moisture content of the hot-air fried chicken sausage incorporated with corn bran at different experimental runs ranged from 49.23–61.33% as presented in Table 2. These chicken sausages fried at increased temperatures and extended time had significantly ($p < 0.05$) lower moisture content when compared with samples fried at lower temperatures and shorter times (Fig. 1a). In the hot-air frying process, which involves the heating of food materials in a closed system with the application of heat transfer by convection, hot air is rapidly blown over the food material causing the movement of water molecules out of the food material. This result is in agreement with those reported by Abd Rahman *et al.*[34] and Yu *et al.*[35] during the hot-air frying of snacks and surimi, respectively. The reduction in moisture could be associated with the loss of the unbound water in the inner part and the surface of the food material.

Andres *et al.*[5] reported that hot-air frying is a technology that allows a 90% decrease in the fat content of fried foods. The demand for fried products with lower fat content has increased as a result of the increasing health consciousness of consumers. The minimum and maximum values for fat content were 3.05 and 7.75%, respectively. A reduction in the fat content of the sausages was observed as the hot-air frying time increased, while it increased as the frying temperature increased (Fig. 1b). Also, the fat content of the chicken sausages incorporated with corn bran was reduced with an increase in the hot-air frying time and increased as the frying temperature increased. The decrease could be a result of the drainage of fat from the chicken sausage samples during the frying process over an extended period. As water was removed from the food sample, neither oil nor other liquid replaced the lost water from the pores due to capillary pressure.[34] However, the increase in fat content as temperature increased was in agreement with the report by Joshy *et al.*[6] for an air-fried fish snack, who adduced similar reasons for the increase.

Table 2 presents the mean values of the protein content, which ranged from 12.2–17.45%. The significant ($p < 0.05$) decrease in protein content with increasing levels of hot-air frying temperature and time (Fig. 1c) can be attributed to heat treatment during the air-frying process. This destroys some

Table 2 Mean values of some quality attributes of hot-air fried chicken sausages enriched with corn bran at different experimental runs[a]

ER	MC	FC	PC	OAC	TPC	TCC	TDF	OA	ΔE	Chewiness (nm)
1	61.33 ± 0.37	5.55 ± 0.04	16.34 ± 0.41	144.00 ± 1.44	55.04 ± 0.40	3.65 ± 0.37	25.55 ± 2.81	6.52 ± 1.29	6.35 ± 0.11	25.10 ± 1.13
2	57.64 ± 1.87	5.26 ± 0.04	13.07 ± 1.32	130.99 ± 0.16	61.32 ± 0.41	4.58 ± 0.10	25.64 ± 1.12[f]	6.67 ± 1.50	9.89 ± 0.21	31.35 ± 4.28
3	57.89 ± 0.34	5.17 ± 0.03	13.91 ± 0.06	133.41 ± 1.33	70.67 ± 1.40	4.05 ± 0.13	28.43 ± 1.13	6.62 ± 1.20	9.60 ± 0.98	31.70 ± 1.43
4	49.52 ± 0.69	4.00 ± 0.03	12.20 ± 0.11	136.54 ± 0.06	74.56 ± 0.49	2.00 ± 0.18	16.86 ± 1.03	6.86 ± 1.74	14.08 ± 0.01	34.39 ± 0.77
5	57.92 ± 0.18	4.41 ± 0.00	15.72 ± 0.03	145.86 ± 1.27	69.68 ± 0.08	5.15 ± 0.10	30.91 ± 2.79	6.19 ± 1.44	11.73 ± 0.06	31.74 ± 0.19
6	59.06 ± 0.10	6.06 ± 0.18	13.76 ± 0.14	130.06 ± 1.26	61.22 ± 0.61	4.90 ± 0.04	27.36 ± 0.21	6.86 ± 0.96	10.23 ± 0.03	31.18 ± 0.02
7	56.59 ± 0.78	6.46 ± 0.17	14.03 ± 0.24	132.17 ± 0.42	74.09 ± 0.17	4.55 ± 0.10	26.69 ± 0.31	6.71 ± 1.06	8.86 ± 0.13	30.71 ± 0.41
8	49.23 ± 0.48	6.31 ± 0.04	13.84 ± 0.04	131.03 ± 1.19	72.40 ± 1.06	3.15 ± 0.91	19.88 ± 0.75	6.81 ± 1.27	13.10 ± 0.16	34.40 ± 2.56
9	58.92 ± 2.77	5.74 ± 0.08	13.02 ± 0.01	134.69 ± 0.62	68.41 ± 0.30	4.65 ± 0.07	22.80 ± 0.10	6.71 ± 1.56	10.28 ± 0.17	32.95 ± 1.46
10	55.30 ± 0.69	3.05 ± 0.11	12.78 ± 0.03	137.04 ± 0.65	69.48 ± 0.61	4.10 ± 0.14	26.13 ± 0.37	7.10 ± 1.41	12.01 ± 0.47	33.38 ± 1.71
11	58.74 ± 2.11	5.27 ± 0.11	14.75 ± 0.06	153.02 ± 2.01	69.48 ± 0.31	4.25 ± 0.28	23.83 ± 1.54	5.95 ± 1.47	7.79 ± 0.54	26.50 ± 1.86
12	52.41 ± 0.04	7.75 ± 0.04	13.02 ± 0.14	141.97 ± 1.15	71.14 ± 2.83	4.55 ± 0.17	21.66 ± 0.04	6.52 ± 1.94	8.40 ± 0.42	34.10 ± 1.20
13	60.09 ± 0.47	3.98 ± 0.11	17.45 ± 0.06	127.36 ± 0.30	53.87 ± 0.41	2.15 ± 0.24	27.96 ± 0.23	7.29 ± 1.45	10.96 ± 0.14	22.16 ± 1.04

