

Qualitative indices of chicken nuggets as affected by different cooking methods

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Abstract

Background: Cooking methods not only influence sensory attributes but also affect the nutritional profile of precooked meat products. This study was designed to evaluate the effects of various cooking methods on the quality attributes of chicken nuggets.

Methods: Chicken nuggets were prepared using four cooking methods: Deep Frying (DF), Air Frying (AF), Grilling (GR), and Microwaving (MW). Quality parameters assessed included lipid oxidation, proximate composition, pH, and sensory characteristics, evaluated at 7-day intervals over 21 days. Total Heterocyclic Aromatic Amines (THAA) were analyzed only on Day 0.

Results: Significant differences ($p < 0.05$) were found across cooking methods. Ash content ranged from 2.27% (MW) to 2.79% (GR), while Dry Matter was highest in GR (63.04%) and lowest in DF (55.87%). Lipid oxidation peaked on Day 0 in MW (4.32 mg MDA/100g) and was lowest on Day 21 in DF (1.57 mg MDA/100g). Sensory evaluation on Day 21 favored AF nuggets for color, flavor, aroma, tenderness, juiciness, and overall acceptability. In contrast, GR nuggets on Day 7 scored lowest in sensory parameters. THAA content was highest in GR (63.47) and undetectable in DF (0.00). DF was consistently the most preferred method across Days 0, 7, and 14, while GR was the least accepted.

Conclusion: Deep frying consistently produced the most consumer-preferred chicken nuggets and showed no detectable levels of THAA. For individuals without fat-related health risks, moderate consumption of deep-fried nuggets may be acceptable.

Keywords: Chicken nuggets, Total Heterocyclic Aromatic Amines, Deep frying, Air frying, Microwaving, Grilling

Introduction

Cooking methods play a pivotal role in determining both the sensory attributes and nutritional value of food products (Barbut et al. 2022). As consumers increasingly prioritize health alongside taste and convenience, understanding how various cooking techniques affect food quality—especially for ready-to-eat meat products—has become essential.

Chicken nuggets, a widely consumed poultry product, are prepared using different cooking methods including deep frying, baking, grilling, and microwaving (Abd-El-Aziz et al. 2021; Faloye et al. 2024). Each of these methods introduces unique changes to the sensory characteristics, nutritional composition, texture, and health-related properties of the final product. Additional factors such as the type of coating and oil used during preparation also significantly influence the overall quality of chicken nuggets (Pan et al. 2020).

Deep frying is a popular method commonly employed in fast-food outlets, producing a crispy exterior and juicy interior that many consumers find appealing. This is due to rapid heat transfer and Maillard reactions that occur at high temperatures (Knipe et al. 2017). However, deep frying is often criticized for its health implications, including high fat retention and the potential formation of undesirable compounds such as trans fats, especially when cooking at the high

temperatures required for this method. Consequently, alternative frying techniques such as vacuum frying and air frying have been explored to reduce the fat content and improve the health profile of fried foods (Honegger et al. 2021).

Baking offers a healthier alternative by minimizing oil absorption and producing a drier texture, although it may lead to reduced flavour intensity compared to deep frying (Amini et al. 2018). Grilling, known for its characteristic smoky flavour and distinct grill marks, enhances the sensory appeal of chicken nuggets while helping to preserve moisture content through indirect heat conduction (Silva et al. 2019).

Despite the favourable sensory outcomes associated with deep frying, its tendency to increase fat content and caloric density has raised concerns about its role in promoting obesity and diet-related health problems (Mihaela et al. 2010; Delgado-Pando et al. 2020). In contrast, air frying circulates hot air rapidly around the food, creating a crispy texture similar to deep frying but with significantly lower oil absorption. This results in reduced fat and calorie content compared to deep-fried products. Baking and grilling also contribute to healthier meat preparations by reducing fat content and aiding in protein retention, aligning with nutritional guidelines aimed at limiting saturated fat intake (Yi et al. 2019). Moreover, the potential formation of harmful compounds such as acrylamide

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during high-temperature cooking highlights the importance of choosing methods that minimize health risks (Tareke et al. 2002).

Given the rising demand for convenience foods such as chicken nuggets in today's fast-paced world (Faloye et al. 2024), this study investigates the effects of different cooking methods on the quality attributes of chicken nuggets. The findings aim to inform consumers and food industry stakeholders about the health and sensory implications associated with various cooking techniques.

Materials and Methods

Experimental Site: The experiment was conducted in the Animal Products Laboratory of the Department of Animal Science, Faculty of Agriculture, University of Ibadan, Ibadan, Nigeria.

Meat Source: Ten live broiler chickens weighing between 2.5 and 3 kg were purchased from a reputable farm in Ibadan. The birds were rested overnight with ad libitum water supply, then slaughtered, dressed, and cut into primal cuts. The breast meat was trimmed of skin, external fats, and visible connective tissues. The carcasses were washed with tap water and cut into boneless chunks of 3 to 4 cm size. Prior to production of chicken nuggets, the meat samples were chilled at 4°C to maintain minimal microbiological load (Kataria et al. 2020).

Non-Meat Ingredients: Non-meat ingredients including dry spices (garlic powder, onion powder, curry, and thyme) were purchased from a reputable source in Ibadan. The spices were sorted of extraneous materials, pulverized individually, and stored in well-covered containers until use. Other ingredients such as liquid milk, eggs, soya oil (for deep frying), and table salt (NaCl) were also obtained.

