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Effect of different starches in batter formulation on oil content and associated quality attributes of fried chicken nuggets

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Abstract

Persistent consumption of heavily fried and breaded foods over an extended period may have the potential to contribute to the development of cardiovascular, cerebrovascular diseases, and elevated blood pressure. The potential of coating using native starches (cassava, sweet potato, and corn) in batter formulation to reduce oil uptake as well as their effects on other quality attributes (moisture, colour and textural properties) were investigated. The chicken nuggets coated with batter from different starches were fried at 170 °C for 5 to 25 min. Scanning electron microscopy (SEM) was used to study changes in microstructural properties of fried chicken nuggets samples at different time intervals. The chicken nuggets coated with batter from sweet potato starch had lower oil (13.09%) and moisture (30.49%) contents compared with those coated with other starches. The SEM revealed that longer frying duration produced chicken nuggets with fewer gas cells and pores and subsequently lower oil content. There are changes in the colour and textural properties of the fried chicken nuggets irrespective of the starches used in batter formulation. Application of starches in batter formulation at different frying time affected some quality attributes of fried chicken nuggets with sweet potato starch having better attributes when compared with others.

Keywords Starches, Wheat flour, Scanning electron microscope, Chicken meat, Frying

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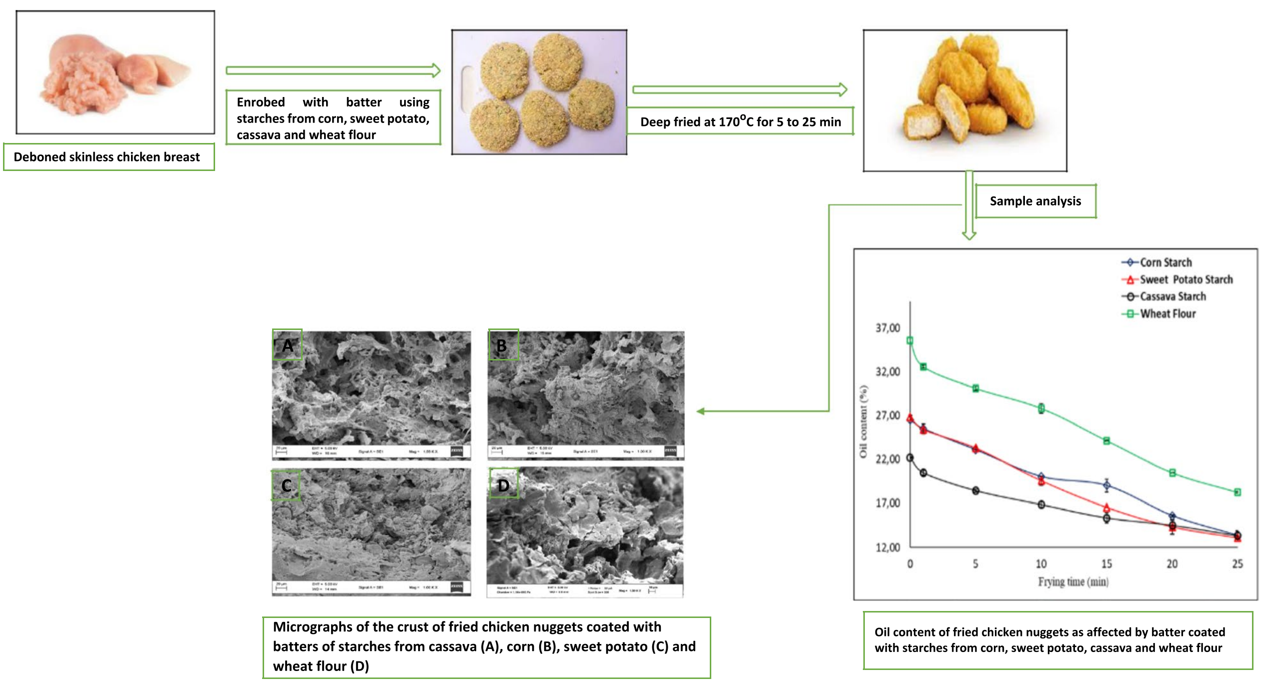
Graphical Abstract



Introduction

Popularly enjoyed food items like chicken nuggets, coated in fried batter, are extensively consumed. Apart from the succulence and softness of the interior, consumers highly value the crunchiness and golden hue of the outer coating. These attributes, hinging on the formulation of the batter used for breading (comprising ingredients like flour or starch, water, seasonings, and protein), are held in high regard. Nevertheless, the outer layer (crust) generated through the process of deep-fat frying harbours notable fat content, comprising as much as one-third of the weight of fried batter-breaded foods, and in certain instances, even escalating to 50%, as documented by Cui et al. (2022). Besides cardiovascular and cerebrovascular conditions, hypertension, and dyslipidemia, continuous consumption of battered and breaded high fatty foods can foster elevated blood pressure and hyperlipidemia, as indicated by studies conducted by Mellon (2003), Zeng et al. (2016), and Ananey-Obiri et al. (2018). As a result, solutions for producing low-fat fried batter-breaded foods with good organoleptic qualities are critical.

The application of batter before frying has piqued researchers' interest in methods for lowering the oil content of fried dishes (modifying the product surface) (Cui et al. 2023; Garcia et al. 2023; Oloruntoba et al. 2022). Batter stands as a fundamental element within coating systems, consisting of blends of flour and water. These mixtures find common application in enveloping food products before submersion in hot oil, enhancing the product's attributes by altering its taste, consistency, size, and mass (Faloye et al., 2021).

Applying a batter and breading coating to samples has been identified as the optimal approach for minimizing oil absorption while preserving the quality attributes. Consequently, there is considerable promise in altering the surface structure to achieve oil reduction in fried foods. These coatings function by creating a moisture-resistant barrier during frying, effectively hindering oil absorption, as evidenced by Wang et al. in (2023). According to Pinkaew and Naivikul (2019), wheat flour stands as the prevailing component in batter formulations, widely accessible across various regions. Starches from different sources which is widely consumed worldwide can be a suitable alternative (Vilpoux & Junior 2023).

