Journal of Agriculture and Food Research 16 (2024) 101196

Contents lists available at ScienceDirect

Journal of Agriculture and Food Research

journal homepage: www.sciencedirect.com/journal/journal-of-agriculture-and-food-research

Effect of assisted drying methods on the microstructure and related quality attributes of fried chicken nuggets

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ARTICLE INFO

Keywords:
Pre-drying techniques
Chicken nugget
Oil uptake
Texture
Colour

ABSTRACT

The potential for reducing oil uptake by applying aided pre-drying techniques (microwave, infrared, and convective hot air) was studied on chicken nuggets. Convective hot air (60, 80, and 100 °C); microwave (20, 40, and 60 W); and infrared (150, 250, and 400 W) drying techniques were used to pre-treat chicken nuggets between 1 and 11 min based on preliminary study before frying at 170 °C for 3 min. Standard laboratory methods were employed to assess the quality attributes of fried chicken nuggets, including oil and moisture content, colour, and texture. By comparing the micrographs obtained from chicken nuggets pre-dried using the three pre-dried methods (Microwave, conventional hot air and infra-red), chicken nugget pre-dried using microwave at 60 W have lesser oil cracks (18.05 %) when compared to the rest pre-dried method.

Pre-drying substantially lowers moisture content, with microwave pre-drying being most effective, particularly at higher power levels (19.38 ± 1.36–43.11 ± 0.10). Microwave pre-drying densifies the nugget structure, reducing oil absorption during frying (13.15 ± 0.13–28.38 ± 0.12). Microscopic examination of chicken nuggets pre-dried using three methods (microwave, conventional hot air, and infra-red) reveals that those pre-dried with a microwave at 60 W exhibit fewer oil cracks (18.05 %) compared to the other pre-drying methods. It also affects ($p < 0.05$) the nugget colour, with higher power levels and longer drying times resulting in a darker (10.12 ± 0.01–25.29 ± 0.15) and less yellow nuggets. Texture is also significantly ($p < 0.05$) affected, with higher power levels and longer drying times leading to increased hardness and chewiness (158.20 ± 1.49–438.14 ± 1.89; 88.00 ± 0.93–165.79 ± 0.86; 96.20 ± 1.44–210.60 ± 0.45). Based on the findings, microwave pre-drying at 60 W for 11 min is recommended for achieving low oil content while maintaining good internal structure in fried chicken nuggets.

1. Introduction

Reconstructed foods (RF) are blends of different ingredients that can be mixed, shaped, and processed into convenient, ready-to-consume items [1]. Various processing methods like drying, and frying are employed in their production. This restructuring allows for diverse shapes and provides consumers with a range of ingredients that offer potential nutritional benefits. Examples of restructured foods include chicken nuggets (Castro-López et al. [2].

One of the techniques used in food processing is the deep fat frying method, which is carried out by submerging foods in heated oil that is greater than the temperature at which water boils. The exchange of both heat and mass occurs in the reverse direction within the fried product [3]. Fried dishes, their distinct taste and texture contribute to their widespread popularity. As well as the fact that they are among the most prevalent food. The literature frequently highlights the widespread practice of enhancing the value of chicken nuggets through the process of deep-fat frying [4]. The most desired qualities of chicken nuggets were crispiness and crunchiness, however, it was widely recognized that they also contains immoderate quantities of oil [5].

Since this was incompatible with the trend of pursuing health, there have recently been serious health concerns about the consumption of fried foods because of too much accumulation of saturated fats and trans fatty acids, which has been widely reported to increase heart diseases,

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https://doi.org/10.1016/j.jafr.2024.101196
Received 6 March 2024; Received in revised form 24 April 2024; Accepted 8 May 2024
Available online 9 May 2024

weight gain, obesity, and cancer, among other things. Fried foods absorb a large quantity of oil during frying and tends to result in 30–50 % fat in the final product [6]. Fat should account for fewer than 35 % of daily calories, according to the American Dietary Guidelines but up to 75 % of the calories in fried foods may come from fat [7]. Continuous consumption of foods that are batter-breaded and fried over extended periods can lead to potential health issues such as cardiovascular, cerebrovascular, and high blood pressure. As it is inevitable to avoid consuming fried food, attempts are being made to develop prevention techniques to minimize the quantity of oil present in fried foods.

Pretreatments used to make less fat absorption and enhance the overall quality of fried food products fall into two main categories: traditional and innovative methods. Traditional methods are based on common and ancient methods of frying food. An example of this is hot air-drying process [8]. On the other hand, these traditional pretreatment techniques have some disadvantage such as high energy utilization, long treatment times and low efficiency (Oladejo et al., 2018). Innovative pretreatments, on the other hand, are technologies that have emerged and started to be used in recent years due to some of their advantages (environmentally friendly, fast, protection of nutrients, low energy use, high efficiency) [9]. Examples of these methods are infrared technologies (Oladejo et al., 2018), microwave process ([10]; Su et al., 2016).

One of the preventive techniques include modifying frying processes such as the pre-drying process [11]. Drying is the process of removing moisture from food by evaporation using heat under regulated conditions. But to reduce the first moisture content of such foods, drying is done before frying, thus the level of available moisture present during frying will be minimized.

Previous studies have indicated a connection between evapotranspiration and oil accumulation [12], suggesting that the pores created by water vapour aids in oil absorption [13]. Hot air drying is the most common method of removing water from foods. Heat and mass transfer, as well as phase alteration, are the principal mechanism of hot air drying. Drying process rise as hot air drying consumes a lot of energy, takes a long time and case hardening of product is almost impossible [14]. According to Al Faruq et al. [15], the use of electromagnetic heating systems, particularly microwave and infrared methods, in the frying process is said to have a positive impact on enhancing the physicochemical characteristics of both fried food and the frying medium.

Microwave and infrared drying are two pre-frying pre-treatment techniques [16] that is receiving increasing attention. Microwave-treated food products have higher quality than those that have been dried with hot air-drying methods. Microwaves could be utilized at any point during the frying, including before, during, and after [17] without significantly affecting product quality negatively. In microwave applications, a water vapour pressure differential emerges between the surface and the inside part of the food product due to application of heat and pressure generated by the microwave field.

Infrared heating constitutes a form of electromagnetic radiation capable of being assimilated and transformed into heat through rapid molecular vibrations within nearly all types of food substances [18]. This method enhanced thermal efficiency, increased heat transfer rate, and diminished deterioration of nutritional elements when contrasted with conventional convective and conductive heating techniques in the culinary treatment of food items (Su et al., 2020). Lately, there has been a considerable focus on the enhanced quality characteristics of fried products and the frying medium brought about by the utilization of infrared frying. Udomkun et al. [19] highlighted that far-infrared frying of chicken nuggets demonstrated a heightened heating rate and a more consistent distribution of heat. Pre-processing of food samples by microwave or infrared heating before frying has been shown in several attempts to decrease the quantity of oil present in the final high-quality product [20].