Breadcrumbs Production: Sliced bread was purchased from a reputable store in Ibadan. The toasting machine was preheated to 150°C (300°F), and the bread was spread evenly in the toaster and baked for 15 to 20 minutes until completely dry and crispy. The toasted bread was cooled before being blended to the desired consistency. The breadcrumbs were stored in airtight containers at room temperature (Alpers et al. 2021).

Chicken Nuggets Production

Formulation and Preparation: Chicken nuggets were prepared by combining chicken breast meat with non-meat ingredients in proportions shown in Table 1. The preparation steps included grinding, mixing, shaping, breading, coating, and cooking.

The nuggets were cooked using four different methods: deep-frying, air-frying, grilling, and

microwaving. Each cooking method represented a treatment in a completely randomized design.

Table 1: Chicken Nuggets Product Formulation

Ingredients	Proportion (%)
Chicken	60.00
Black pepper	5.00
Chili pepper	5.00
Soya sauce	5.00
Salt	1.50
Fresh bread	6.20
Breadcrumbs	3.00
Garlic powder	5.00
Egg (raw)	6.50
Onion powder	2.80
Total	100.00

Grinding: Sliced bread and chicken breast meat were ground separately using an automated meat mincer fitted with a 4 mm plate. Dry spices and other ingredients were sorted separately.

Mixing: Ground bread and chicken breast were mixed with dry spices (garlic powder, black pepper, chili powder, salt) and soya sauce in a bowl, then re-ground to achieve a homogenous mixture.

Shaping: The dough was flattened on a clean flat surface and cut into nuggets weighing 20 g each. Sixty nuggets were prepared, with 15 pieces per treatment.

Breading: Three shallow bowls were arranged containing the prepared chicken nuggets, beaten egg mixed with milk, and breadcrumbs respectively.

Coating: Each nugget was dipped into the beaten egg mixture to ensure full coating, then rolled in breadcrumbs, and chilled at 4°C for 15 minutes.

Cooking

i. **Deep-Frying:** Breaded nuggets were fried in pure soya oil heated to 175°C. Nuggets were fried in batches for 5 to 7 minutes, turning occasionally until golden brown and crispy. After frying, excess oil was drained, and nuggets were cooled to room temperature before packaging in Ziploc bags and refrigeration.

ii. **Grilling:** Nuggets were grilled on a preheated barbecue gas grill at 190-200°C. Nuggets were placed directly on grill grates and cooked for 4 to 5 minutes per side, flipped with tongs to ensure even cooking. They were monitored closely to avoid burning. After grilling, nuggets were cooled, packaged, and refrigerated.

iii. **Microwaving:** Nuggets were arranged on a microwave-safe plate with space between

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pieces and microwaved on high power for 5 to 7 minutes, flipping halfway for even heating. Nuggets were cooled, packaged, and refrigerated.

- iv. **Air-Frying:** Nuggets were placed in a single layer in a preheated air fryer at 190°C. They were air-fried for 10 to 12 minutes, flipping halfway to ensure even cooking and crispiness. After cooking, nuggets were cooled, packaged, and refrigerated.

Physicochemical, Microbial, and Sensory Analyses

Microbial Load (Aerobic Plate Count): Ten grams of nugget sample were mixed with 90 ml of sterile peptone water (1 g/l) and homogenized using a laboratory homogenizer (AM-5 Ace homogenizer, Nihonseiki, Japan). Serial dilutions were prepared, and 0.1 ml from each dilution was spread on duplicate plates of standard plate count agar. Plates were incubated at 35°C for 48 hours, after which colonies were counted. Results were expressed as log₁₀ CFU/g of sample. This analysis was conducted on days 1, 7, 14, and 21 post-production (Babatunde and Adewunmi 2015).

pH Measurement: One gram of nugget sample was homogenized in 5 ml distilled water, and pH was measured using a digital pH meter. The meter was calibrated with buffer solutions before use. The average of three readings was recorded. Measurements were taken on days 0, 7, 14, and 21.

Proximate Composition: Moisture, protein, fat, and ash content were determined following AOAC (2011) methods.

Moisture Content: Ten grams of sample were oven-dried at 105°C for 6 hours until constant weight. Moisture content was calculated as the percentage weight loss (AOAC 2011 method 925.09).

Ash Content: Five grams of sample were ashed in a muffle furnace at 550°C for 3 hours until light gray or white ash was obtained. The ash was cooled in a desiccator and weighed. Ash content was expressed as percentage of sample weight (AOAC 2011 method 923.03).

Protein Content: Protein was determined by the Kjeldahl method using a conversion factor of 6.25. Nitrogen content was measured with DK20 heating digester and UDK129 distillation unit. Protein content was calculated based on titration volume, normality of acid, and sample weight (AOAC 2011 method 920.87).

Fat Content: Crude fat was extracted using Soxhlet extraction with diethyl ether for 6 hours. Fat was weighed after solvent evaporation and expressed as

percentage of sample weight (AOAC 2011 method 930.09).

Carbohydrate Content: Carbohydrate content was calculated by difference: 100 minus the sum of moisture, protein, fat, and ash percentages (AOAC 2011).