Growing attention is being directed towards exploring alternatives like corn, cassava, sweet potato, and various other starches. Additionally, health considerations beyond just reducing oil usage, adopting alternative batters and coatings devoid of wheat can potentially minimize the threat of consuming gluten. Gluten is a prominent allergen present in numerous wheat-based coating components commonly employed in commercial applications (Nanda et al. 2020).

The method of applying a starch-based batter coating to food pieces before deep-fat frying is an extensively employed culinary technique. This process results in the formation of a crispy outer layer on the food items following frying, thereby augmenting the sought-after qualities of texture, visual appeal, and flavour. This technique has been highlighted in studies by Ketjarut and Pongsawatmanit (2015) as well as Pongsawatmanit et al. (2018). Furthermore, this approach preserves the flavours and succulence of the food beneath the crunchy crust, as demonstrated in research by Ketjarut et al. (2010).

The characteristics of food products, including their size, shape, surface attributes, as well as their composition and density, play an important role in affecting the absorption of oil. Analyzing the internal arrangement and surface properties of materials is achievable through the application of scanning electron microscopy (SEM) (Maroof et al. 2023). This technique has proven instrumental in investigating the alterations in structure within numerous fried items, such as beef scraps (Nimitkeatkai et al. 2022), pork chip snacks (Liang et al. 2023), and French fries (Li et al. 2022). The configuration of these food items exhibits diversity based on factors like the constituents of the batter, the food substrate, and the frying conditions (Wang et al. 2022).

Grasping the shifts in oil absorption, texture, and visual attributes throughout the stages of a frying procedure is crucial to attain a final product possessing the desired characteristics. Scanty scientific literature exists regarding the juxtaposition of starches, their operational roles, and impacts on the excellence of coated and deep-fried items like the chicken nuggets investigated within this research. In light of this, the current investigation aims to determine the impact of various starch types in batter composition as well as frying duration on the qualitative characteristics of fried chicken nuggets, utilizing advanced microstructural analysis techniques.

Materials and methods

Freshly harvested TME 419 cassava roots, aged 11 months, were procured from the research farm located at the International Institute of Tropical Agriculture in Ibadan, Nigeria. Sweet potato tubers, freshly harvested, and corn starch were sourced from an open market situated in Abeokuta, Nigeria. Fresh eggs weighing 50–55 g each were acquired from the Directorate of University Farm (DUFARMS) at the Federal University of Agriculture, Abeokuta, Nigeria.

Starch extraction from cassava root and sweet potato tubers

Starch was obtained from freshly harvested cassava roots and sweet potato tubers using the method outlined in the study by Folake et al. (2012). Initially, the cassava roots and sweet potato tubers were freshly harvested and individually prepared. They were peeled and thoroughly washed with clean water before being grated into pulpy substances. These pulps were then passed through muslin cloth to separate the starch. The obtained filtrate was left for 4 h, allowing the starch to settle. The starch was washed four times with distilled water and then dried at a temperature of 50 °C for 24 h. The resulting dried cake was crushed into powders, placed in Ziplock bags, and stored in a cool, dry place for subsequent use.

Processing of broiler chicken

The breed and detailed information of the chicken used for the study was the same as reported by Faloye et al. (2021). The Broilers with an average weight of 2.0 kg, were used for the experiments. Slaughtering and dressing of the chicken were prepared at the slaughterhouse of the DUFARMS, Federal University of Agriculture, Abeokuta, Nigeria. Carcasses were washed thoroughly with clean water, followed by the deboning process, carried out manually in sterile conditions.

Preparation of chicken nugget samples

A similar procedure with a slight modification of Soorgi et al. (2012) was adopted. One hundred gram of de-boned skinless chicken breast, 10 g refined wheat flour (control), 10 g of starch (cassava, corn, and sweet potato) were the main ingredients. The fresh chicken meat was mixed with the ingredients mentioned above. Subsequently, it was processed using a meat grinder (Panasonic, model MK-1500P, Matsushita Electric Industrial Co., Japan) for 30 s. Following that, the chicken nuggets were shaped into rectangular forms, each weighing 25 ± 1 g and measuring 5 cm in length, 3 cm in width, and 1.5 cm in thickness. Each pre-formed chicken nugget was enrobed in *egg albumen*, then batter-coated with starch. The batter contains a solid and water ratio of 3:5 wheat flour, cassava, corn, and sweet potato starches. After draining for 30 s, the battered nuggets samples were breaded with a crumb mix (breading materials; cornflakes and breadcrumbs) and weighed to determine the coating mass before deep-frying.

Deep fat frying operation

The method of Faloye et al. (2021) was used. A kitchen deep fat fryer (model 614 SAISHO, China) was initially filled with about 2.5 L of frying oil (refined deodorized bleached palm olein) and preheated for 1 h until the temperature of the oil reached the frying temperature of 170 °C for each experiment. The frying basket which already had the coated chicken nuggets was immersed in the hot oil and fried for different frying times of 5—25 min. Fried chicken nuggets were blotted with tissue paper immediately after the frying process. They were allowed to cool for further analysis, while sample for microstructure analysis were stored in freezer.

Characterization of fried chicken nuggets samples

Determination of moisture and oil contents of fried chicken nuggets

The average moisture and oil content of fried chicken nuggets was analysed according to AOAC (2000). The chicken nuggets were individually ground into fine particles using a laboratory grinder (LEM grinder, 5 Big Bite Grinder-0.35 HP, West Chester, OH, USA). Subsequently, 5 g of the ground sample were placed into a pre-weighed drying pan within an oven (MX-50 model, A and D Co. Limited, Tokyo, Japan). Using a spatula, the ground chicken nugget samples were uniformly spread across the pan. These samples were then subjected to drying at 105 °C for a duration of 3 h. After the drying process, the chicken nugget samples were allowed to cool before being weighed.