[a] ± SD = standard deviation, values are means of duplicate; values with different superscripts within the same column are significantly ($p < 0.05$) different from each other, where ER = experimental runs, as shown in Table 2, MC = moisture content (%), FC = fat content (%), PC = protein content (%), OAC = oil absorption capacity (%), TPC = total phenolics content (mg/100 g), TCC = total carotenoid (μg g^{-1}), TDF = total dietary fibre (%), OA = overall acceptability, ΔE = colour change.

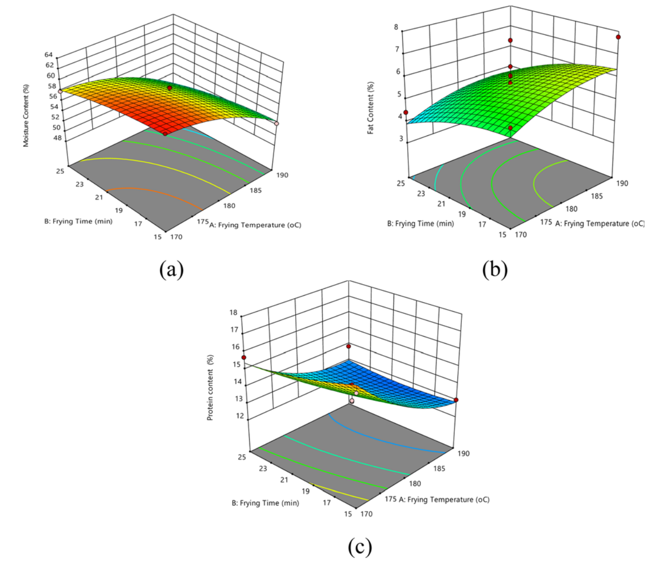

Fig. 1 Response surface plots for moisture (a), fat (b), and protein (c) contents of hot-air fried chicken sausages.

amino acids, resulting in changes in the quality of the protein composition in food.[36] A similar observation was made by Joshy *et al.*[6] for air-fried fish snacks; the proteins might have gone through aggregation by increasing unfolded or partially unfolded monomer states.[37] Zhang *et al.*[38] and Sobowale *et al.*[39] also reported that the reduction in the protein content may be due to an increase in the frying time and temperature. These authors attributed this loss of protein content during frying to the formation of new chemicals such as heterocyclic amines and polycyclic aromatic hydrocarbons.