Product Yield: Product yield was calculated by weighing the sample before and after cooking using the formula:

$$\text{Product Yield (\%)} = (\text{Final weight of product} / \text{Initial weight of product}) \times 100$$

Sensory Evaluation: Twenty semi-trained panelists from the Department of Animal Science evaluated coded nugget samples. Samples were scored on a 9-point hedonic scale for colour, flavour, aroma, tenderness, juiciness, and overall acceptability. Sensory evaluations were conducted on days 0, 7, 14, and 21 post-productions.

Lipid Oxidation (TBARS): Thiobarbituric acid reactive substances (TBARS) were determined following Buege and Aust (1978) to assess lipid peroxidation. Homogenized samples (0.6 ml) were mixed with 3 ml glacial acid and 1% TBA solution, incubated in boiling water bath for 15 minutes, cooled, centrifuged, and absorbance measured at 532 nm. TBARS values were expressed as mg malondialdehyde per 100 g sample. Measurements were done on days 0, 7, 14, and 21. The formula used was:

$$\text{TBA} = \frac{O.D \times V \times 1000}{A \times v \times I \times Y}$$

where O.D = absorbance at 532 nm, V = total volume of reaction mixture (6.6 ml), A = molar extinction coefficient (1.56×10^5), I = light path length (1 cm), v = volume of extract used (0.6 ml), Y = sample weight in ml.

Determination of Total Heterocyclic Aromatic Amines (THAA): Half a gram of each sample was macerated and extracted with 50 ml solvent mixture of methanol, methylene chloride, and acetonitrile (4:2:1). The mixture was shaken in a separating funnel; the organic layer was collected and treated with 1 ml 5% trichloroacetic acid and 2 ml 10M NaOH, then brought to volume. Absorbance was measured at 415 nm using a Cecil spectrometer. THAA concentration was calculated using the formula:

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Absorbance of sample $\times$ Gradient factor $\times$ Dilution factor.

Experimental Design: A completely randomized design was employed with three replicates per treatment.

Statistical Analysis: Data were analyzed by one-way ANOVA using SPSS version 20. Duncan's Multiple Range Test (DMRT) was used to separate means at a significance level of $p < 0.05$.

Ethical Consideration

This study did not involve invasive procedures or any disclosure of confidential information from individuals; therefore, ethical approval was not required or sought.

Results

Effect of Different Cooking Methods on Yield of Chicken Nuggets: The yield of chicken nuggets varied depending on the cooking method employed, although statistical analysis indicated that the difference was not significant ($p > 0.05$). Deep-frying (Treatment 1) resulted in the highest yield at 92.35%, followed by air frying (Treatment 2) at 89.25%. The lowest yield was observed in grilling (Treatment 3), at 82.60%, while microwaving (Treatment 4) recorded a yield of

86.00%. This suggests that cooking methods involving lower moisture loss tend to retain more product weight.

Effect of Cooking Methods on Proximate Composition of Chicken Nuggets: The proximate composition of chicken nuggets was significantly influenced by the cooking method ($p < 0.05$), particularly in ash and dry matter content, as shown in Table 2. Grilling (Treatment 3) resulted in significantly higher ash (2.79%) and dry matter content (63.04%) compared to other methods. Deep frying, on the other hand, recorded the lowest values for ash (2.30%) and dry matter (55.87%). However, no significant differences were observed in crude protein, ether extract, and crude fibre content among treatments.

Crude protein ranged from 30.70% in microwaved nuggets to 33.32% in deep-fried nuggets. Ether extract levels were slightly higher in deep-fried samples (8.63%) and lowest in grilled nuggets (8.08%). Crude fibre content ranged narrowly from 0.90% to 1.05%, with the highest value found in grilled nuggets. Moisture content (MC) was inversely related to dry matter content, with the highest MC in deep-fried nuggets (44.20%) and the lowest in grilled samples (36.88%).

Table 2: Effects of different cooking methods on proximate composition of chicken nuggets

Parameters	Deep frying	Air frying	Grilling	Microwaving	SEM
%CP	33.32	32.22	32.16	30.7	1.12
%ASH	2.3 ^c	2.53 ^b	2.79 ^a	2.27 ^c	0.05
%EE	8.63	8.33	8.08	8.54	0.37
%CF	0.98	0.98	1.05	0.9	0.15
%DM	55.87 ^c	58.51 ^b	63.04 ^a	58.62 ^b	0.56
%MC	44.2 ^a	41.57 ^b	36.88 ^c	39.9 ^b	0.49

($p < 0.05$) ^{a,b,c}: means with different superscripts along the same column are significantly different $\alpha_{0.05}$

SEM: Standard Error of Mean

CP: Crude Protein, EE: Ether Extract, CF: Crude Fiber, DM: Dry Matter, MC: Moisture Content

Note: Means with different superscripts within the same row are significantly different ($p < 0.05$).

Interaction of Cooking Methods and Storage Days on Proximate Composition:

A significant interaction ($p < 0.05$) between cooking method and storage duration was observed for all proximate parameters. As shown in Table 3, crude protein (CP) peaked at 43.79% on day 14 in deep-fried samples, while the lowest value (22.20%) occurred in deep-fried nuggets on day 7. Ash content was highest (3.10%) on day 7 in air-fried nuggets, and lowest (2.12%) in deep-fried samples on day 14.

Ether extract values increased over time, with the highest (12.13%) observed in air-fried nuggets on day 14. Crude fibre was initially high (2.44%) in grilled samples on day 0 but became undetectable in all treatments by day 14. Dry matter content reached its highest value (65.41%) in grilled nuggets on day 21, while the lowest (51.52%) was seen in microwaved nuggets on day 0.