The moisture content of each sample was calculated using the equation:

$$\frac{\text{Weight of sample before drying}(g) - \text{weight of the sample after drying}}{\textit{weight of sample before drying}} = \times 100 \quad (1)$$

The Soxhlet extraction method was used to determine the oil content (AOAC, 2000) of the samples. Two grams of the sample was placed within a fat-free thimble. Subsequently, the thimble was introduced into the extraction apparatus, followed by the gradual addition of petroleum ether until it began to siphon over. Additional petroleum ether was introduced until the extractor barrel reached a half-filled state. After ensuring the tightness of all joints and replacing the condenser, the extractor was positioned on a boiling water bath. The solvent was then gently boiled, facilitating the siphoning process to occur a minimum of ten times.

$$\text{Oil content } (\%) = \frac{W_3 - W_2}{W_1} \quad (2)$$

W_1 = Weight of sample (g), W_2 = Empty extraction cup weight (g) and W_3 = Extraction cup + residue weight (g).

Determination of colour properties of fried chicken nuggets

The colour attributes of the fried chicken nuggets samples were determined by utilizing a Minolta Chroma Meter CR-400 colorimeter (Minolta Camera Co. Ltd., Japan) (Ananey-Obiri et al. 2020). The tristimulus colour values L* (lightness), a* (red to green), and b* (yellow to blue) values were determined and recorded in triplicate.

Determination of texture properties of fried chicken nugget

Texture analysis of the fried chicken nuggets involved the utilization of a Universal Testing Machine (Model 500, Testometric AX, Rochdale, Lancashire, England). Fried chicken nuggets with consistent size and thickness (1.5 cm) were chosen for the study. To measure textural attributes, the samples were subjected to compression using a probe with a diameter of 75 mm. The compression was allowed to reach 50% of the sample's original height, with a crosshead speed of 50 mm/min. The resulting data curves were used to ascertain various characteristics including chewiness, hardness, cohesiveness, gumminess, and adhesiveness. The analysis was conducted in triplicates for each sample to ensure accuracy (Qiao et al. 2007).

Scanning electron microscopy of fried chicken nuggets

The core and crust sections of the fried chicken nuggets were extracted following the methodology of Adedeji and Ngadi (2011) with minor adjustments. The samples were sliced into approximately $5 \times 5 \times 2$ mm^3 cubes using a sharp razor and then placed in 4% glutaraldehyde fixative for 24 h. Subsequently, the samples underwent three 20-min washes with 0.1 M sodium cacodylate buffer each. Following the washing steps, the samples were post-fixed at 4 °C for 2 h using 1% osmium tetroxide. The washing process was repeated three times for 20 min each. Next, the samples were progressively dehydrated in acetone of increasing concentrations (35%, 50%, 75%, 95%, and 100%), and they were then subjected to critical point drying using a Bal-Tec CPD 030 apparatus (Netherlands) for a duration of 1.5 h. After the drying process, the samples were positioned on a specimen holder and coated with a layer of gold–palladium using a Polarion Range sputter coater (East Grinstead, U.K).

The gold-coated samples were examined utilizing a scanning electron microscope (JEOL JSM-6460LV, Tokyo, Japan) operating at an acceleration voltage of 20.0 kV. Images were captured at magnifications of × 250, × 500, and × 1000.

Data analysis

The experimental data collected were subjected to analysis of variance (ANOVA) for assessment, and the results were presented as mean values accompanied by their corresponding standard deviations (SD). Statistical significance was determined at a confidence level of 95% ($p < 0.05$). Pearson's correlation coefficients among the parameters were calculated using SPSS 13.0 software.

Results and discussion

Moisture and Oil contents (%) of fried chicken nuggets using wheat flour and different starch types in batter formulation

The role of moisture in the formation of quality fried food has been documented in various studies exploring the connection between moisture reduction and oil absorption. Researchers such as Chen et al. (2017), Su et al. (2017), and Yang et al. (2019), among others, have extensively investigated this relationship. The relationship between moisture content and oil absorption is inversely proportional. In the context of deep-frying, a significant amount of moisture loss results in a corresponding increase in the food product's oil absorption, as outlined by Akdeniz et al. (2006). Figure 1(A) illustrates this trend, demonstrating that regardless of the starch types employed in the investigation, the moisture content of the fried chicken nuggets declined as frying time increased. Statistical analysis using analysis of variance (ANOVA) indicated a significant ($p < 0.05$) effect of both starch types and frying time on the moisture content of the fried chicken nuggets. The oil content (Fig. 1 (B)) of the fried chicken nuggets with corn, sweet potato, and cassava starches in batter formulation respectively ranged from13.36 to 26.49; 13.09 to 26.81 and 13.31 to 22.22%.

The oil content of chicken nuggets in wheat flour (control) in batter formulation ranged from 18.26 to 35.57%. Regardless of the different starches used in batter coating or formulation and the duration of the frying process, a consistent reduction in oil content was observed (Fig. 1b). Frying time and starch types had a significant ($p < 0.05$) effect on oil the content of fried chicken nuggets. It's crucial to acknowledge that employing diverse origins or compositions for batter coating leads to variations in viscosity and gelatinization behaviours. These variances, as highlighted by Rahimi et al. (2019), play a role in influencing the distinctive quality traits found in fried foods, which consequently account for the disparities observed in the attained measurements. Sweet potato, corn, and cassava starches as well as wheat flour used in this study was seen to create a protective layer of matrix by reducing the loss of water and by changing the surface structure. Rahimi and Ngadi (2016) as well as Kurek et al. (2017) indicated that the frying process leads to the formation of an elastic matrix involving starch and other constituents like lipids and soluble proteins.

The application of heat and mass transfer during frying induces physicochemical changes, including starch gelatinization. These alterations in the coating's microstructure, as explained by Adedeji et al. (2011) and Rahimi and Ngadi (2016), serve to hinder or minimize moisture evaporation. The increase in moisture content in chicken nuggets coated with corn starch could potentially result from the amylose content present in the corn starch. Prior research by Chaudhary et al. (2009) suggested that the amylose content plays a role in affecting the moisture content of coatings made from starch. In another study, Muscat et al. (2012) conducted a comparison between starch films with varying levels of amylose content. Their findings indicated that as the amylose content increased, so did the moisture content.