3.3 Total phenolic, carotenoid, and dietary fiber contents of fried chicken sausage

Phytochemicals are bioactive non-nutrient chemical components in plants such as whole grains, vegetables, and fruits that contribute to the reduction of the risk of chronic diseases.[40] From Table 2, the mean values of the total phenolic content of hot-air fried chicken sausage incorporated with corn bran ranged from 53.87 to 74.56 mg/100 g. The total phenolic content of chicken sausage in this study (as shown in Fig. 2a), increased with the increase in the frying temperature ($p < 0.05$) and time ($p > 0.05$). Ferulic acid and flavonoids contribute to the total phenolic content in corn and are related directly to the total antioxidant activity, and 87% of them are in a bound state. This increase in the total phenolic content could be a result of the release of the bound form of the phytochemicals in the corn bran during the frying process.[41] The report of Fang *et al.*[42] showed a similar result where the total phenolic content of cooked sausages was higher than that of fresh sausages. The

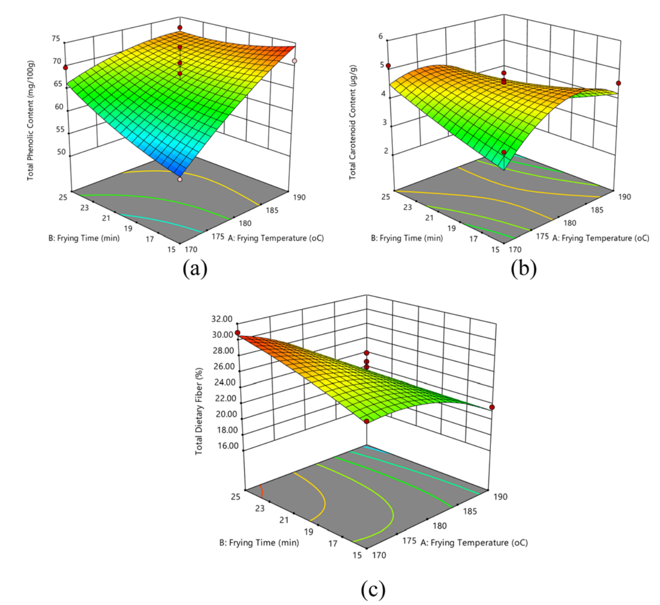

Fig. 2 Response surface plots for total phenolic (a), carotenoid (b), and dietary fibre (c) contents of hot-air fried chicken sausages.

increase was attributed to the probability that mild cooking conditions could have led to the partial release of the phenolic compounds in the sugarcane fiber. Moreover, many studies have reported an increase in the total phenolic content upon heating.[43,44]

In this study, the mean value of the total carotenoid content of the chicken sausage ranged from 2.0–5.1 μg g^{-1} (Table 2). The total carotenoid content was observed to initially increase with increasing the hot-air frying temperature and time and thereafter, decreased at higher hot-air frying temperatures and extended frying times (Fig. 2b). Yellow corn contains 40% of zeaxanthin and 50% of lutein which are xanthophylls of the carotenoid family.[45] Processing techniques (like thermal treatment, and mechanical homogenization) may have caused the increase in the bioavailability of carotenoid.[45,46] However, carotenoids are lipid-soluble compounds, thus their absorption only requires 3–5 grams of fat/oils to be available in the food material.[45] Baek *et al.*[47] reported that lutein and zeaxanthin are heat labile, which could have contributed to the reduction of the total carotenoid content at higher temperatures and with extended time.[48] The increase in carotenoids may be due to the leaching of soluble solids leading to the increased concentration of the carotenoids per unit weight of food. Similarly, the increment in the carotenoid content was associated with the effect of heat causing softening of the plant tissue, rupturing of the cell membrane, and denaturation of the carotene–protein complexes, resulting in the release of more carotenoids from the complexes.[49]

The majority of corn bran is dietary fiber which is nearly completely insoluble in water.[12] From Table 2, the mean value of total dietary fiber in this study varied from 16.86–30.91%. As shown in Fig. 2c, the total dietary fiber content initially increased with an increase in the hot-air frying time ($p > 0.05$) and temperature ($p < 0.05$). This was similar to the report by Dhingra *et al.*[50] on wheat bran that thermal treatments resulted in an increase in the total dietary fiber, which is not because of the synthesis of new fiber but is due to the fiber–protein complexes formed, which are heat-resistant and therefore measured as dietary fiber. However, the dietary fiber was later discovered to decrease at higher frying temperatures above 180 °C. This could be related to the degradation of hemicellulose and cellulose partially into simple carbohydrates as a result of thermal treatments. Also, heat treatment may cause pectic polysaccharides to disintegrate since the eliminative degradation of these polysaccharide types is promoted.[51]