*Chicken nugget quality: impact of cooking methods***Table 3: Effects of cooking methods and days of storage proximate composition of chicken nuggets prepared using different cooking methods**

Days	Treatment	%CP	%Ash	%EE	%CF	%DM	%MC
Day 0	Deepfrying	25.12 ^m	2.6 ^{cde}	6.70 ^e	2.15 ^c	55.23 ^l	44.89 ^b
	Airfrying	25.54 ^l	2.30 ^{gh}	5.06 ^g	2.37 ^b	60.66 ^c	39.62 ^h
	Grilling	25.98 ^k	2.74 ^{bc}	6.19 ^{ef}	2.44 ^a	61.51 ^d	38.4 ⁱ
	Microwaving	29.23 ⁱ	2.44 ^{fg}	7.07 ^e	2.13 ^c	51.52 ^m	42.43 ^d
Day7	Deepfrying	22.2 ^p	2.2 ^h	6.17 ^{ef}	1.78 ^d	51.53 ^m	48.63 ^a
	Airfrying	22.63 ^o	3.10 ^a	5.47 ^{fg}	1.55 ^c	57.64 ⁱ	42.4 ^d
	Grilling	23.14 ⁿ	2.8 ^b	5.55 ^{fg}	1.77 ^d	60.66 ^c	39.11 ⁱ
	Microwaving	26.43 ^j	2.15 ^h	6.17 ^{ef}	1.46 ^f	61.72 ^c	38.43 ^j
Day14	Deepfrying	43.79 ^a	2.12 ^h	11.57 ^{ab}	0.00 ^g	59.64 ^f	40.36 ^g
	Airfrying	41.21 ^c	2.53 ^{ef}	12.13 ^a	0.00 ^g	58.46 ^h	41.54 ^e
	Grilling	40.32 ^d	2.99 ^a	11.03 ^{bc}	0.00 ^g	64.57 ^b	35.43 ^l
	Microwaving	34.17 ^g	2.23 ^h	11.5 ^{ab}	0.00 ^g	61.81 ^c	38.19 ^k
Day21	Deepfrying	42.17 ^b	2.27 ^{gh}	10.1 ^{cd}	0.00 ^g	57.09 ^k	42.91 ^c
	Airfrying	39.5 ^e	2.18 ^h	10.67 ^{bc}	0.00 ^g	57.27 ^j	42.73 ^c
	Grilling	39.20 ^f	2.63 ^{bcd}	9.57 ^d	0.00 ^g	65.41 ^a	34.59 ^m
	Microwaving	32.97 ^h	2.27 ^{gh}	9.43 ^d	0.00 ^g	59.44 ^g	40.56 ^f
SEM		1.12	0.05	0.37	0.15	0.56	0.49

($p < 0.05$) a,b,c,d,e,f,g,h,i,j,k,l,m,n,o,p: means with different superscripts along the same column are significantly different $\alpha_{0.05}$

SEM: Standard Error of Mean

CP: Crude Protein, EE: Ether Extract, CF: Crude Fiber, DM: Dry Matter, MC: Moisture Content

Effect of Cooking Methods on Physicochemical Properties of Chicken Nuggets: Cooking methods had no significant effect ($p > 0.05$) on most physicochemical parameters of chicken nuggets, except for total fungal counts (TFC), which was significantly ($p < 0.05$) higher in microwaved nuggets (2.22×10^2 cfu/g) and lowest in air-fried samples (1.46×10^2 cfu/g). Total bacterial counts (TBC) were slightly higher in deep-fried nuggets (4.23×10^5 cfu/g) compared to grilled ones (3.95×10^5 cfu/g). Lipid oxidation measured through TBARS was highest in

microwaved nuggets (2.71 mg MDA/100g) and lowest in deep-fried samples (2.38 mg MDA/100g). pH values remained similar across treatments, ranging from 5.69 in grilled to 5.86 in microwaved samples.

Interaction of Cooking Methods and Storage Duration on Physicochemical Properties: A significant interaction ($p < 0.05$) was observed between cooking methods and storage time on physicochemical characteristics (Table 4).

Table 4: Effect of storage days and cooking methods on physicochemical and microbial properties of chicken nuggets

Days	Treatments	TBC (cfu/g X10 ⁻⁵)	TFC (cfu/g X10 ⁻²)	TBARS (mgMDA/100g)	pH
Day 0	Deep frying	5.22 ^f	2.17 ^d	3.13 ^{bc}	6.12 ^a
	Air frying	5.64 ^d	1.17 ^{gh}	3.09 ^{bc}	6.00 ^{bc}
	Grilling	4.98 ^g	1.20 ^{gh}	3.50 ^b	5.92 ^c
	Microwaving	5.38 ^e	1.93 ^e	4.32 ^a	6.16 ^a
Day 7	Deep frying	6.34 ^c	2.74 ^b	2.53 ^{cde}	5.94 ^c
	Air frying	6.66 ^b	2.35 ^{cd}	2.81 ^{cd}	5.91 ^c
	Grilling	6.81 ^a	3.08 ^a	2.01 ^{ef}	5.76 ^d
	Microwaving	6.85 ^a	2.55 ^{bc}	1.90 ^{ef}	5.94 ^c
Day14	Deep frying	2.14 ^j	1.07 ^{gh}	2.287 ^{de}	6.07 ^{ab}
	Air frying	1.66 ^k	1.00 ^h	2.37 ^{de}	6.02 ^{bc}
	Grilling	1.10 ^l	1.00 ^h	2.07 ^{ef}	5.98 ^{bc}
	Microwaving	1.67 ^k	1.90 ^e	2.04 ^{ef}	6.07 ^{ab}
Day21	Deep frying	3.20 ^h	1.63 ^f	1.57 ^f	5.22 ^c
	Air frying	3.26 ^h	1.30 ^g	2.48 ^{cde}	5.01 ^g
	Grilling	2.90 ⁱ	1.66 ^f	2.11 ^{ef}	5.12 ^f
	Microwaving	3.27 ^h	2.50 ^{bc}	2.56 ^{cde}	5.25 ^c
SEM		0.28	0.10	0.11	0.06