Various frying techniques yield diverse microstructures, which are potentially connected to moisture loss, oil absorption, starch degradation, and nutritional changes. Diverse thermal methods employed during frying process generate distinct microscopic formations, potentially leading to varied configurations of crust or inner layers in the fried specimen [21]. To fully comprehend and characterize the processes, detailed knowledge of the structure of the raw food product and how it changes during processing is required. The ability to understand the microstructural features of food materials is critical for optimizing the design and control of food processing procedures, as well as improving the final product's quality. Gaining insight into the variations in oil absorption, texture, and visual characteristics that manifest during distinct stages of the frying procedure is imperative in achieving a final product that meets the desired standards. Therefore, this study aimed to investigate how various assisted drying techniques (hot air, microwave, and infra-red) before deep fat frying impacts on some quality attributes of fried chicken nuggets.

2. Materials

2.1. Raw materials and processing of broiler chicken

The basic ingredients for producing chicken nuggets are 100 g of deboned skinless chicken breast, 2.5 g of table salt, 4 g of refined wheat flour, and 1 g of dried pepper. FUNAAB Alpha broilers with an average weight of 2 kg and fresh eggs were purchased from DUFARMS, Federal University of Agriculture, Abeokuta, Nigeria, while vegetable oil, refined wheat flour, table salt and ground pepper were purchased from the local market. The chickens were sacrificed and dressed hygienically. Fresh chicken breasts were first peeled to remove the skin with a stainless-steel knife before rinsing in clean water. The bones were separated from the chicken breast with a kitchen knife after the surface water had been drained off. The boneless and skinless chicken meat was combined with the above-mentioned ingredients, seasonings, and ground for 30 s in a meat grinder (Panasonic, model MK-1500 P, Matsushita Electric Industrial Co., Japan).

The chicken nuggets were then formed into individual rectangular shape (25 ± 1 g) with dimensions 5 cm (length), 3 cm (width) and 1.7 cm (thicknesses). Individual chicken nugget piece was then breaded using three step procedure: first they were enrobed in egg albumin, then batter-coated and finally breaded (The batter formulations were composed of solid and water in a ratio 3:5. The solid content of the batter formulations contained wheat four) allowed to drain for 30 s, and immediately coated with breading materials [4].

2.2. Pre-drying of battered and breaded chicken nuggets

The reason for using different pre-dried methods that are using different power levels are stated in the supplementary document 1.

2.2.1. Microwave drying of battered and breaded chicken nuggets

In a calibrated laboratory microwave oven (Model MEJ11K, LG, Kuala Lumpur, Malaysia) which have a highest output of 700 W with a frequency of 2450 MHz, the microwave pre-drying experiments were carried out using the modified approach of Soorgi et al. [22]. Prior to starting the drying experiment, the microwave oven was warmed by putting it on for 30 min. The chicken nugget samples which have been previously battered and breaded were evenly distributed across the pan. The microwave was 530 × 500 x 322 (ht) mm in size, with a spinning plate that was 300 mm in diameter. The drying process was conducted at 20 W, 40 W, and 60 W with time range between 1 and 11 min (based on preliminary study).

2.2.2. Infra - red drying of battered and breaded chicken nuggets

Rahimi et al. [18]'s modified approach was applied for infra-red drying process of the chicken nuggets. An infra-red heating oven was developed at the Department of Agricultural and Bio-resources Engineering, Federal University of Agriculture, Abeokuta (Picture). In order to maintain a consistent heat flow, the lamps were turned on 10 min before starting the drying treatment. Three pieces of chicken nugget was placed in a sample holder (40 × 20 cm). The infra-red drying experiments were conducted using 150, 250, and 400 W halogen lamps in an infrared drying chamber. The chicken nugget samples were evenly distributed throughout the pan. Chicken nuggets were exposed to infra-red heat for 1–11 min at power levels of 150, 250, and 400 W.

2.2.3. Conventional hot air drying of battered and breaded chicken nuggets

Martnezvila et al. [23] modified's approach was used. In a conventional hot air oven (Model JBP25DOJ2WH, General Electric, Louisville, KY), the pan and its contents were dried for 1–11 min at 60, 80, and 100 °C. Before hot air-drying experiments were carried out, the oven was put on about 1 h at the different drying temperatures used.

2.3. Deep fat frying of pre-dried chicken nuggets

For the frying experiments, a kitchen deep fat fryer (model 614 SAISHO, China) was filled with around 2.5 L of frying oil (refined deodorized bleached palm olein) and preheated for 1 h until the temperature of the oil reached 170 °C. The frying basket containing the pre-dried chicken nuggets was dipped in the hot oil and fried for 3 min (based on the preliminary study) at 170 °C. After frying, the fried chicken nuggets were blotted using tissue paper. They were allowed to cool (3 min) before being analysed further to ensure safety, stability, shelf life and accuracy in the results from the analysis.

2.4. Determination of quality characteristics

2.4.1. Determination of moisture and oil contents of fried chicken nuggets

The average moisture level and oil content of fried chicken nuggets was determined using the method of AOAC (2000).

2.4.2. Determination of colour properties of fried chicken nuggets

Using a Minolta Chroma Meter CR-400 colorimeter (Minolta Camera Co. Ltd., Japan), the colour characteristics of the fried chicken nuggets samples were determined [24]. L* (lightness), a* (red to green), and b* (yellow to blue) tristimulus colour values were determined and recorded in triplicates.

2.4.3. Determination of texture properties of fried chicken nugget

The Universal Testing Machine (Model 500, Testometric AX, Rochdale, Lancashire, England) was used for texture examination on the fried chicken nuggets. The fried chicken nuggets were chosen for their homogeneous size and thickness (1.5 cm). The textural characteristics of the samples were determined by compressing them using a probe with a diameter of 75 mm. At a crosshead speed of 50 mm/min, up to 50 % of the sample could be compressed by the probe. Chewiness, hardness, cohesiveness, gumminess, and adhesiveness were all determined using the curves generated. The tests were carried out in triplicate [25].

2.4.4. Scanning electron microscopy of fried chicken nuggets

The central and outer portions of the fried chicken nuggets were prepared for viewing under SEM as described by Adedeji and Ngadi [26] with minor adjustments. With a sharp razor, samples were cut into roughly 5 × 5 × 2 mm^3 cubes and submerged in 4 percent glutaraldehyde fixative for 24 h. For each washing, samples were washed three times for 20 min with 0.1 M sodium cacodylate buffer. At 4 °C for 2 h, the samples were post-fixed with 1 percent osmium tetroxide. The washing process was performed three times for a total of 20 min. Following that, samples were dried in acetone dilutions of various concentrations (35, 50, 75, 95, and 100 %) and dried using a critical point dryer (Bal-Tec CPD 030, Netherlands) for 1.5 h. Using a sputter coater, the dry samples were placed on a specimen holder and coated with gold-palladium (Polarion Range, East Grinstead, U.K). A scanning electron microscope (JEOL JSM-6460LV, Tokyo, Japan) was used to examine gold-coated samples at magnifications of 250, 500, and 1000 in a 20.0 kV acceleration voltage.

2.5. Data analysis

Experimental data obtained were analysed using analysis of variance (Two-way ANOVA) and expressed as mean values ± standard deviations (SD). Differences were considered at significant level of 95 % ($p < 0.05$) using LSD. The pore size dimensions were measured by means of Image J (an open-source freeware designed for scientific image processing and analysis) and randomly selected pores were analysed for both long and short pore axis.