3.4 Overall acceptability and colour parameters of fried chicken sausage

Overall acceptability determines how the consumer accepts the food product based on the desired attributes. A score equal to 6.0 on a nine-point hedonic scale could be an appropriately acceptable limit.[52] The mean values of overall acceptability in this study ranged from 5.95–7.29% (Table 2). It was apparent that the overall acceptability rating insignificantly ($p > 0.05$) increased with the increase in the hot-air frying temperature and frying time (Fig. 3a). This was done to obtain an optimization condition that includes sensory tests by a panel.

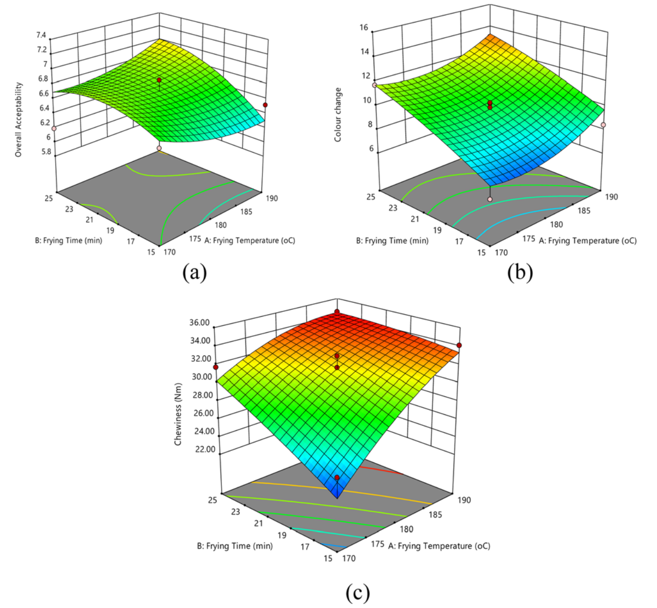

Fig. 3 Response surface plots for the overall acceptability (a), colour change (b), and chewiness (c) of hot-air fried chicken sausages.

Aesthetically, colour is one major important quality parameter that has a great influence on whether a fried food will be accepted by consumers or not. The fried product's colour is attributed to the loss of moisture, movement of oil, and the Maillard reaction, which is based on the quantity of reducing sugars and amino acids of proteins at the food surface, the frying time, and temperature.[53] The mean value of colour change in this study ranged from 6.35–14.08 as presented in Table 2. As shown in Fig. 3b, the colour change was observed to increase with the increase in the hot-air frying time ($p < 0.05$) and temperature ($p < 0.05$). This result is consistent with the observation of Fikry *et al.*[52] The increase in the colour change reflects the darkening of the crust, and this could be attributed to the non-enzymatic browning and pyrolysis reactions that took place during frying. Heat and mass transfers during frying cause physicochemical transformations that affect the colour of the fried products.[34]

3.5 Chewiness of fried chicken sausage

For any processed food, texture plays a vital role in its perception and acceptability. The differences that occur in the textural attributes of hot-air fried chicken sausage incorporated with corn bran could be associated with the transformations in the chemical and physical properties that take place during the frying process. Chewiness was observed to increase with increasing frying conditions (Fig. 3c). Chewiness is a secondary textural parameter that exhibits similar variation profiles to the hardness parameter. Increases in frying temperature increase the heat transfer rate and subsequently surface hardening (crust formation). Also, a loss of moisture increases the mechanical energy and viscosity, leading to the formation of a compact structure of the fried food.[54] Hardness has been discovered to affect the chewiness of foods, where chewiness increases with an increase in hardness.[55] In comminuted meat products, textural attributes are associated with the functionality of muscle proteins, especially their emulsification and gel-forming abilities, which are related to the inclusion of non-meat ingredients. The starch and protein content of non-meat ingredients are key factors in the hardness of the samples and this directly influences the chewiness of the food samples as an increased force will be needed to penetrate the food.[56]