a,b,c,d,e,f,g,h,i,j,k: means with different superscripts along the same column are significantly different $\alpha_{0.05}$

SEM: Standard Error of Mean

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Total bacterial counts (TBC) increased sharply by day 7, with the highest value of 6.85×10^5 cfu/g found in microwaved nuggets, then declined by day 21 across all treatments. Grilled samples had the lowest TBC on day 14 (1.10×10^5 cfu/g). Fungal counts followed a similar pattern, peaking on day 7 and decreasing thereafter.

Lipid oxidation was highest (4.32 mg MDA/100g) in microwaved nuggets on day 0 and declined over time, with the lowest value (1.57 mg MDA/100g) recorded in deep-fried samples on day 21. The pH values followed a decreasing trend with time, with the highest pH (6.16) at day 0 in microwaved samples and the lowest (5.01) at day 21 in air-fried samples.

Effect of Cooking Methods and Storage Days on Sensory Attributes: The sensory evaluation (Table 5) revealed that air frying on day 21 yielded the most acceptable chicken nuggets, with significantly ($p < 0.05$) higher scores for colour (8.44), flavour (8.44), aroma (8.33), tenderness (8.11), juiciness (8.33), and overall acceptability (8.78). In contrast, grilling on day 7 recorded the lowest scores for colour (5.56), flavour (6.56), aroma (6.56), juiciness (5.11), and overall acceptability (6.44). This suggests that air frying maintains the sensory qualities of nuggets better over time.

Table 7. Effect of cooking methods and days of storage on sensory attributes of chicken nuggets

Days	Treatments	Colour	Flavour	Aroma	Tenderness	Juiciness	Overall Acceptability
Day0	Deepfrying	7.67 ^{abc}	7.67 ^{ab}	8.00 ^a	7.22 ^{ab}	7.782 ^{abc}	8.33 ^{ab}
	Airfrying	7.78 ^{abc}	7.67 ^{ab}	7.22 ^{ab}	7.33 ^{ab}	7.22 ^{abc}	7.67 ^{abc}
	Grilling	7.56 ^{abc}	7.78 ^{ab}	7.44 ^{ab}	7.33 ^{ab}	6.44 ^c	7.78 ^{abc}
	Microwaving	7.67 ^{abc}	7.44 ^{ab}	7.56 ^{ab}	7.44 ^{ab}	7.33 ^{abc}	7.78 ^{abc}
Day 7	Deepfrying	7.89 ^{abc}	8.56 ^a	8.33 ^a	8.22 ^a	7.44 ^{abc}	8.003 ^{ab}
	Airfrying	6.56 ^{cd}	7.67 ^{ab}	7.11 ^{ab}	5.44 ^d	6.67 ^{bc}	7.33 ^{bc}
	Grilling	5.56 ^d	6.56 ^b	6.56 ^b	5.78 ^{cd}	5.11 ^d	6.44 ^c
	Microwaving	8.00 ^{ab}	7.33 ^{ab}	7.22 ^{ab}	7.22 ^{ab}	7.22 ^{abc}	7.33 ^{bc}
Day14	Deepfrying	7.78 ^{abc}	7.11 ^{ab}	7.33 ^{ab}	8.00 ^a	7.67 ^{abc}	7.78 ^{abc}
	Airfrying	7.56 ^{abc}	7.44 ^{ab}	7.78 ^{ab}	6.56 ^{bcd}	7.00 ^{abc}	7.44 ^{abc}
	Grilling	7.89 ^{abc}	7.33 ^{ab}	7.00 ^{ab}	7.44 ^{ab}	7.44 ^{abc}	7.11 ^{bc}
	Microwaving	6.89 ^{bc}	6.56 ^b	7.11 ^{ab}	6.89 ^{abc}	7.33 ^{abc}	7.22 ^{bc}
Day21	Deepfrying	8.00 ^{ab}	8.228 ^a	8.11 ^a	7.78 ^{ab}	7.78 ^{abc}	8.44 ^{ab}
	Airfrying	8.44 ^a	8.44 ^a	8.33 ^a	8.11 ^a	8.33 ^a	8.78 ^a
	Grilling	7.78 ^{abc}	8.22 ^a	8.22 ^a	7.56 ^{ab}	8.22 ^{ab}	8.00 ^{ab}
	Microwaving	7.78 ^{abc}	8.11 ^a	7.78 ^{ab}	8.112 ^a	8.00 ^{abc}	8.22 ^{ab}
SEM		0.11	0.12	0.11	0.12	0.13	0.11

($p > 0.05$) abc: means with different superscripts along the same column are significantly different $\alpha_{0.05}$

SEM: Standard Error of Mean

Effect of Cooking Methods on Total Heterocyclic Aromatic Amines (THAA): The levels of THAA varied with the method of cooking. As shown in Figure 1, grilling (Treatment 3) produced the highest level of THAA (63.47 $\mu\text{g/kg}$), whereas deep frying (Treatment

1) recorded no detectable amount (0.00 $\mu\text{g/kg}$). Air frying and microwaving had moderate values, indicating that grilling poses the highest health risk in terms of carcinogenic compounds.