3. Results and discussion

3.1. Moisture content

Gupta et al. (2000) reported that pre-drying modifies the initial moisture content, surface morphology, interior structure, and solid content of food. Moisture plays a significant effect in the quality of a food sample when it is fried, according to several other researchers [27, 28]. The final moisture content of fried chicken nuggets significantly ($p < 0.05$) reduced by the pre-drying process of microwave, conventional hot air, and infrared used in this study (Fig. 1 (A1-3)) regardless of power level (microwave and infra-red) and drying temperature (conventional hot air drying), used. At 11 min of microwave drying process, the fried chicken nuggets pre dried at 60 W was observed to have the least moisture content value (19.38 %) when compared with fried samples pre dried at power levels of 20 and 40 W (27.47 and 24.12 %), respectively.

In Fig. 1 (A2), the effect of conventional hot air-drying pre-treatment method (60, 80 and 100 °C) on the moisture content of the fried chicken nuggets was presented. The values ranged from 37.74 to 48.18 %; 43.44–48.46 % and 40.56–47.93 %, respectively. The fried chicken nuggets pre-dried using conventional hot air oven (60 °C for 11 min) was observed to have the lowest value (37.74 %) of moisture content, while nuggets sample pre dried at 80 °C for 1 min have the highest (48.46 %). The amount of unbound moisture that can be extracted while frying chicken nuggets as seen in this study has been reduced by the microwave, infrared, and conventional hot air-drying, as a result, as the pre-drying time increased, the final moisture content after the frying process decreased.

Rahimi and Ngadi [29] and Li [30] reported that prior to frying, pre-drying process cause a rapid and intensive moisture loss, resulting in a product with a low moisture content which was observed in this study as well. In the report of Fortes Da Silva [31], the author compared microwave pre-dried fried chicken nuggets with a convective hot air pre-dried fried sample and reported that the fried sample, which had been pre-dried using a microwave, exhibited a significantly greater rate of moisture loss. They attributed the moisture loss to heat produced within the product because of molecular friction induced by oscillating dipole molecules and ions movement caused by the alternating electric field. Thus, microwave pre-drying is predicted to deliver more heterogeneous heat at a faster rate than the conventional hot air drying, which depends on conduction and convection to move heat from the source to the product [32]. This observation is like what was observed in this study. Melito and Farkas, (2013) reported a decrease in the moisture content of the doughnuts using infra-red as pre drying source. They attributed the decrease in the moisture content to high heat fluxes by infra-red used. The utilization of infrared drying techniques has been documented to exhibit advantages such as direct heat penetration, accelerated and even heating, and reduced deterioration of nutritional constituents [18]. Infra-red drying method was reported by Boateng and Yang [33] to be effective due to the high heat radiation efficiency of infrared ray. The reduction in moisture content could also be ascribed to the extended drying duration employed in this investigation. This aligns with findings from a previous study [34] which indicated that a

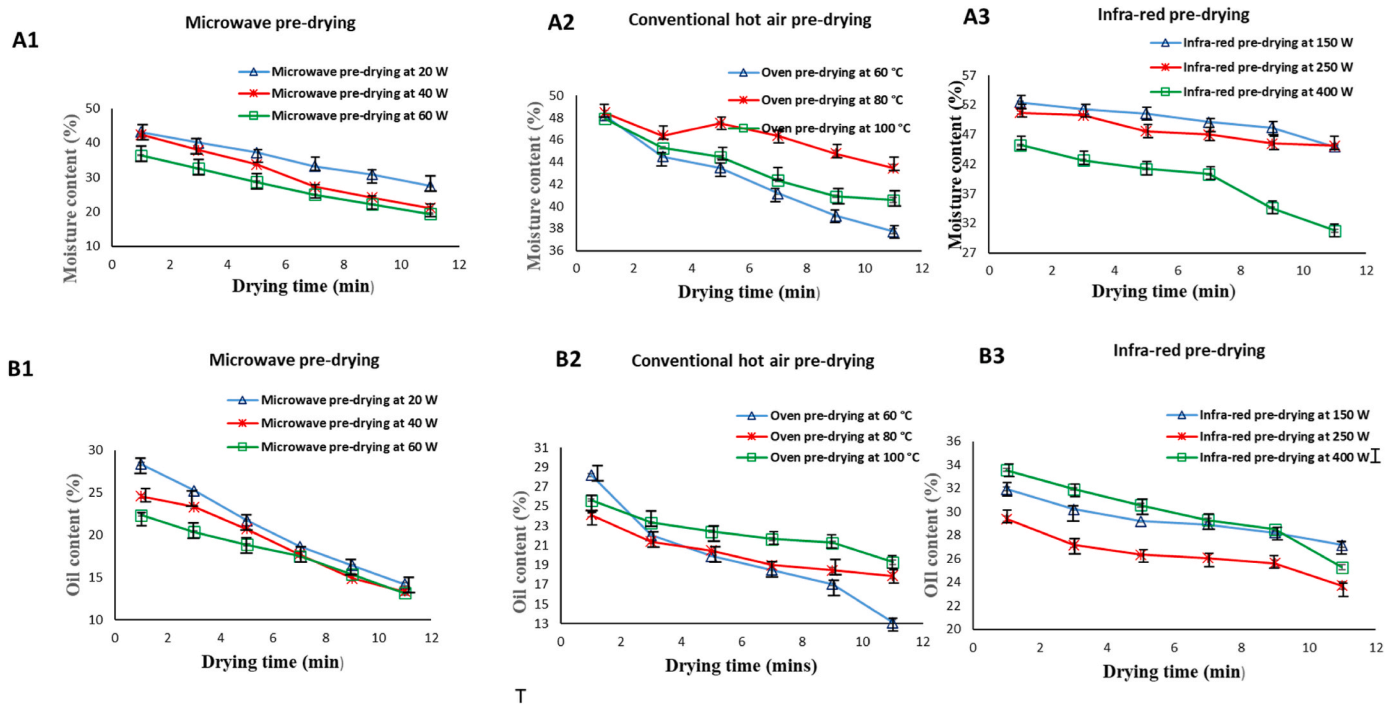

Fig. 1. Effect of pre-drying treatments on the moisture (A) and oil (B) content (%) of fried chicken nuggets.

prolonged pre-drying period results in a decreased availability of free moisture for elimination during the frying process.

3.2. Oil contents

The intricate processes of oil absorption during deep-fat frying result from the complex interplay between oil and food, undergoing multiple transformations throughout the frying procedure. As a result, oil uptake quality and amount must be carefully monitored (Fig. 1 (B1-3)). Pre-drying as reported by Liu et al. [14] has been acknowledge as one of oil reduction pre-treatment methods for fried foods. For the microwave pre-dried fried chicken nuggets, at power level of 20, 40, and 60 W, the oil content ranged from 14.22 to 28.38 %, 13.35–24.57 %, and 13.15–22.34 %, respectively.