3.6 Regression modelling of hot-air frying conditions

The Central Composite Design (CCD) of the RSM was used and quadratic models were fitted for each of the responses, and at the 5% level, the significance of the terms in each polynomial regression was statistically estimated. The p value for each term in the regression equations, the models and the coefficient of determinations (R^2) are shown in Table 3. These values are indications of the significance of the terms to the model for each response. For moisture content, the main and quadratic effect of frying temperature and main effect of frying time were significant at p values of <0.0001, 0.0017, and 0.0037, respectively. R^2, which indicates the validity and accuracy of the regression equation, was 0.9647 with a good significant regression relationship (p value = <0.0001). None of the model terms had a significant ($p > 0.05$) effect on the fat content of the incorporated hot-air fried chicken sausage. The coefficient of determination of the equation was 0.4198 with a p value of 0.4754. The first- and second-order terms of hot-air frying temperature in the regression equation were the only significant terms that affected the protein content of the chicken sausage, with p values of 0.0003 and 0.0206, respectively, while the R^2 of the equation was 0.8928 with a significant p value of 0.0027.

Table 3 shows that the total phenolic content was significantly affected by the hot-air frying temperature (p value of 0.0117), while the total carotenoid content was significantly affected by the interaction of both process variables (p value = 0.0455) and the second-order term of the frying time (p value = 0.0033). The linear and quadratic effects of the hot-air frying temperature had a significant effect on the total dietary fiber contents of the chicken sausage with p values of 0.0004 and 0.0333, respectively. Also, the total phenolic, carotenoid, and dietary fiber contents have R^2 and p values of 0.6901 and 0.0852; 0.7891 and 0.0256; and 0.8870 and 0.0033, respectively. It was observed that the model p values for the total carotenoid and dietary fiber contents were significant ($p < 0.05$).

None of the model terms had significant ($p > 0.05$) effects on the overall acceptability of the hot-air fried chicken sausage incorporated with corn bran. R^2 of the regression equation is 0.4959 with a p value of 0.3373. Accordingly, the model parameters for colour change as shown in Table 3 indicated significant linear terms for the hot-air frying temperature, time, and the quadratic model of the hot-air frying temperature (p value of 0.0280, 0.0008, and 0.0285, respectively). The R^2 and p values of the regression equation for colour change were 0.8738 and 0.0048, respectively, indicating significant model equations. For chewiness (Nm), as shown in Table 3, the linear terms of both the hot-air frying temperature (p value of 0.0004) and time (p value of 0.0081) are significant. The regression model was also significant with a p value of 0.0024 while the R^2 was 0.8972.

3.7 Optimization and validation

Design Expert version 11 was employed to obtain polynomial regression equations to optimize the hot-air frying temperature and time while retaining the high quality of hot-air fried chicken sausage. Fig. 1–3 show the response surface plots for each of the responses, which indicated the properties of the fried chicken sausages as affected by the frying temperature and time. To obtain the optimal conditions for the hot-air frying process of chicken sausage, the variables considered were those seen to have a major effect on the quality of the food during frying. The desired goal for each independent variable (in range) and the responses (moisture and oil contents -minimum; chewiness, colour change, overall acceptability, protein, total dietary fiber, total carotenoid, and total phenolic contents-maximum) were chosen. Hence, a hot-air frying temperature of 170 °C and a hot-air frying time of 25 minutes with a desirability value of 0.63 were obtained.

3.8 Comparison of the characteristics of optimized hot-air and deep-fat (control) fried chicken sausage

To compare the optimized hot-air fried chicken sausage with the control, the optimized processing conditions obtained were used (hot-air frying temperature and hot-air frying time of 170 °C and 25 minutes, respectively). Table 4 shows the mean values

Table 3 p-values of individual responses, models and R^2 of hot-air fried enriched chicken sausages[a]