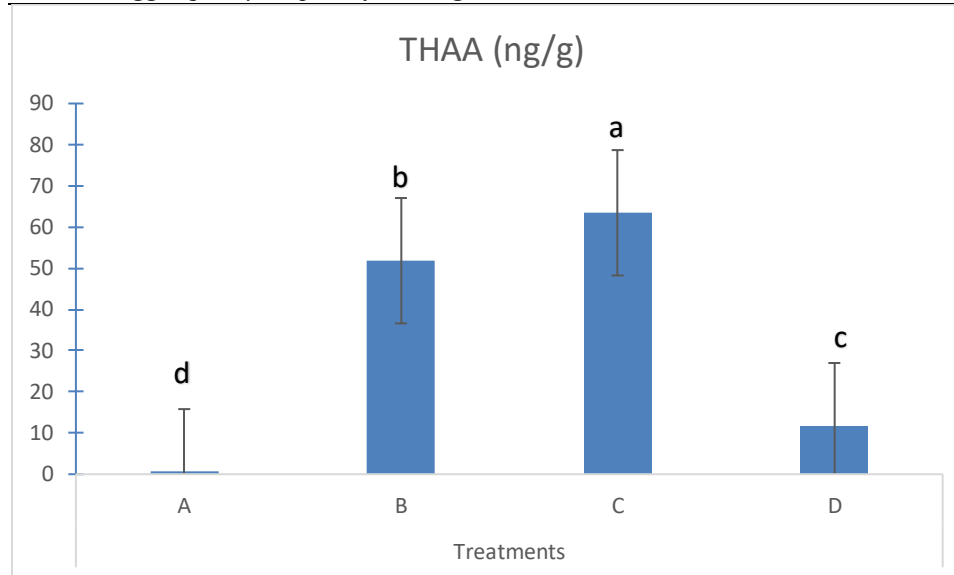
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Figure 1: Showing effects of different cooking methods on the formation of Total Heterocyclic Aromatic Amines (THAA) in chicken nuggets

THAA: Total Heterocyclic Aromatic Amines

A: Deep frying, B: Air frying, C: Grilling, D: Microwaving

Discussion

The findings from this study demonstrate that cooking methods significantly influence the nutritional quality, physicochemical characteristics, and sensory attributes of chicken nuggets, with variations also observed over storage duration. These results provide critical insights into optimizing meat processing practices, particularly in the context of enhancing food safety, nutritional value, and consumer acceptability.

Cooking methods impacted the yield of chicken nuggets, with deep frying producing the highest yield (92.35%), likely due to oil uptake and reduced moisture loss. Conversely, grilling, which applies dry heat directly, resulted in the lowest yield (82.60%), reflecting higher evaporation rates. These outcomes align with existing literature that identifies oil-based cooking as effective in retaining product mass due to lower dehydration (McDermott et al. 2015).

The proximate composition was significantly influenced by cooking method, particularly in terms of dry matter and ash content. Grilling resulted in the highest dry matter (63.04%) and ash (2.79%), suggesting higher concentration of nutrients due to moisture loss. In contrast, deep-fried samples had the highest moisture content (44.20%) and the lowest dry matter (55.87%). These trends reflect the inverse relationship between water loss and concentration of other components. The variation in ash content suggests differences in mineral retention or leaching depending on the cooking environment. This aligns

with evidence that preparation techniques significantly affect micronutrient profiles of food (Yazdanpanah et al. 2023).

Crude protein values ranged narrowly among treatments, with deep frying yielding the highest (33.32%) and microwaving the lowest (30.70%). The minimal variation suggests limited protein denaturation across methods, though slight differences may be due to thermal degradation or solubilization of protein during cooking (Korir et al. 2024). Ether extract content was also slightly elevated in deep-fried samples (8.63%), likely due to oil absorption, while grilling resulted in the lowest fat content (8.08%). Crude fibre content was generally low across all treatments, with no significant differences, and it declined completely by day 14 of storage, suggesting degradation of fibrous materials over time.

Storage duration, in interaction with cooking methods, significantly influenced all proximate parameters. Crude protein increased over storage in some treatments, peaking at 43.79% in deep-fried samples on day 14, possibly due to moisture loss concentrating the nutrients. Dry matter and fat content also followed similar trends. These dynamics underscore the importance of evaluating not just immediate but also post-processing nutrient stability, particularly for value-added meat products intended for storage.

Cooking methods also affected the physicochemical properties of chicken nuggets, with significant differences noted in total fungal counts (TFC).

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Microwaved nuggets had the highest TFC (2.22×10^2 cfu/g), while air-fried samples had the lowest (1.46×10^2 cfu/g), suggesting that dry heat in air frying may offer better microbial control. Lipid oxidation, measured by TBARS, was highest in microwaved nuggets (2.71 mg MDA/100g), indicating increased susceptibility to oxidative rancidity, potentially due to the rapid and uneven heating nature of microwave cooking. These values declined with storage, particularly in deep-fried samples, indicating the protective effect of oil immersion in limiting oxygen exposure. These findings are consistent with studies highlighting how cooking technique influences shelf stability and microbial safety (Ojo et al. 2021).