Chicken nuggets pre dried at microwave power level of 60 W, irrespective of the drying time was observed to have a lower value of oil content when compared with samples pre dried at power levels 20 and 40 W. The oil content of conventional hot air pre-dried chicken nuggets sample after deep fat frying process at 170 °C for 3 min ranged from 13.14 to 28.20 % (60 °C), 17.90–24.11 % (80 °C) and 19.28 to 25.63 (100 °C). The oil content of the fried chicken nuggets sample pre-dried with infra – red drying method at 150, 250 and 400 W before frying ranged from 27.18 to 31.92 %. 23.72–29.39 % and 25.26–33.55 %, respectively. The result of oil content of fried chicken nuggets pre-dried with microwave at power level of 60 W for 11 min (13.15 %) was observed to be the least when compared with other power level of 20 W (14.22 %) and 40 (13.35 %). Among the three conventional hot air-drying temperatures, the chicken nuggets pre-dried at 80 °C had the least oil content. For fried chicken nuggets samples pre-dried using infra-red (150, 250 and 400 W), it was observed that the fried chicken nuggets sample, pre-dried at 250 W for 11 min was seen to have the lowest oil content value of 23.72 %. The pre-drying methods used in this study reduces the oil content of fried chicken nuggets, i.e., as the drying temperature and power level increased with drying time, the oil content reduces (Fig. 1 (B1-3)).

In this study, the decreased moisture content observed in chicken nugget samples can be attributed to a phenomenon where water replaces oil due to absorption mechanisms. When the food matrix encounters frying oil, it experiences a rise in surface temperature, causing moisture to evaporate. As the frying duration extends, the temperature within the food surpasses the boiling point of water. Consequently, the internal water vapour exerts positive pressure, aiding in the escape of water vapour. This process leads to the creation of internal pores, crevices, and an outer crust in the food's structure (Ziaiifar et al., 2010). For infrared pre-dried treatment, the reduction in oil content observed could be attributed to surface dryness and the formation of a thick crust, which intensified at higher infrared treatment intensities. This crust acts as a barrier, impeding oil diffusion and absorption during the frying process. The initial stages of frying led to an expansion of capillary pores due to moisture evaporation, facilitating oil flow through the chicken nuggets. However, as a significant portion of moisture content evaporated, the oil flow decreased due to a reduction in interfacial tension and capillary pressure, a phenomenon akin to findings by Rahimi et al. [18]. Furthermore, oil content decreased when chicken nugget samples underwent treatment at higher heat flux levels (150–400 W) for extended durations. This decrease can be attributed to the lower viscosity of the oil, allowing it to escape from the sample more easily under the influence of higher infrared treatment intensities. These outcomes align with the observations reported by Melito and Farkas (2013).

From the oil content results, it could be said that fried chicken nuggets samples pre-treated by conventional hot air drying and the other pre-drying methods (infra-red and microwave drying), led to development of cohesive crust which block the intrusion of oil into the food during the frying process. The decrease in oil absorption resulting from above-mentioned pre-drying process could also result from initial solid content and hardening of the structure before frying, which then inhibits the uptake of oil during the frying process, since it has been reported that pre-drying leads to shrinkage, resulting in a reduction in the size of open pores [35]. This process of pre-drying generates a denser matrix, ultimately amplifying the solid content of the pre-dried sample as demonstrated by Debnath et al. [35], Pedreschi and Moyano [36], and Van Loon et al. [37].

3.3. Microstructural characterization of pre dried chicken nuggets

One of the most important elements in determining product quality is morphological characteristics. Different drying methods, according to Qiu et al. [38], can affect the microstructure of dried food product items. Fig. 2 A shows that the microwave pre-dried fried chicken nuggets at 20 W (21.71 %) had a more porous cell with larger pores than the micrographs of chicken nuggets pre-dried at 40 (20.73 %) and 60 W (18.05 %) before frying. The SEM pictures of pre-dried fried chicken nuggets at 60 W indicated a smoother, more compact matrix with fewer crevices (less pores diameter). Furthermore, the micrographs (Fig. 2 B) of the conventional hot air pre-dried chicken nuggets at 60, 80, and 100 °C before frying revealed similar patterns, which is the identical thick inner structure with closed air cells, particularly for micrographs of pre-dried chicken nuggets at 60 °C and 80 °C.

This explains the lower oil content values of 19.90 % obtained for fried chicken nuggets pre dried at 60 °C and 20.47 %% for 80 °C when compared with values obtained for chicken nuggets pre dried at 100 °C. The chicken nuggets pre-dried at 100 °C revealed a more porous interior structure with numerous air cells of varying sizes which may be attributed to the higher oil content value obtained. Again, fried chicken nuggets pre-dried using infrared at 400 W before frying process revealed a few bigger holes or pores caused by the drying process (Fig. 2C). This discovery is consistent with the high oil content values recorded when infra-red power level was increased from 150 to 400 W. There was a clear difference in the micrographs produced from nuggets samples pre-dried at 250 and 400 W power levels, with the former (nuggets sample pre-dried at 250 W) showing less oil gaps or cracks. The structure of pre-dried fried chicken nuggets at 150 W was found to be very comparable to that of chicken nuggets pre-dried at 400 W, as evidenced by the earlier values obtained (29.29 and 30.55 %) which are extremely close.

This finding suggests that the presence of low moisture content in the fried chicken nuggets may lead to the formation of surface holes. This is attributed to the increased heat exchange rate between the frying oil and nuggets with lower moisture content, thereby encouraging the development of more compact holes, as highlighted in the study by Liu et al. [14]. The pores on the surface of the fried product significantly impact the absorption of oil, as they create pathways for oil infiltration. The increase in pre-drying time when using microwave pre-drying leads to a decrease in the number of holes or pores. When the frying process takes place, the cellular structure of the food contracts and undergoes irregular deformation, resulting in the formation of pores due to moisture loss, as discussed in Su et al. [12].

This mirrors the findings of Liu et al. [14] who explored the connection between crust attributes and oil absorption in potato strips during frying through hot-air pre-drying. The study concluded that extending the pre-drying duration led to the development of a denser and more uniform crust with fewer pores. Similarly, Pongpichaiudom and Songsermpong [39] observed comparable results in their examination of protein-enriched instant noodles. Their scanning electron microscope (SEM) images revealed a more compact surface and reduced voids after different drying techniques, including frying, microwave drying, infra-red drying, and conventional hot air drying, impacting the microstructure and quality of the noodles.