Parameters	Constant	A	B	AB	A^2	B^2	Model	R^2
Moisture content (%)	0.0000	< 0.0001*	0.0037*	0.9069	0.0017*	0.1038	<0.0001*	0.9647
Fat content (%)	0.0000	0.2771	0.1466	0.9070	0.4322	0.5351	0.4754	0.4198
Protein content (%)	0.0000	0.0003*	0.2070	0.3098	0.0206	0.4228	0.0027*	0.8928
Total phenolic content (mg/100 g)	0.0000	0.0117*	0.3000	0.2245	0.4834	0.5410	0.0852	0.6901
Total carotenoid content (μg g^{-1})	0.0000	0.4626	0.9489	0.0455*	0.0033*	0.7834	0.0256*	0.7891
Total dietary fibre (%)	0.0000	0.0004*	0.1945	0.0718	0.0333*	0.5490	0.0033*	0.8870
Overall acceptability	0.0000	0.9899	0.1273	0.3709	0.4089	0.2164	0.3373	0.4959
Colour change	0.0000	0.0280*	0.0008*	0.7462	0.0285*	0.5074	0.0048*	0.8738
Chewiness (nm)	0.0000	0.0004*	0.0081*	0.0899	0.1105	0.6535	0.0024*	0.8972

[a] A = hot-air frying temperature, B = hot-air frying time, *significance at ($p < 0.05$).

Table 4 Mean values and standard deviation of the optimized and control hot-air fried chicken sausage samples[a]

Quality attributes	Optimized sample	Control sample	t-Stat	$P(T \leq t)$ 2-tail
Moisture content (%)	57.56 ± 0.24	61.01 ± 0.06	−15.923	0.040*
Fat content (%)	4.36 ± 0.04	10.35 ± 0.12	−51.106	0.012*
Protein content (%)	13.76 ± 0.03	15.39 ± 0.18	−10.930	0.058
Total phenolics content (mg/100 g)	67.57 ± 0.21	10.83 ± 0.04	466.045	0.001*
Total carotenoid content (μg g^{-1})	4.91 ± 0.21	2.16 ± 0.01	17.069	0.037*
Total dietary fibre (%)	32.05 ± 0.24	2.56 ± 0.07	251.510	0.003*
Colour change	9.35 ± 0.06	8.51 ± 0.37	2.738	0.223
Chewiness (nm)	28.98 ± 0.23	28.17 ± 0.41	1.784	0.325

[a] ±SD = standard deviation, values are means of duplicate, *significance at ($p < 0.05$).

± SD of the determined parameters. Significant ($p < 0.05$) differences were observed in the moisture, fat, total dietary fiber, total phenolic, and total carotenoids of the samples. The incorporation of fillers into meat products such as sausages has some advantages such as increasing the product yield and quality, enhancing the formulation properties, improving the health and nutritional benefits, and reducing cost.[56,57] Positive results have been reported in the incorporation of different fillers such as tapioca starch and flour from wheat, cassava, rice, coconut, and high-quality cassava[55,58–60] in sausages. A comparison of the optimized sample with the control revealed that the control sample had higher mean values for moisture, fat, and protein contents. Dietary fiber is known for its ability to bind water. Yadav *et al.*[25] found that the lower moisture content of the optimized sausages can be attributed to the quantitative substitution of the chicken meat with corn bran, which contains a very small amount of moisture when compared with meat. Similar observations were also reported by Zaini *et al.*[61] and Ayandipe *et al.*[56] According to Elleuch *et al.*,[62] the tendency of dietary fiber to bind with water is dependent on its origin, physicochemical, and structural characteristics. The meat product in which the dried form of dietary fiber has been incorporated has been discovered to undergo a reduction in moisture content. The fat content in the control samples was significantly ($p < 0.05$) higher when compared with that of the optimized sample. This was expected as the control samples were completely submerged in oil during deep-fat frying as compared with the optimized hot-air fried samples with drops of oil. This result is in agreement with the observations of Joshy *et al.*[6] and Fikry *et al.*[52] It was suggested that several factors might influence the complication of deep-fat frying mechanisms, like the moisture content of food products, oil characteristics, frying time, frying temperature, chemical reactions, structural characteristics of the product, and the drainage time.[63] These results indicated that the hot-air frying technology is a good choice for frying the sausage product, especially for consumers who are health-oriented. Protein is often an indicator of the nutritional quality of the material.[64] The control sausage sample had the highest protein content, due to its relatively greater amount of protein in the wheat flour. There was no significant ($p > 0.05$) difference between the protein content values of both chicken sausage samples; this is unlike the report by Ayandipe *et al.*,[56] where significant ($p < 0.05$) differences were observed for chicken sausages with coconut, wheat, and high-quality cassava flour. The corn bran, which is rich in fiber, total phenolic, and total carotenoid content,[10,12] may have accounted for higher levels of dietary fiber, total phenolic, and total carotenoid content in the optimized hot-air fried sample. The analysis of the colour of the chicken sausage reflects the changes in colour upon frying. The optimized sausage sample had a higher value for colour changes than the control sample. This may be a result of the influence of fibers that contain pigments such as carotenoids on the colour of the meat products. Texture profile analysis is suitable for the determination of textural parameters of meat products. The degree of myofibrillar proteins obtained, stromal protein present, and the type and amount of non-meat ingredients are factors influencing the textural parameters of comminuted meat products.[62] In meat products that have undergone grinding, the textural attributes are interlinked with muscle protein functionality, especially their emulsification and gel-forming abilities, which are associated with the inclusion of non-meat ingredients.[61] The higher values of the optimized chicken sausage could be a result of the ability of corn bran present in the food material to bind water. Different authors have reported various observations on the textural attributes of meat products. The optimized sample had higher values for chewiness as compared to the control sample. This is expected for food samples that are fiber-rich as they require higher energy for chewing as compared with others.[65]