The interaction of storage time and cooking method also affected microbial load, pH, and lipid oxidation. Total bacterial counts (TBC) increased initially but declined by day 21, potentially due to nutrient depletion or the presence of inhibitory compounds from cooking. The pH decreased over time in all treatments, indicating increasing acidity during storage—possibly from microbial metabolism or lipid oxidation by-products (Food and Affordable 2022). Notably, grilled and air-fried nuggets showed better microbial stability over time, suggesting that dry heat may offer extended preservation benefits compared to microwave or oil-based cooking.

Sensory attributes were highest for air-fried nuggets evaluated on day 21, with significant scores in colour, aroma, tenderness, and overall acceptability. This indicates that air frying not only retains sensory quality over time but may even enhance it, possibly due to Maillard browning and controlled dehydration. Conversely, grilled samples on day 7 recorded the lowest acceptability, likely due to increased dryness and textural toughness. These findings align with Keeley et al. (2019), who argue that food preparation methods significantly influence consumer perception and satisfaction.

A major health-related concern in meat processing is the formation of carcinogenic compounds such as heterocyclic aromatic amines (HAA). This study found that grilled nuggets contained the highest level of total HAA (63.47 µg/kg), while deep-fried samples had none detected. The high HAA concentration in grilled products confirms the association between direct dry-heat cooking and the formation of harmful compounds, as also reported by Yazdanpanah et al. (2023). Microwaving and air frying produced moderate HAA levels, indicating that while they reduce oil use and preserve nutrients, they may still pose some risk depending on duration and temperature. This suggests a trade-off between sensory quality, nutrient retention, and safety, which

must be carefully balanced in meat processing practices.

Overall, these results suggest that air frying presents the best compromise among cooking methods, offering high sensory acceptability, moderate nutrient retention, lower microbial loads, and reduced formation of hazardous compounds. Grilling, while producing a nutrient-dense product, also increases the risk of HAA formation and moisture loss, affecting both safety and palatability. These insights reinforce the importance of integrating food science with consumer safety in value-added product development (Mancone et al. 2024).

Conclusions

This study concludes that cooking methods significantly influence the nutritional quality, safety, and sensory attributes of chicken nuggets, with air frying emerging as the most favourable technique. It consistently delivered high sensory scores, moderate fat content, low microbial loads, and reduced formation of harmful compounds such as heterocyclic aromatic amines. While deep frying improved yield and protein content, it also increased lipid levels and microbial risk. Grilling enhanced nutrient concentration but resulted in the highest HAA levels, raising safety concerns, and microwaving offered moderate outcomes across most parameters. These findings highlight the need to carefully consider cooking methods in the development of meat-based products to ensure optimal nutritional value, consumer acceptability, and food safety.

Availability of data and material: The datasets during and/or analysed during the current study available from the corresponding author on reasonable request.

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References

- AOAC (2011). *Official Methods of Analysis of AOAC International*, 18th edn, AOAC International, Gaithersburg, pp. 2590.
- Ab Aziz MF, Hayat MN, Kaka U, Kamarulzaman NH & Sazili AQ (2020). Physico-chemical characteristics and microbiological quality of broiler chicken pectoralis major muscle subjected to different storage temperature and duration. *Foods*, 9(6): 741.