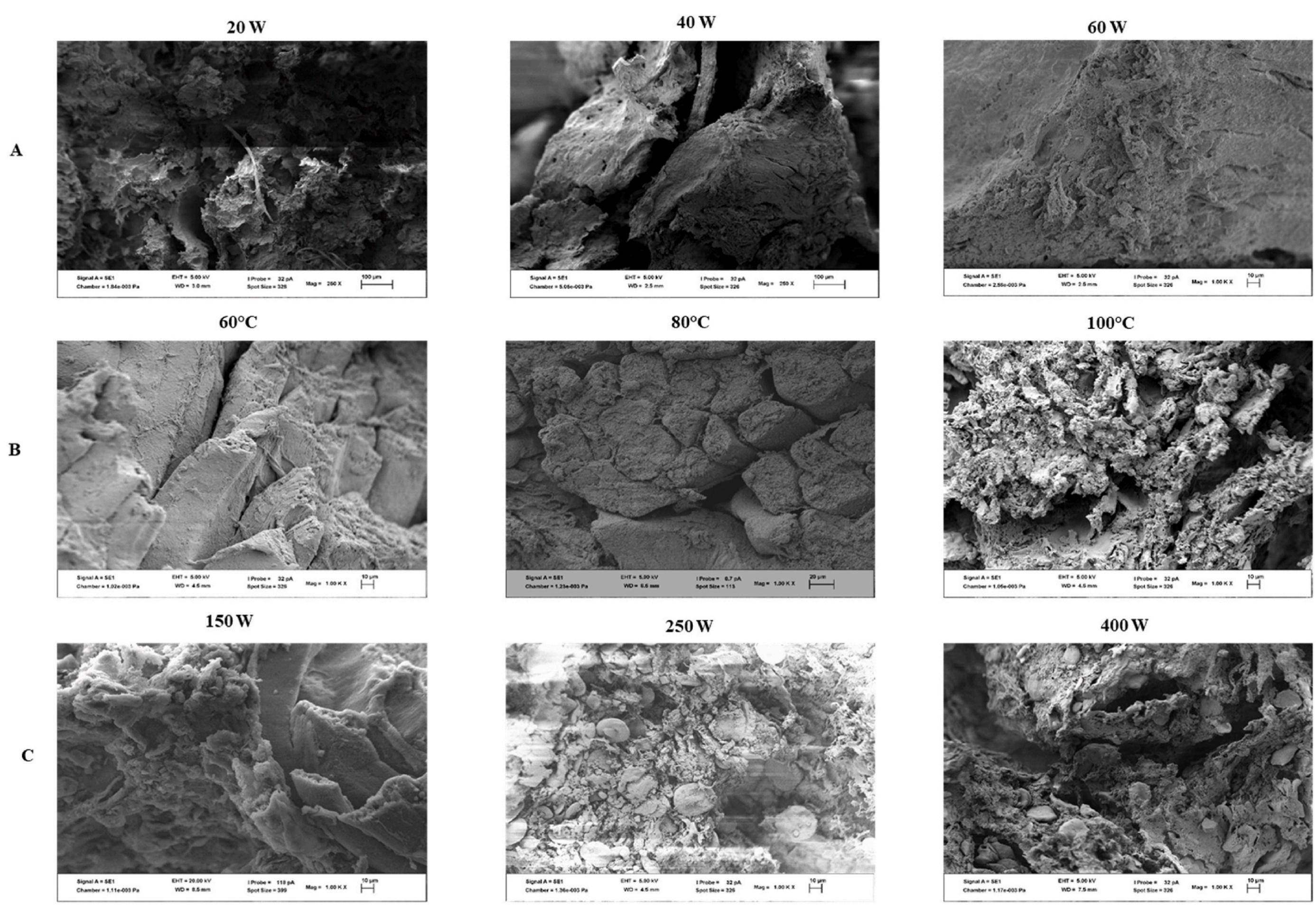

Fig. 2. Microstructural characterization of pre dried chicken nuggets. (A) Microwave pre-dried chicken nugget, (B) Hot-air pre-dried chicken nugget, (C) Infrared pre-dried chicken nugget.

3.4. Effect of pre-drying treatments on the colour properties of fried chicken nuggets

Consumers who favour light-coloured fried foods are influenced by to buy fried foods with such attribute, which is one of the most important qualitative aspects of enrobed ready-to-eat fried products [40]. Fig. 3 shows that as the power level, pre-drying temperature and pre-drying time increased; the lightness and yellowness values of the fried nuggets sample reduced significantly ($p < 0.05$) while redness was observed to increase. At drying time of 3 min, microwave pre-dried chicken nuggets at power level of 20 W (Fig. 3A i), has higher value of lightness (47.27) when compared with other power levels (40 and 60 W). At 7 min, chicken nuggets sample pre dried at 100 °C was observed to have the least lightness value of 34.74 (Fig. 3A ii) when compared with other fried nuggets sample pre dried at drying temperatures of 60 and 80 °C.

The decrease in lightness irrespective of the drying methods and drying time could be attributed to non-enzymatic browning reactions that are temperature or power level dependent. After frying, lightness reduction is determined by the amount of free water present on the sample surface, which favours light reflection. This explains the low lightness parameter observed for most of the pre-dried fried chicken nuggets. In the study conducted by Heredia et al. [41], a comparable finding was documented during the examination of how different frying techniques (air-frying and deep oil-frying) and pre-treatment methods (freezing and blanching) impact the changes in mechanical and optical characteristics of French fries.

As drying duration and pre-drying temperature/power level increased, the yellowness of the parameter of the pre dried fried chicken nuggets samples decreased using microwave, conventional hot air, and infrared drying techniques (Fig. 3 B (i-ii)). Irrespective of the microwave pre-drying process duration, samples pre-dried at the maximum power level (60 W) had the least yellowness value of 15.23, while pre-dried chicken nuggets with conventional hot air (100 °C) have the least yellowness value of 14.56and samples pre-dried with infra-red (400 W) have the least value of 17.25. The redness of the pre-dried chicken nuggets increased with increase in time and the power levels (Fig. 3C (i-ii)). The result of the conventional hot air pre-drying process was found to be higher than the result of the microwave heat procedure and that of infra-red.

Due to the browning reactions that occur throughout the drying process (regardless of the drying technique or time), the yellowness parameter diminishes (Fig. 3 B), implying that drying has a negative effect on the colour of chicken nuggets. The increase in drying temperature and drying time can cause the Maillard reaction which may result in a darker, more brownish colour, that can obscure the yellow colour. The alteration in redness values displayed an opposing pattern compared to the changes in lightness and yellowness values.

In accordance with these findings, the preliminary hot-air drying treatment predominantly led to a reduction in brightness, along with a decline in colour intensity and hue. These colour variations align with the outcomes reported in earlier study by Quan et al. (2016). The infrared drying techniques influenced the levels of redness and yellowness, both of which are associated with the Maillard reaction that takes place during the heating process (Ngadi et al., 2007). Within this non-enzymatic browning phenomenon, the carbonyl groups present in reducing sugars undergo a reaction with the nucleophilic amino groups found in amino acids, leading to changes in the chemical characteristics of proteins and the creation of brown pigments (Pedreschi et al., 2007). Melito and Farkas (2013) reported that higher levels of infrared heating led to a decrease in lightness and yellowness values, accompanied by an elevation in redness value during donut cooking. Also, Turp et al. [42] concluded that beef meatball samples, which had undergone ohmic pre-cooking, exhibited a reduction in lightness when subjected to prolonged infrared heating.