According to Rahimi and Ngadi's reports from 2014 and 2015, it was noted that applying a coating to batter forms a barrier that hinders the infiltration of oil into both the inner core and outer crust of chicken nuggets when they are fried. During the frying, the starch granules within the batter coating of the chicken nuggets swell, releasing amylose fraction. This amylose fraction then forms a film-like barrier, as previously mentioned, which effectively prevents the penetration of oil and the loss of moisture from the coated food items.

In a corresponding study by Ananey-Obiri et al. (2018), a similar observation and conclusion were drawn, highlighting the inhibitory effect of coatings on oil absorption. This inhibition arises from the creation of a barrier against moisture loss during the frying process.

Microstructure characterization of fried coated chicken nuggets

Numerous researchers (Cui et al. 2022; Feng et al. 2022; Zhang et al. 2023) have investigated how alterations in microstructure effects mass transfer during the frying process. A consensus has generally emerged from these studies, indicating that exposing food to high frying temperatures leads to rapid moisture evaporation and subsequent crust formation. The SEM image depicted in Fig. 2 (A-D) illustrates the progressive microscopic changes at the interface between the core and crust of battered chicken nuggets coated with cassava, corn, and sweet potato formulations. Notably, the battered and breaded chicken nuggets exhibited substantial deformation in both their crust and core cross-sectional areas.

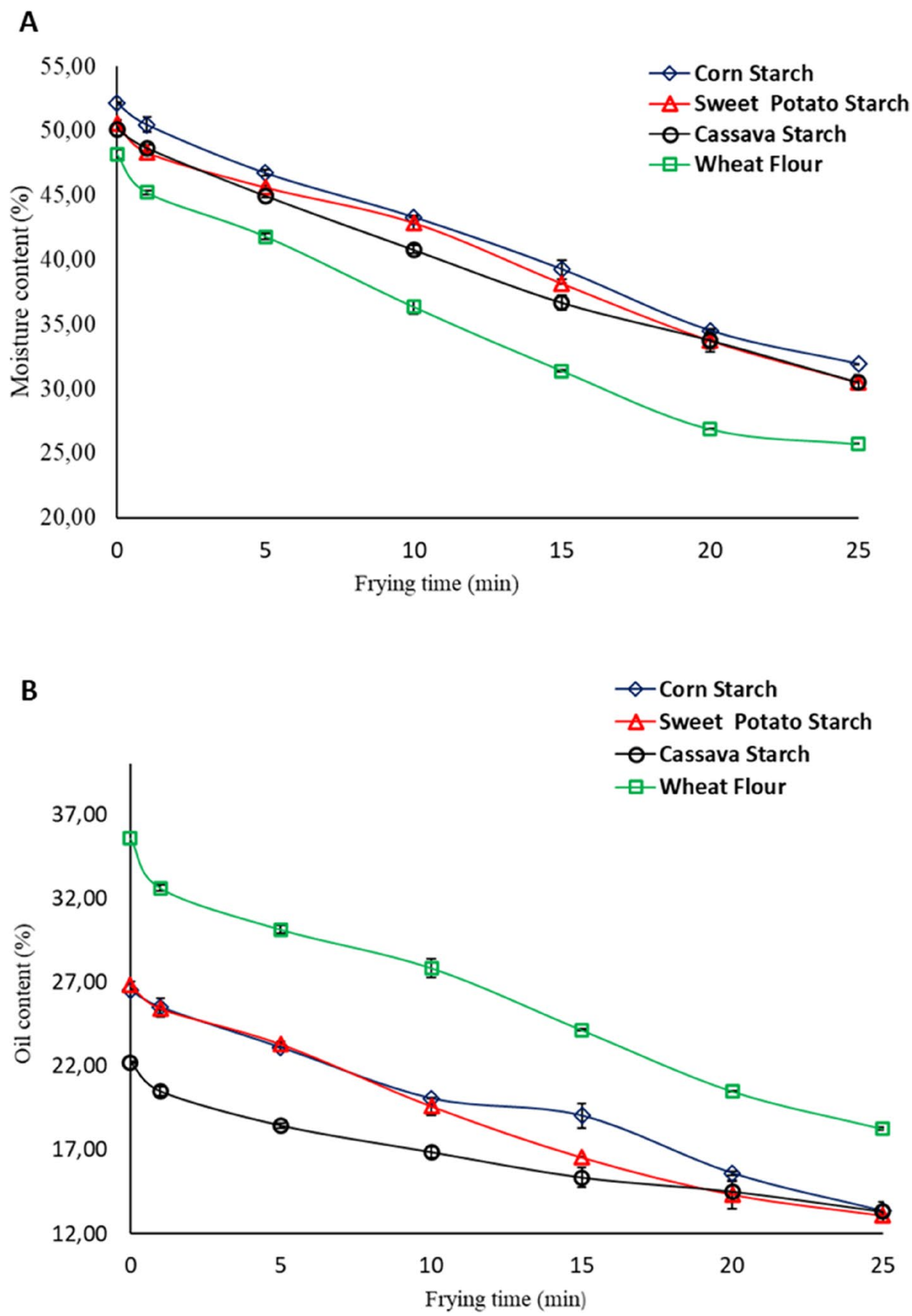


Fig. 1 **A** Moisture content (%) of fried chicken nuggets using wheat flour different starches in batter formulation. **B** Oil content (%) of fried chicken nuggets using wheat flour and different starches in batter formulation

The micrographs reveal oil globules appearing in a spherical form. Within the cross-sectional area of both the core and crust, one can observe numerous oil globules varying in size and displaying irregular shapes. The chicken nuggets sample fried for 5 min (irrespective of the starch as batter) showed a more damaged cells with a deep and larger groove, with its pore's diameter bigger and numerous than what was observed in the SEM image of chicken nuggets sample with 15 min of frying. The chicken nuggets fried for 15 min, shows a smoother, more gelatinized matrix structure with fewer and lesser pores diameter. This implies that increasing.