3.9 Descriptive sensory evaluation of optimized chicken sausage and the control

Based on the attributes assigned for the chicken sausage by the descriptive sensory panellists with its intensity determined using a 15 cm rule, the acceptability of the control (deep-fat fried chicken-wheat flour sausage) and the optimized (hot-air fried chicken-corn bran) sausage was determined. The mean values of the sensory rating ranged from 4.20 to 10.00 and 5.50 to 12.70 for the optimized hot-air fried samples and the control, respectively. The control sausage sample had higher intensity ratings for most of the attributed characteristics except for surface smoothness and mouth feel, as shown in Fig. 4.

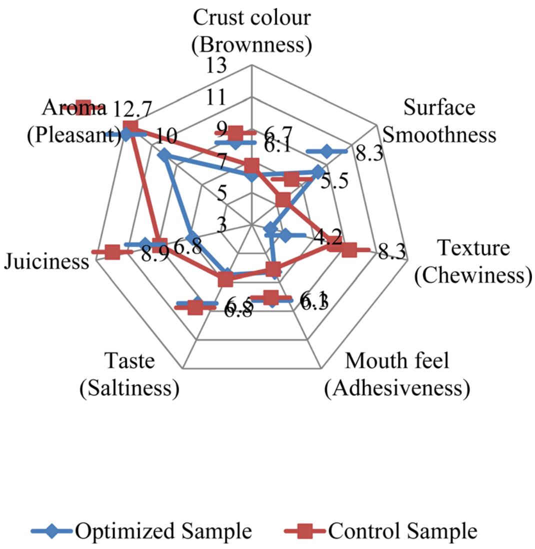

Fig. 4 Spider chart for the descriptive sensory analysis of hot-air fried optimized and control chicken sausage samples.

4 Conclusion

Novel hot-air frying processing conditions (frying time and frying temperature) significantly affect some quality characteristics of chicken sausage incorporated with corn bran. With a desirability value of 63%, the optimum conditions were 170 °C and 25 min for frying temperature and time, respectively. When compared with the control sample, the optimized fried chicken sausage significantly differed in moisture, fat, total phenolic, total carotenoid, and total dietary fiber parameters. About 43% fat reduction was observed in the optimized sausage as compared to the deep-fat fried sausage. The descriptive sensory assessment of the fried chicken sausage revealed the description of the product by the panellists based on their various ratings. Hence, the development of chicken sausages with the inclusion of corn bran as a means of value addition, and waste valorisation can be achieved using the optimized processing conditions determined to improve product quality and provide health benefits to humans and economic benefits to the food and corn milling industries.

Author contributions

Akinlade, F. A.: written original draft which includes formatting, referencing. Sobukola, O. P.: edited the manuscript, guided in the writing of contents for the manuscript and reviewing. Adebowale, A. A., Bakare, H. A. and Omidiran, A. T.: edited the manuscript.

Conflicts of interest

The authors have no conflicts of interest to declare.

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