Microwave drying has been reported to cause a minimal colour to change in the product and preserved the product colour without causing any surface overheating phenomena (Ozkan et al., 2007). An increasing redness values observed in the microwaved pre dried chicken nuggets during the frying process may be due to the high power which promoted

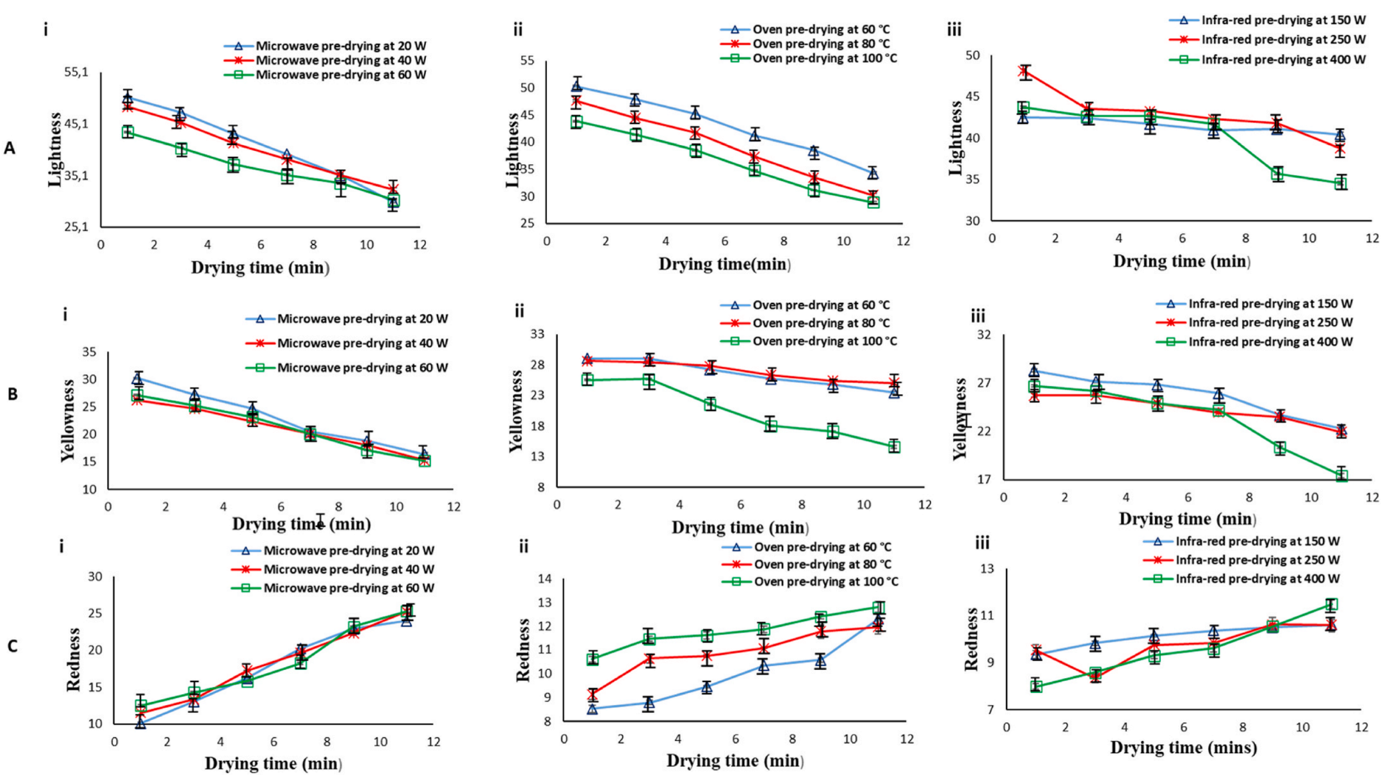

Fig. 3. Effect of pre-drying treatments on yellowness fried chicken nuggets. (A) Lightness (B) Yellowness and (C) Redness.

the development of melanoidins and led to brown discolouration (Song et al., 2007). Piwinska et al. [43] observed that very high power used during microwave pre-drying caused a decrease in the lightness value and an increase in the redness value, which were related to nonenzymatic browning during the drying process.

3.5. Effect of pre-drying methods on textural attributes of fried chicken nuggets

The data presented in Table 1 illustrates how variations in microwave power levels and pre-drying time affect the textural characteristics of the fried chicken nuggets. The hardness values ranged from 158.20 to 438.14 N. As microwave power level (20–60 W) and drying time (1–11 min) increased, hardness, adhesiveness, cohesiveness, chewiness, and gumminess of fried chicken nuggets at 170 °C for 3 min increased, respectively. The interaction of power level and pre-drying time had a significant ($p < 0.05$) effect on hardness parameter. The adhesiveness and cohesiveness value of the pre-dried fried chicken nuggets ranged between 0.81 and 31.71 N s and 0.37–1.76 N s. Chicken nuggets sample pre dried at 40 W for 1 min had the least value, while samples dried at 20 W for 11 min, had the highest value of 31.71 N s for adhesiveness. The main effect of power level and pre-drying time as well as interaction of power level and pre-drying time had a significant ($p < 0.05$) effect on adhesiveness and cohesiveness.

The textural properties of fried chicken nuggets pre-dried with conventional hot air oven were shown in Table 2. An increase was observed in all the textural attributes as pre-drying temperature and time increased for the chicken nuggets. Regardless of the pre-drying temperature and time of the conventional hot air-pre-drying process used in this study, a significant ($p < 0.05$) difference was observed in the hardness, adhesiveness, cohesiveness, chewiness, gumminess values and all the textural parameters of the fried chicken nuggets sample.

The result in Table 3 shows the influence of infra-red power level and pre-drying time on the textural properties of the fried chicken nuggets. As the infra-red power level (150–400 W) and pre-drying time (1–11min) increased, hardness, adhesiveness, cohesiveness, chewiness, and gumminess increased, respectively. The pre-dried (150 W for 1 min) fried chicken nuggets sample recorded the least value of 96.20 N, while at power level of 400 W for 11 min, the highest value of 210.60 N was recorded for hardness parameter. The conformational alterations of muscle proteins account for all these discoveries, leading to the tissue structure's contraction and solidification (Erdogdu et al., 2004). Due to the rapid increase in heat during the pre-drying procedure, myofibrillar protein had less structural alterations. Application of different pre drying methods had both positive and negative effects on textural properties. These findings are closely associated with the effects of microwave, conventional hot air, and infra-red heating on the denaturation of structural proteins in chicken nuggets. Additionally, they contribute to the development of a firm outer texture, changes in fat composition, and modifications in water holding capacity, as described by Rahimi et al. [18].

4. Conclusion

Pre-drying using microwave, conventional hot air and infra-red are introduced as a pretreatment method to reduce the initial moisture content thereby significantly decrease oil content of the fried chicken nuggets with microwave assisted drying having lower oil content and good internal structural qualities than the conventionally hot air frying and infra-red especially, at power level of 60 W. Microwave pre-drying exhibits superior drying rates in contrast to conventional hot air and infrared drying methods. The reduction in the oil content and the internal structure of the pre-dried chicken nuggets by microwave is attributed to the internal heat generation through volumetric heating facilitated by microwaves. Increasing the power level, pre-drying temperature, and pre-drying time reduced the lightness and yellowness while increasing redness of fried chicken nuggets. Also, changes in microwave power levels and pre-drying time significantly ($p < 0.05$) had effects on the texture, with higher values leading to increased hardness, adhesiveness, cohesiveness, chewiness, and gumminess. The use of microwave assisted drying method at power level of 60 W for 11 minis recommended for pre-drying chicken nuggets.

Table 1
Effect of microwave assisted drying method on the textural properties of fried chicken nuggets.