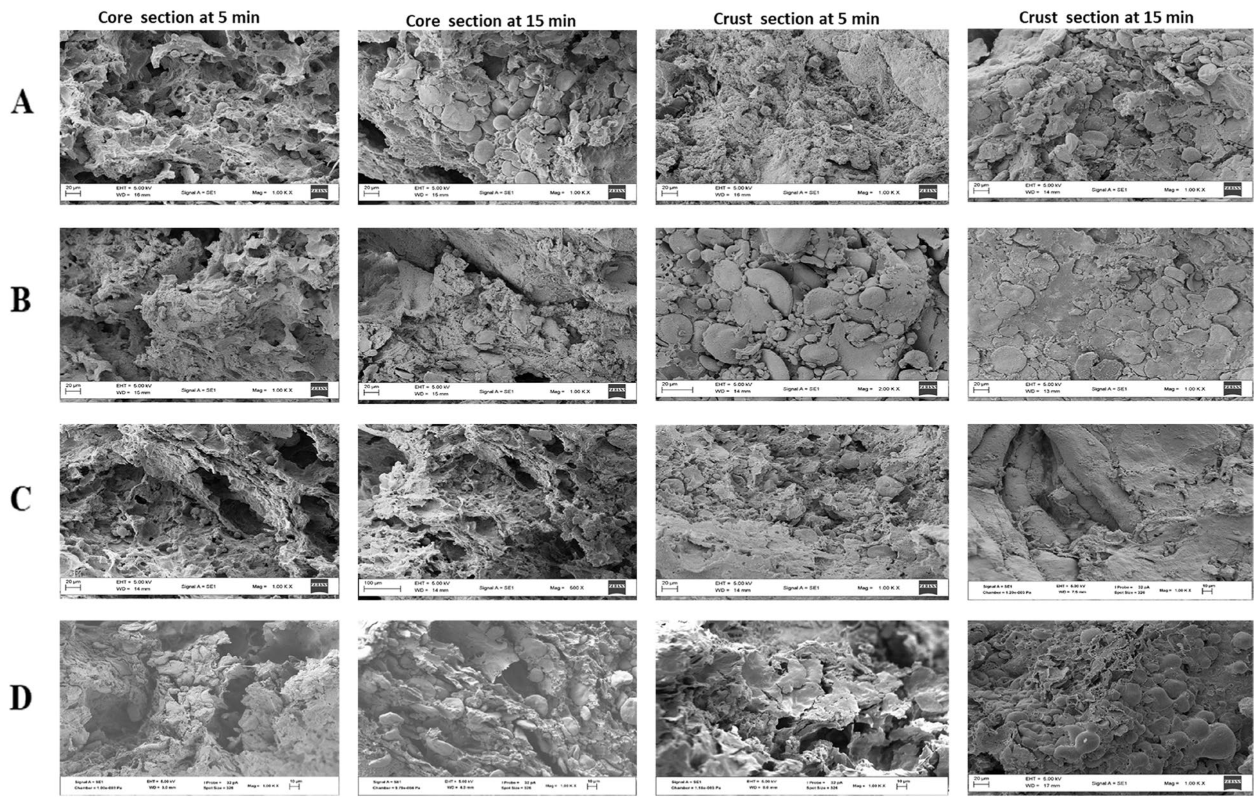


Fig. 2 **A**-**D**: Micrographs of (**A**) cassava starch (**B**) Corn starch (**C**) Sweet potato starch (**D**) wheat starch coated chicken nuggets fried for 5 and 15 min (Core and crust section)

the frying duration as observed in this study led to lesser number of gas cells and pores as observed both in the core and crust region.

The images captured from the surface (core and crust) of fried chicken nuggets coated with batter containing wheat flour (Fig. 2 D) revealed differences in number and size of the pores. The micrograph showing the chicken nuggets fried at 5 min reveal pores, which are big compared to the image obtained from nuggets fried for 15 min, which has a tighter and closed small cracks, i.e. It reveals a denser microstructure with reduced hollows and indentations. The particles within this sample were firmly enclosed within the membranous gluten matrix. Additionally, a relatively coarse and uninterrupted gluten network, featuring larger crevices and empty spaces, was identified on the fried nugget samples' crust surfaces after being fried for 5 min.

This observation aligns with the previously obtained oil content result of 30.14% for chicken nuggets fried at 5 min, which showcased a crust characterized by fractures, open capillaries, and formed channels. As the frying duration increase to 15 min, a lower oil content value was obtained, which could be seen in the micrograph obtain for chicken nuggets, showing a lesser small pores and voids. As observed in this study, chicken nuggets coated with starches (Cassava, Corn and Sweet Potato) showed fewer number of ruptures when compared with those coated with wheat flour (larger number of ruptures). The fewer rupture observed may be attributed to the presence of elastic gluten film in the batter made from wheat that have the ability to serve as a barrier against moisture evaporation which is responsible for the rupture.

The changes observed in the microstructure of chicken nuggets can be attributed to processes involving the transfer of mass and various physicochemical changes, including the denaturation of proteins and the gelatinization of starch during the frying process (Adedeji & Ngadi 2009; Adedeji et al. 2011). The loss of moisture during frying leads to the development of surface irregularities such as voids, holes, and cracks. Comparatively, the network formed by the interaction of starch and water in batter compositions was found to be less robust to the network formed in batters based on wheat flour, which includes gluten proteins.

The weaker network formed structure resulted in a higher occurrence of ruptures on the surface of the chicken nuggets. As the size of surface ruptures increases, the inner resistance decreases due to the presence of positive water vapor pressure. Consequently, a greater amount of oil is drawn into the fried food. This phenomenon was discussed by Li et al. (2023). Variations in batter formulations lead to distinct behaviours in the occurrence of surface ruptures. The batter made from wheat flour exhibited the highest quantity of ruptures, while batters crafted with starches sourced from various origins displayed the lowest amount of ruptures. The formation of the ruptures was influenced by the composition of the batter. As the quantity of starch utilized in the batter's formulation increased, a corresponding increase in the size of created cavities and fissures on the surface was noted (Fig. 2 (A-D)).

Colour attributes of fried chicken nuggets using different starches in batter formulation

Generally, colour serves as a crucial indicator for assessing consumer acceptability regarding changes. The utilization of starch as a coating agent, coupled with the frying time, exhibited a reduction in lightness. A significant ($p < 0.05$) difference occur between the chicken nuggets coated with batter containing corn starch versus wheat flour, as the frying duration advanced. Among the unfried chicken nugget samples, the inclusion of sweet potato starch in the batter formulation yielded the highest lightness value, whereas those incorporating wheat flour demonstrated the lowest lightness.