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- Abd-El-Aziz NA, El Sesy TA & Hashem SM (2021). Evaluation of Nutritional Value and Acceptability of Chicken Nuggets Produced by Chicken Wings and Dehydrated Shellfish. *Food and Nutrition Sciences*, 12(08): 805–817. <https://doi.org/10.4236/fns.2021.128060>
- Adeyemi IA & Osilesi O (2012). Influence of frying on the nutritional and sensory qualities of soy-tiger nut composite flour fried snacks. *Journal of Food Processing and Preservation*, 36(4): 348–355.
- Akanbi CT, Gureje BO & Adeyemi IA (2013). Effect of processing methods on the properties of instant yam bean (*Sphenostylis stenocarpa*) flour. *International Journal of Food Science and Technology*, 48(5): 1051–1057.
- Al-Ruzzeh S, Al-Qadiri HM & Rasco BA (2018). Influence of cooking methods on the quality and safety of meat. *Journal of Food Quality*, 2018: 1–8.
- Amini MR, Rostami H, Razavi SH, Safari M & Javadian SR (2018). Optimization of chicken nugget processing using response surface methodology. *Food Science and Nutrition*, 6(5): 1102–1112.
- Alpers T, Kerpess R, Frioli M, Nobis A, Hoi KI, Bach A & Becker T (2021). Impact of storing condition on staling and microbial spoilage behavior of bread and their contribution to prevent food waste. *Foods*, 10(1): 76.
- Babatunde OA & Adewumi AO (2015). Effects of ethanolic extract of garlic, roselle and ginger on quality attributes of chicken patties. *African Journal of Biotechnology*, 14(8): 688–694.
- Barbut S & Leishman EM (2022). Quality and processability of modern poultry meat. *Animals*, 12(20): 2766.
- Dave D & Ghaly AE (2011). Meat spoilage mechanisms and preservation techniques: a critical review. *American Journal of Agricultural and Biological Sciences*, 6(4): 486–510.
- De Leon JAD & Borges CR (2020). Evaluation of oxidative stress in biological samples using the thiobarbituric acid reactive substances assay. *Journal of Visualized Experiments: JoVE*, (159).
- Delgado-Pando G, Fischer ARH, Tobi H & van Boekel MAJS (2020). Chicken consumers' motivation and interpretation of the label regarding salt and fat reduction and animal welfare. *Food Quality and Preference*, 86: 104023.
- Faloye OR, Sobukola OP, Shittu TA, Bakare HA, Omidiran AT, Akinlade FA & Bamidele OP (2024). Effect of different starches in batter formulation on oil content and associated quality attributes of fried chicken nuggets. *Food Production, Processing and Nutrition*, 6(1): 40. <https://doi.org/10.1186/s43014-023-00214-4>
- Honegger LT, Bryan EE, Price HE, Ruth TK, Boler DD & Dilger AC (2021). The effect of cooking method and cooked color on consumer acceptability of boneless pork chops. *Foods*, 11(1): 106.
- James OP, Adeyemi TA & Adebayo AA (2017). Effect of different cooking methods on the proximate composition and sensory properties of chicken nuggets. *Journal of Food Science and Nutrition*, 5(3): 123–130.
- Kataria J, Garner LJ, Monu EA, Wang Y & Morey A (2020). Investigating the effects of Functional Ice (FICE) on Salmonella-food safety, microbial spoilage and quality of raw poultry thigh meat during refrigerated storage. *PLoS One*, 15(6): e0234781.
- Knipe LS & Koutsidis G (2017). Impact of frying on the nutritional value of food: general overview. In RJR Bajaj (ed.), *Food Processing Technologies: Impact on Product Attributes*, pp. 281–297. CRC Press.
- Knize MG & Felton JS (2005). Formation and human risk of carcinogenic heterocyclic amines formed from natural precursors in meat. *Nutrition Reviews*, 63(5): 158–165.
- Lawless HT & Heymann H (2010). *Sensory Evaluation of Food: Principles and Practices*. Springer.
- Mancini RA & Hunt MC (2005). Current research in meat color. *Meat Science*, 71(1): 100–121.
- Mihaela G, Mira T, George B & Petru N (2010). Nutritional and health aspects related to frying (1). 15(6): 5675–5682.
- Naveena BM, Muthukumar M, Muthulakshmi L, Anjaneyulu ASR & Kondaiah N (2014). Effect of different cooking methods on lipid oxidation and microbial quality of vacuum-packaged emulsion products from chicken. *Journal of Food Processing and Preservation*, 38(1): 39–47.
- Ndukwe OK, Ejoh SI & Malu SP (2014). Effect of different cooking methods on the nutritional and phytochemical composition of soybean. *African Journal of Food Science*, 8(8): 418–423.
- Ogunsina BS, Radha C & Raghavarao KSMS (2011). Temperature-induced interactions of proteins during storage and the impact on textural and functional properties of chicken nuggets. *Journal of Food Engineering*, 103(1): 26–34.
- Olusola OO, Ezechi OC & Akintunde AF (2018). Comparative analysis of the effects of grilling, deep frying, and microwaving on the nutritional composition of meat products. *African Journal of Food Science*, 12(6): 150–157.

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- Osagie AU & Eka OU (2012). *Nutritional quality of plant foods*. University of Benin Press.
- Oz F & Kaya M (2011). Heterocyclic aromatic amines in meat. *Journal of Food Processing and Preservation*, 35(6): 739–753.
- Pan T, Wang Z, Chen BH, Hui T & Zhang D (2020). Frying oils with lower levels of saturated fatty acids induce less heterocyclic amine formation in meat floss (boiled, shredded and fried pork). *International Journal of Food Science & Technology*, 55(2): 823–832. <https://doi.org/10.1111/ijfs.14368>
- Shakeri M, Haghighi AH & Heshmati M (2020). Air frying as a promising technique for producing healthy fried products: a review. *Journal of Food Processing and Preservation*, 44(5): e14403.
- Silva AFD, Amaral AB & Machado TR (2019). The effects of marinating chicken breasts and grilling techniques on the formation of heterocyclic aromatic amines. *Food Research International*, 116: 105–112.
- Suleman R, Wang Z, Aadil RM, Hui T, Hopkins DL & Zhang D (2020). Effect of cooking on the nutritive quality, sensory properties and safety of lamb meat: current challenges and future prospects. *Meat Science*, 167: 108172.
- Tareke E, Rydberg P, Karlsson P, Eriksson S & Törnqvist M (2002). Analysis of acrylamide, a carcinogen formed in heated foodstuffs. *Journal of Agricultural and Food Chemistry*, 50(17): 4998–5006.
- Vieira ECS, Mársico ET, Conte-Junior CA, Damiani C, Canto AC, Monteiro MLG & Silva FAD (2018). Effects of different frying techniques on the color, fatty acid profile, and lipid oxidation of *Arapaima gigas*. *Journal of Food Processing and Preservation*, 42(11): e13820.
- Yi H, Zhang B, Chen X, Yao Y & Ma H (2019). Effects of different cooking methods on the bioaccessibility of nutritional compositions and antioxidant capacities of chicken liver. *Journal of Food Quality*, 2019: 1–8.
- Zhang W, Xiao S, Samaraweera H, Lee EJ & Ahn DU (2017). Improving functional value of meat products. *Meat Science*, 132: 89–95.