Microwave power level (W)	Drying Time (Min)	Hardness (N)	Adhesiveness (N.s)	Cohesiveness	Chewiness (N)	Gumminess (N)
20	1	158.20 ± 1.49^{a}	4.64 ± 00.26^{ac}	0.37 ± 0.01^{ab}	41.05 ± 0.84^{a}	56.66 ± 1.84^{a}
	3	180.09 ± 1.41^{ab}	7.34 ± 00.39^{bc}	0.51 ± 0.03^{b}	63.17 ± 1.12^{ab}	83.64 ± 1.77^{ab}
	5	200.99 ± 2.47^{ac}	10.77 ± 00.33^{c}	0.64 ± 0.02^{bc}	82.26 ± 1.40^{ac}	99.89 ± 0.16^{ac}
	7	224.50 ± 2.75^{ad}	16.09 ± 0.59^{cd}	0.85 ± 0.02^{bd}	102.7 ± 1.26^{ad}	112.26 ± 2.7^{ad}
	9	247.80 ± 2.04^{ae}	21.42 ± 0.94^{ce}	0.93 ± 0.02^{be}	117.99 ± 2.65^{ae}	140.36 ± 2.21^{ae}
	11	268.93 ± 1.51^{af}	31.71 ± 1.78^{cf}	1.11 ± 0.04^{bf}	128.64 ± 2.73^{af}	151.35 ± 0.32^{af}
40	1	238.36 ± 2.19^{ab}	0.81 ± 00.04^{a}	0.38 ± 00.03^{a}	37.24 ± 03.33^{ab}	63.78 ± 01.24^{ac}
	3	260.89 ± 00.83^{b}	1.40 ± 0.08^{ab}	0.45 ± 0.01^{ab}	86.91 ± 01.63^{b}	96.92 ± 01.96^{bc}
	5	292.88 ± 1.51^{bc}	2.71 ± 0.05^{ac}	0.54 ± 0.02^{ac}	119.98 ± 1.68^{bc}	117.86 ± 2.38^{c}
	7	326.02 ± 2.43^{bd}	3.12 ± 0.10^{ad}	0.65 ± 0.04^{ad}	178.63 ± 2.32^{bd}	136.32 ± 1.60^{cd}
	9	349.05 ± 0.99^{be}	4.69 ± 0.28^{ae}	0.74 ± 0.04^{ae}	206.72 ± 2.73^{be}	210.29 ± 1.39^{ce}
	11	363.17 ± 2.54^{bf}	6.77 ± 0.90^{af}	0.93 ± 0.04^{af}	216.11 ± 7.80^{bf}	218.19 ± 4.78^{cf}
60	1	376.63 ± 1.26^{ac}	3.42 ± 0.60^{ab}	0.56 ± 0.04^{ac}	141.07 ± 1.11^{ac}	85.90 ± 2.71^{ab}
	3	389.47 ± 7.22^{bc}	4.99 ± 00.14^{b}	0.74 ± 0.04^{bc}	163.18 ± 1.08^{bc}	96.59 ± 1.91^{b}
	5	403.50 ± 02.01^{c}	9.74 ± 0.06^{bc}	0.90 ± 0.03^{c}	188.45 ± 02.49^{c}	105.89 ± 0.38^{bc}
	7	416.29 ± 2.11^{cd}	10.17 ± 0.22^{bd}	1.24 ± 0.04^{cd}	204.03 ± 0.95^{cd}	128.67 ± 0.66^{bd}
	9	426.17 ± 1.32^{ce}	11.59 ± 0.49^{be}	1.36 ± 0.02^{ce}	221.52 ± 0.75^{ce}	154.59 ± 6.52^{be}
	11	438.14 ± 1.89^{cf}	15.37 ± 0.57^{bf}	1.76 ± 0.19^{cf}	240.31 ± 0.43^{cf}	206.03 ± 12.96^{bf}
Power level (A)		0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.00[a]
F-Value		27296.72	1778.33	381.48	7243.75	331.94
Drying time (B)		0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.00[a]
F-Value		2078.28	734.95	284.54	2985.68	1260.64
A × B		0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.00*
F-Value		92.20	140.66	15.76	206.34	55.70
R^2		0.99	0.99	0.98	0.99	0.99

Means with different superscript on the same column are significantly different.
A × B = Interaction of power level and drying time.
[a] Significant difference $P \le 0.05$.

Table 2
Effect of conventional hot air-drying on the textural properties of fried chicken nuggets.

Drying Temperature (^{0}C)	Drying Time (Min)	Hardness (N)	Adhesiveness (N.s)	Cohesiveness	Chewiness (N)	Gumminess (N)
60	1	88.00 ± 0.93^{a}	3.28 ± 0.01^{ab}	0.27 ± 0.11^{a}	12.97 ± 0.20^{a}	29.39 ± 0.36^{a}
	3	110.80 ± 0.68^{ab}	6.18 ± 0.03^{b}	0.36 ± 0.04^{ab}	15.49 ± 0.42^{ab}	35.96 ± 0.83^{ab}
	5	117.60 ± 0.56^{ac}	9.46 ± 0.27^{bc}	0.42 ± 0.01^{ac}	16.19 ± 0.18^{ac}	37.57 ± 0.41^{ac}
	7	121.19 ± 0.50^{ad}	11.69 ± 0.08^{bd}	0.53 ± 0.04^{ad}	19.69 ± 0.45^{ad}	41.56 ± 0.60^{ad}
	9	126.72 ± 1.14^{ae}	13.49 ± 0.29^{be}	0.63 ± 0.04^{ae}	23.98 ± 0.29^{ae}	48.21 ± 0.25^{ae}
	11	130.50 ± 0.41^{af}	15.25 ± 0.23^{bf}	0.83 ± 0.03^{af}	29.96 ± 0.67^{af}	52.95 ± 0.85^{af}
80	1	96.19 ± 0.16^{ab}	3.54 ± 0.06^{ac}	0.37 ± 0.02^{ab}	14.54 ± 0.11^{ab}	30.40 ± 0.47^{ab}
	3	112.92 ± 1.92^{b}	5.43 ± 0.04^{bc}	0.43 ± 0.03^{b}	17.77 ± 0.51^{b}	38.54 ± 0.42^{b}
	5	123.93 ± 1.44^{bc}	7.71 ± 0.26^{c}	0.52 ± 0.01^{bc}	23.04 ± 1.43^{bc}	46.47 ± 1.52^{bc}
	7	136.01 ± 2.0^{bd}	10.61 ± 0.55^{cd}	0.60 ± 0.02^{bd}	28.32 ± 0.93^{bd}	56.35 ± 2.00^{bd}
	9	142.67 ± 2.94^{be}	13.46 ± 0.4^{ce}	0.76 ± 0.02^{be}	35.73 ± 1.86^{be}	64.96 ± 2.72^{be}
	11	152.96 ± 0.65^{bf}	16.68 ± 0.29^{cf}	0.90 ± 0.08^{bf}	40.47 ± 0.57^{bf}	72.06 ± 3.42^{bf}
100	1	110.61 ± 0.61^{ac}	4.07 ± 0.07^{a}	0.41 ± 00.02^{a}	15.47 ± 0.26^{ac}	36.25 ± 0.91^{ac}
	3	119.28 ± 1.20^{bc}	4.67 ± 0.11^{ab}	0.52 ± 0.01^{ab}	18.38 ± 1.14^{bc}	40.64 ± 0.60^{bc}
	5	129.93 ± 5.42^{c}	5.03 ± 0.03^{ac}	0.60 ± 0.01^{ac}	22.80 ± 0.46^{c}	45.53 ± 0.53^{c}
	7	153.45 ± 3.65^{cd}	5.20 ± 0.08^{ad}	0.65 ± 0.01^{ad}	25.80 ± 0.77^{cd}	51.68 ± 0.35^{cd}
	9	160.39 ± 0.55^{ce}	5.72 ± 0.08^{ae}	0.72 ± 0.02^{ae}	30.69 ± 0.43^{ce}	55.37 ± 0.16^{ce}
	11	165.79 ± 0.86^{cf}	6.62 ± 0.39^{af}	1.04 ± 0.20^{af}	36.00 ± 0.82^{cf}	57.81 ± 1.00^{cf}
Drying temperature (A)		0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.00[a]
F-Value		694.83	2186.93	10440.25	13192.08	303.92
Drying time (B)		0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.00[a]
F-Value		895.35	1893.84	284.89	891.96	636.69
A × B		0.00[a]	0.00[a]	0.00[a]	0.00[a]	0.00[a]
F-Value		28.69	284.40	253.33	216.85	34.62
R^2		0.99	0.99	0.99	0.99	0.99

Means with different superscript on the same column are significantly different.
A × B =Interaction of drying temperature and drying time.
[a] Significant difference $P \leq 0.05$.