Frying time (Fig. 3 (A)) was observed to affect lightness significantly, and a significant ($p < 0.05$) difference was observed between the frying time of 1 min and 5 min. Irrespective of the type of starch used in coating formulation, redness (Fig. 3 (B)) increased as frying time increased. It was also observed that fried chicken nuggets containing batter with corn starch had the lowest mean values for redness irrespective of the frying time.

It was observed that yellowness decreases as frying time increases from 0 to 25 min, regardless of starches used in formulating the coating batter (Fig. 3 (C)). The reduction in lightness value observed has been associated with non-enzymatic browning reactions that become more pronounced at elevated temperatures (Salehi 2019). Comparably, Nourian et al. (2003) also noted lower lightness values at lower frying temperatures compared to those obtained at higher frying durations. The effect of starch, a constituent of the coating batter used in this research, was indicative of its varying influence on crust colouration.

Similar outcomes were derived from investigations into the influence of wheat starch/wheat protein ratios in batters on the absorption of fat and quality attributes of fried battered and breaded fish nuggets (Chen

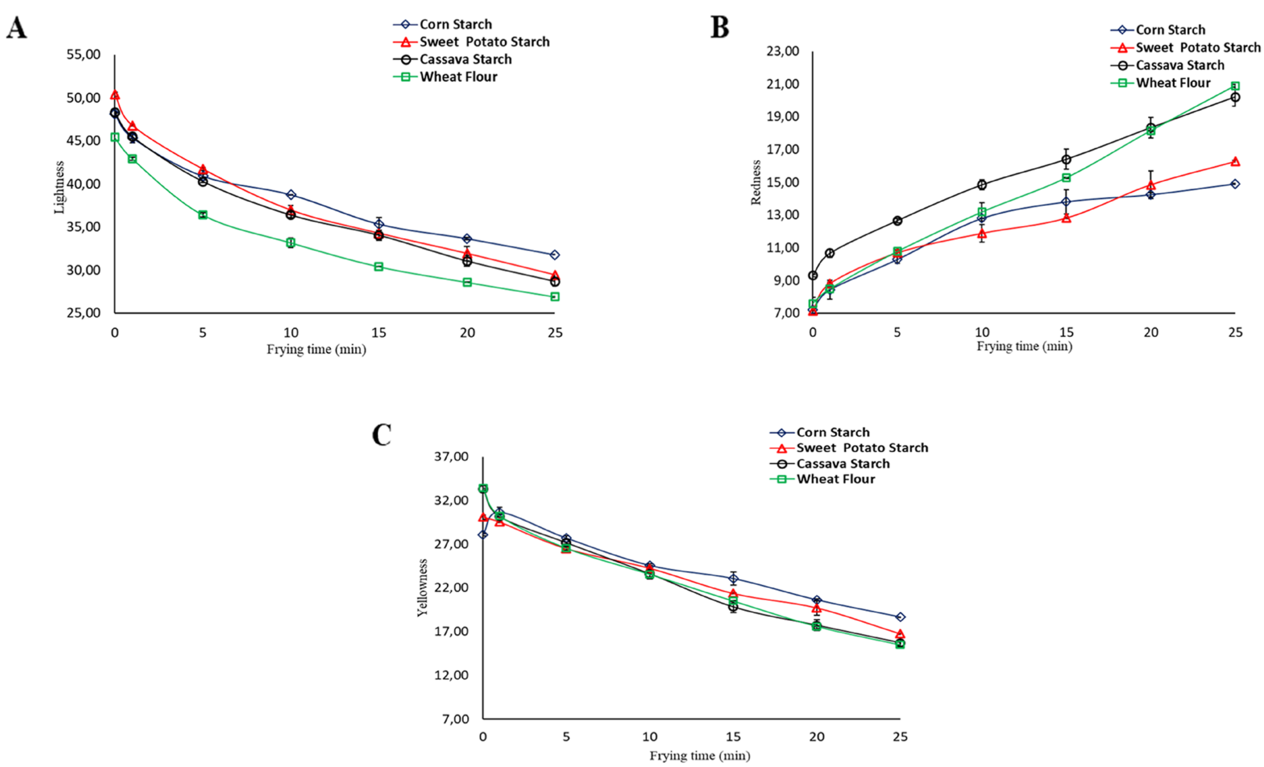


Fig. 3 **A** Lightness **B** Redness **C** Yellowness parameter of fried chicken nuggets using wheat flour and different starches in batter formulation

et al. 2020). Likewise, Oloruntoba et al. (2022) reported analogous findings when studying the effects of ultrasound-pretreated hydrocolloid batters on the quality attributes of fried chicken nuggets during post-fry holding. The negativity of the redness value became more pronounced as the frying time extended. Processing led to an elevation in the a-value, which was linked to a reduction in lightness (Salehi 2018).

The augmentation in redness value (shown in Fig. 3(B)) could be attributed to moisture depletion, oil interaction, and the formation of Maillard reaction. Comparable outcomes were documented in the instance of deep-fat frying potato slices (Sahin 2000). The redness values exhibited a notable increase ($p < 0.05$) in potato chips fried under atmospheric pressure compared to those fried in a vacuum environment. This difference can be attributed to a substantial increase in Maillard reaction byproducts, as noted by Garayo and Moreira (2002).

The findings in this study are aligned with that of Salehi (2019), who noted similar trends while examining the kinetics of colour changes in kohlrabi during deep fat frying. Diverse factors, including lowering of moisture, uptake of oil, non-enzymatic browning reactions, and their interplay, were all contingent on frying time. These factors collectively influenced the fluctuations observed in colour attributes such as lightness, redness, and yellowness.

Textural attributes of fried chicken nuggets using wheat flour and different starches in batter formulation

The sensory quality of food, as perceived through sight, touch, and oral experience, encompasses its inherent texture. This characteristic is intricately connected to the food's rheological and structural transformations, which directly impact consumer acceptance and repeat purchasing behaviour (Chen and Rosenthal 2015). The duration of frying exhibited a significant ($p < 0.05$) effect on the textural attributes of the fried chicken nuggets. The hardness of chicken nuggets coated with batter containing corn, sweet potato, and cassava starches ranged from 135.54 to 215.16 N, 125.08 to 20.21 N, and 120.61 to 200.66 N, respectively.

Irrespective of the starch in the batter, hardness, cohesiveness, adhesiveness, gumminess was found to increase alongside with frying time. There was a significant ($p < 0.05$) difference in all the textural parameters among all the fried chicken nuggets sample with wheat flour and starches (Cassava, Corn and Sweet Potato) as batter formulation, fried between 1 and 25 min (Tables 1, 2, 3, 4 and 5). Frying time had a significant ($p < 0.05$) effect on the gumminess of the fried chicken nuggets coating with all the materials used in this study. The consistency of the food products is significantly influenced by the level of moisture, fats, batter coatings, and proteins (Kutlu et al. 2022), while the textural qualities exhibit comparable trends, the underlying factors behind the changes.

Table 1 Effect of starch types used in batter formulation and frying time on hardness (N) of fried chicken nuggets

CM	0 min	1 min	5 min	10 min	15 min	20 min	25 min
CS	135.54 ± 0.22^{d}(A)	142.48 ± 0.64^{c}(B)	150.28 ± 0.39^{c}(C)	165.30 ± 0.03^{c}(D)	180.52 ± 0.41^{c}(E)	200.20 ± 0.05^{c}(F)	215.16 ± 0.16c(G)
SPS	125.08 ± 0.56^{c}(A)	130.34 ± 0.21^{b}(B)	140.66 ± 0.80^{b}(C)	161.63 ± 2.24^{b}(D)	190.45 ± 0.30^{d}(E)	210.45 ± 0.29^{d}(F)	220.21 ± 0.15d(G)
CAS	120.61 ± 0.29^{b}(A)	130.71 ± 0.57^{b}(B)	140.16 ± 0.08^{b}(C)	150.63 ± 0.13^{a}(D)	165.37 ± 0.23^{a}(E)	180.41 ± 0.24^{a}(F)	200.66 ± 0.36^{a}(G)
WF	110.20 ± 0.23^{a}(A)	124.67 ± 1.09^{a}(B)	130.16 ± 0.06^{a}(C)	150.19 ± 0.17^{a}(D)	170.35 ± 0.19^{b}(E)	185.41 ± 0.37^{b}(F)	210.18 ± 0.06^{b}(G)

Values are means ± standard deviation of triplicates determination

Mean with different superscript within the same column are significantly difference ($p < 0.05$)

Mean with different Uppercase in bracket within the same row are significantly difference ($p < 0.05$)

CM Coating material, *CS* Corn starch, *SPS* Sweet potato starch, *CAS* Cassava starch and *WF* Wheat flour

Table 2 Effect of wheat flour and different starches used in batter formulation and frying time on cohesiveness of fried chicken nuggets

Coating material	0 min	1 min	5 min	10 min	15 min	20 min	25 min
Corn starch	8.78 ± 0.13^{a}(A)	10.35 ± 0.12^{a}(B)	15.41 ± 0.32^{c}(C)	18.52 ± 0.49^{d}(D)	20.19 ± 0.13^{b}(E)	23.93 ± 0.25^{b}(F)	26.07 ± 0.06^{b}(G)
Sweet Potato starch	9.22 ± 0.29^{ab}(A)	10.28 ± 0.07^{a}(B)	11.71 ± 0.16^{a}(C)	12.92 ± 0.14^{a}(D)	14.83 ± 0.17^{a}(E)	18.53 ± 0.25^{a}(F)	21.75 ± 0.06^{a}(G)
Cassava starch	9.14 ± 0.27^{ab}(A)	10.17 ± 0.16^{a}(B)	12.42 ± 0.58^{b}(C)	17.23 ± 0.11^{c}(D)	20.35 ± 0.08^{b}(E)	24.52 ± 0.22^{c}(F)	29.41 ± 0.28^{c}(G)
Wheat flour	9.49 ± 0.42^{b}(A)	10.45 ± 0.18^{a}(B)	12.76 ± 0.16^{b}(C)	16.62 ± 0.21^{b}(D)	20.32 ± 0.21^{b}(E)	25.49 ± 0.33^{d}(F)	30.08 ± 0.05^{d}(G)

Values are means ± standard deviation of triplicates determination

Mean with different superscript within the same column are significantly difference ($p < 0.05$)

Mean with different Uppercase in bracket within the same row are significantly difference ($p < 0.05$)

Table 3 Effect of wheat flour and different starches used in batter formulation and frying time on adhesiveness (N.s) of fried chicken nuggets

Coating material	0 min	1 min	5 min	10 min	15 min	20 min	25 min
Corn starch	0.25 ± 0.01^{b}(A)	0.37 ± 0.01^{c}(B)	0.42 ± 0.01^{c}(C)	0.48 ± 0.01^{b}(D)	0.56 ± 0.02^{b}(E)	0.66 ± 0.03^{b}(F)	0.75 ± 0.03^{b}(G)
Sweet Potato starch	0.26 ± 0.02^{b}(A)	0.33 ± 0.02^{b}(B)	0.42 ± 0.01^{c}(C)	0.49 ± 0.02^{b}(D)	0.64 ± 0.03^{c}(E)	0.75 ± 0.04^{c}(F)	0.84 ± 0.04^{c}(G)
Cassava starch	0.26 ± 0.02^{b}(A)	0.32 ± 0.02^{b}(B)	0.38 ± 0.03^{b}(C)	0.49 ± 0.02^{b}(D)	0.58 ± 0.02^{b}(E)	0.65 ± 0.02^{b}(F)	0.85 ± 0.02^{c}(G)
Wheat flour	0.22 ± 0.01^{a}(A)	0.27 ± 0.02^{a}(B)	0.35 ± 0.01^{a}(C)	0.43 ± 0.02^{a}(D)	0.51 ± 0.02^{a}(E)	0.58 ± 0.02^{a}(F)	0.63 ± 0.03^{a}(G)