Table 3
Effect of infra-red assisted drying methods on the textural properties of fried chicken nuggets.

Power level (W)	Drying Time (Min)	Hardness (N)	Adhesiveness (N.s)	Cohesiveness	Chewiness (N)	Gumminess (N)
(N)150	1	96.20 ± 1.44^{a}	8.65 ± 0.85^{a}	0.29 ± 0.02^{a}	10.28 ± 1.37^{a}	27.40 ± 2.00^{a}
	3	98.69 ± 0.42^{ab}	6.49 ± 0.46^{a}	0.36 ± 0.01^{a}	13.51 ± 0.48^{ab}	35.4 ± 0.18^{ab}
	5	112.42 ± 0.39^{ac}	10.46 ± 0.34^{ab}	0.48 ± 0.01^{a}	12.62 ± 0.19^{ac}	34.64 ± 0.27^{ac}
	7	116.51 ± 0.45^{ad}	12.77 ± 0.40^{ac}	0.54 ± 0.03^{a}	14.59 ± 0.32^{ad}	38.88 ± 0.76^{ad}
	9	122.47 ± 3.08^{ae}	15.59 ± 0.41^{ad}	0.63 ± 0.04^{a}	18.59 ± 0.29^{ae}	43.84 ± 0.24^{ae}
	11	140.33 ± 0.28^{af}	19.38 ± 0.28^{ae}	0.36 ± 5.18^{a}	21.51 ± 0.37^{af}	48.47 ± 0.44^{af}
250	1	130.48 ± 1.24^{ab}	10.89 ± 0.07^{ac}	1.44 ± 0.02^{a}	31.97 ± 0.79^{ac}	33.13 ± 1.01^{ab}
	3	139.32 ± 0.4^{b}	12.71 ± 0.32^{ac}	1.75 ± 0.14^{a}	35.7 ± 0.84^{bc}	42.01 ± 1.69^{b}
	5	150.6 ± 0.55^{bc}	18.47 ± 0.49^{bc}	2.10 ± 0.03^{a}	40.75 ± 1.13^{c}	52.71 ± 0.61^{bc}
	7	157.64 ± 0.93^{bd}	22.61 ± 0.88^{c}	2.19 ± 0.02^{a}	47.37 ± 1.22^{cd}	57.44 ± 0.41^{bd}
	9	161.36 ± 0.37^{be}	28.89 ± 0.32^{cd}	2.72 ± 0.17^{a}	52.8 ± 0.68^{ce}	60.3 ± 0.42^{be}
	11	165.38 ± 0.5^{bf}	32.24 ± 0.79^{ce}	2.59 ± 0.59^{a}	56.48 ± 0.48^{cf}	67.6 ± 0.56^{bf}
400	1	140.38 ± 0.94^{ac}	10.53 ± 0.13^{ab}	1.46 ± 0.09^{a}	29.21 ± 0.78^{ab}	56.17 ± 0.75^{ac}
	3	152.5 ± 0.95^{bc}	12.33 ± 1.35^{ab}	1.78 ± 0.01^{a}	31.27 ± 0.20^{b}	60.55 ± 0.52^{bc}
	5	165.77 ± 0.43^{c}	15.58 ± 0.46^{b}	2.11 ± 0.02^{a}	35.53 ± 0.69^{bc}	66.62 ± 1.00^{c}
	7	183.66 ± 1.64^{cd}	17.57 ± 0.49^{bc}	2.28 ± 0.04^{a}	42.4 ± 0.48^{bd}	76.76 ± 0.79^{cd}
	9	201.46 ± 0.54^{ce}	25.32 ± 0.92^{bd}	2.60 ± 0.07^{a}	45.03 ± 0.75^{be}	82.63 ± 1.26^{ce}
	11	210.60 ± 0.45^{cf}	29.11 ± 0.64^{be}	2.00 ± 0.03^{a}	50.64 ± 0.53^{bf}	93.32 ± 0.65^{cf}
Temperature (A)		0.00[a]	0.00[a]	0.63	0.00[a]	0.00[a]
F-Value		14984.39	958.92	0.46	8189.43	6861.13
Time (B)		0.00[a]	0.00[a]	0.32	0.00[a]	0.00[a]
F-Value		2818.09	1105.15	1.23	917.23	1430.60
A × B		0.00[a]	0.00[a]	0.51	0.00[a]	0.00[a]
F-Value		186.20	40.06	0.94	57.80	68.34
R^2		0.99	0.99	0.31	0.99	0.99

Means with different superscript on the same column are significantly different.
A × B = Interaction effect of power level and drying time.
[a] Significant difference $P \leq 0.05$.

Future considerations

Further investigations could delve into conducting a complementary study specifically focusing on the oxidative stability and formation of oxidation parameters (peroxide value, anisidine value, total oxidation value) for fats, acrylamides, and polar compounds during the pre-drying and frying processes of chicken nuggets. Also, cconsumer sensory evaluations could offer valuable insights into the acceptability of chicken nuggets treated with different pre-drying methods, guiding product development towards healthier and higher-quality fried food options based on consumer preferences.

CRediT authorship contribution statement

O.R. Faloye: Writing – original draft, Formal analysis, Data curation. **O.P. Sobukola:** Writing – review & editing, Supervision, Project administration, Conceptualization. **T.A. Shittu:** Writing – review & editing, Supervision, Data curation, Conceptualization. **H.A. Bakare:** Methodology, Formal analysis, Data curation. **A.T. Omidiran:** Writing – review & editing, Formal analysis, Data curation. **F.A. Akinlade:** Methodology, Formal analysis, Data curation. **O.P. Bamidele:** Writing – review & editing, Methodology, Formal analysis.

Declaration of competing interest

The authors declare that there is no conflict of interest whatsoever on this manuscript. The final draft was accepted for submission by all the authors.

Data availability

Data will be made available on request.

Acknowledgment

The authors would like to acknowledge Prof. Gueguim Kana E.B. (School of Life Sciences Pietermaritzburg Campus, University of Kwazulu-Natal, South Africa) and Microscopy and Microanalysis Unit, Ground Floor, John Bews B Block, Agriculture Campus, University of KwaZulu Natal, End of Carbis Road, Scottsville, Pietermaritzburg for the opportunity to carry out this study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jafr.2024.101196.

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