Values are means ± standard deviation of triplicates determination

Mean with different superscript within the same column are significantly difference ($p < 0.05$)

Mean with different Uppercase in bracket within the same row are significantly difference ($p < 0.05$)

Table 4 Effect of wheat flour and different starches used in batter formulation and frying time on chewiness (N) of fried chicken nuggets

Coating material	0 min	1 min	5 min	10 min	15 min	20 min	25 min
Corn starch	29.32 ± 0.19^{b}(A)	30.56 ± 0.11^{a}(B)	34.30 ± 0.54^{a}(C)	40.18 ± 0.07^{a}(D)	45.17 ± 0.10^{a}(E)	49.94 ± 0.57^{a}(F)	54.43 ± 0.77^{a}(G)
Sweet Potato starch	27.28 ± 0.26^{a}(A)	30.38 ± 0.16^{a} B)	34.63 ± 0.42^{a}(C)	40.33 ± 0.17^{a}(D)	46.75 ± 0.11^{b}(E)	51.33 ± 1.22^{a}(F)	56.78 ± 0.55^{b}(G)
Cassava starch	32.37 ± 0.33^{c}(A)	35.28 ± 0.17^{b}(B)	45.92 ± 0.36^{b}(C)	58.54 ± 0.13^{b}(D)	65.62 ± 0.04^{c}(E)	76.63 ± 1.62^{b}(F)	123.34 ± 2.30^{d}(G)
Wheat flour	38.43 ± 0.25^{d}(A)	40.26 ± 0.11^{c}(B)	45.63 ± 0.33^{b}(C)	64.12 ± 0.40^{c}(D)	75.36 ± 1.09^{d}(E)	80.42 ± 0.16^{c}(F)	92.17 ± 0.05^{c}(G)

Values are means ± standard deviation of triplicates determination

Mean with different superscript within the same column are significantly difference ($p < 0.05$)

Mean with different Uppercase in bracket within the same row are significantly difference ($p < 0.05$)

Table 5 Effect of wheat flour and different starches used in batter formulation and frying time on gumminess of fried chicken nuggets

Coating material	0 min	1 min	5 min	10 min	15 min	20 min	25 min
Corn starch	55.34 ± 0.22^{a}(A)	60.52 ± 0.18^{a}(B)	64.00 ± 0.52^{a}(C)	71.60 ± 1.48^{a}(D)	84.17 ± 1.07^{b}(E)	91.18 ± 0.14^{b}(F)	97.86 ± 0.59^{b}(G)
Sweet Potato starch	59.38 ± 0.40^{c}(A)	63.55 ± 0.59^{c}(B)	76.30 ± 0.32^{c}(C)	80.44 ± 0.19^{b}(D)	85.49 ± 0.18^{c}(E)	90.95 ± 0.82^{b}(F)	97.71 ± 1.66^{b}(G)
Cassava starch	57.22 ± 0.21^{b}(A)	62.27 ± 0.23^{b}(B)	67.64 ± 0.22^{b}(C)	73.12 ± 0.39^{a}(D)	80.42 ± 0.37^{a}(E)	85.14 ± 0.22^{a}(F)	89.91 ± 0.42^{a}(G)
Wheat flour	56.67 ± 0.67^{b}(A)	60.31 ± 0.18^{a}(B)	68.13 ± 0.28^{b}(C)	72.64 ± 0.34^{a}(D)	80.51 ± 0.27^{a}(E)	85.22 ± 0.36^{a}(F)	90.83 ± 0.78^{a}(G)

Values are means ± standard deviation of triplicates determination

Mean with different superscript within the same column are significantly difference ($p < 0.05$)

Mean with different Uppercase in bracket within the same row are significantly difference ($p < 0.05$)

For example, variations in hardness are linked to the duration of frying. Additionally, the coating components, such as wheat flour and starches, undergo both physical and chemical transformations, ultimately leading to changes in the textural properties of these samples. The combined effects of moisture removal, protein denaturation, and starch gelatinization result in changes in the overall texture of the coated product. These changes can include a crispy or crunchy outer layer due to decreased moisture, a firmer texture due to protein denaturation, and a thicker, more cohesive coating due to starch gelatinization.

Conclusion

The utilization of various starch types in batter composition, along with variations in frying duration, exhibited a significant effect ($p < 0.05$) on some quality characteristics of fried chicken nuggets. This effect is particularly evident in terms of oil absorption and distribution, as observed through scanning electron micrographs. The use of corn starch in batter formulation enhances the lightness and yellowness colour parameter of the fried chicken nuggets. Chicken nuggets coated with wheat-based batters exhibited a greater occurrence of surface ruptures compared to those coated with starch-based batters. Longer frying times resulted in a reduction in the quantity of vented holes and the porosity of deep-fried chicken nuggets. Significant differences are seen in the microstructure of fried chicken nuggets that were coated with batter sourced from various starches. Irrespective of the starch in the batter, hardness, cohesiveness, adhesiveness, gumminess was found to increase alongside with frying time. The utilization of sweet potato starch is observed as the most effective batter formulation for minimizing oil absorption during the deep-fat frying of chicken nuggets.

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Limitations and future perspectives
The study's limitations include a narrow focus on certain starches in batter formulation, lack of human clinical data, and short frying time. To better understand the health risks associated with fried foods, clinical research should explore longer frying times, diverse ingredients, and coating materials, providing a comprehensive perspective on frying processes.

Authors' contributions
Faloye OR carry out the analysis and discuss the results. Sobukola, OP conceptualise the study and supervise the study. Shittu, TA co-supervise the study and discuss some of the results. Bakare, HA carry out some analysis of the study. Akinlade, FA took part in the laboratory experiment and edit the first draft of the write up. Bamidele, OP proofread the manuscript and correct the first draft.

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Availability of data and materials
The data for this study will be made available by the corresponding author on request.

Declarations

Ethics approval and consent to participate
This study does not require ethics approval since no human or animal are involved in the study. Also, there is no need for consent to participate.

Consent to publication
All the authors agreed on publishing the manuscript in the present format in this Journal.

Competing interests
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