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ORIGINAL ARTICLE

Effects of Different Thermal Processing Methods and Enrichment on The Quality and Consumer Acceptability of Cassava Mash Based Extruded Snacks

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ABSTRACT

This study explored effects of heat processing and nutrient enrichment on the qualities of cassava- snacks. The snacks were prepared using three methods, baking, frying, and roasting, and were enriched with cocoa powder and desiccated coconut. Moisture levels ranged between 3.42% and 7.46%. Frying caused some nutrient loss, but enrichment boosted fibre and ash content, especially with desiccated coconut. Fried samples had the highest fat content (4.20% to 16.17%). Although protein levels decreased slightly after frying, enrichment significantly increased it from 4.04% to 12.24%. Potassium, zinc, calcium, iron, and magnesium also increased with enrichment. However, frying reduced the antioxidant benefits of cocoa powder. Enrichment also affected physical properties, reducing both snack length and lateral spread. Sensory tests showed fried snacks, particularly those with coconut, were the most appealing in taste, texture, and appearance. Overall, while frying improved sensory appeal, baking, and roasting were more effective in preserving nutritional and antioxidant properties.

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1. INTRODUCTION

Extrusion is a common food processing technique. It involves pushing a mixture of foods through a specially created opening (which is referred to as a die) to produce snacks or other food products that have specific textures and shapes (Bordoloi & Ganguly, 2014). This process helps in making products that are uniform in size and shape, and it also allows for creativity in producing a variety of snack types. According to Charles *et al.* (2016), extrusion can produce high-quality snacks, while Khanna *et al.* (2019) noted that it allows for a wide range of textures, colours, and shapes. This versatility has motivated the use of composite flours in developing new extruded snacks. Composite flours have been utilized to make foods like breakfast cereals and pasta, but comparatively fewer studies have been carried out using fermented cassava mash mixed with cocoa powder and desiccated coconut through extrusion. This is an area worth exploring, especially because these ingredients offer both nutritional and functional benefits.

Cassava is a major crop in food production in the majority of African countries. Cassava is mainly used as food, but some are used for animal feed. Cassava has a high concentration of carbohydrates and some necessary nutrients and vitamins (Bayata, 2019; Hidayat *et al.*, 2023). Cassava flour is used to make a variety of foods like strips, biscuits, porridges, pasta, and snacks (Dada *et al.*, 2018; Dudu *et al.*, 2020). However, since cassava has little protein, it is beneficial to add other foods that can improve the nutritional value of cassava (Jisha *et al.*, 2010).

Desiccated coconut, or dried and shredded coconut, contains healthy carbohydrates, fibre, and a minute amount of protein (Gunathilake *et al.*, 2009; Adeoye *et al.*, 2020). It does not contain gluten, and has a low glycaemic index, hence suitable for usage by people with diabetes or those suffering from gluten intolerance (Indian Food Industry, 2013; Nadanasabapathy & Kumar, 2013). Cocoa powder, on the other hand, is high in polyphenols and other bioactive substances that have been linked to several health benefits (Hii *et al.*, 2009; Glacometti *et al.*, 2015).

There is growing need for the application of food by-products and flours blends for the purpose of increasing the quality of nutrition of foods. For this reason, there is necessity to conduct research on new mixes of ingredients, especially those which had lesser application in the past. Accordingly, this study aims to create extruded snack food based on a mixture of fermented cassava mash, dried coconut, and cocoa powder. It also seeks to examine their sensory, chemical, and physical characteristics, thereby contributing to the creation of functional snacks.

2. METHODOLOGY

2.1 Production of Cassava mash mixes and Extruded Snacks

The traditional process for the production of fermented cassava mash, as reported by Obadina *et al.* (2012), was employed in addition to the traditional process for the production of desiccated coconut by Akinwotu *et al.* (2020) to produce cassava mash and desiccated coconut. Based on early experimental findings, blends of samples (water, fermented cassava mash, cocoa powder, and desiccated coconut) were weighed and blended in 70:0:0:30, 68:0:2:30, 54:16:0:30, and 52:16:2 proportions, which were labeled as Samples A, B, C, and D, respectively. The ingredients that were measured thoroughly blended and transferred into four different clean bowls. Sugar (16%) was added in equal amounts to each mixture and mixed thoroughly to create a batter, which was then portioned into three. Further specifics of the procedure appear in **Figure 1** and **Table 1**.

2.2 Chemical Analysis

2.2.1 Proximate Analysis

The ash, moisture, protein, fat and fiber of the extruded snacks were analyzed using the standard AOAC (2010) procedures. The carbohydrate content was quantified by difference.

2.2.2 Mineral Composition

The mineral composition (Zn, Fe, Mg) of the flour samples was investigated as reported by Tuncturk, *et al.* (2015) with the help of an atomic absorption spectrophotometer (Hitachi Z6100, Tokyo, Japan) while potassium and Calcium were determined by emission flame photometry method.

2.2.3 Analysis of Bioactive Constituents

The free radical scavenging ability of the extracts against DPPH free radical was determined as described by Gyamfi *et al.* (1999). The total phenol content was measured and expressed as gallic acid equivalent (GAE) as described by Singleton, *et al.* (1999).

2.3 Physical Properties of the Snacks

Physical properties determined included bulk density, apparent density, porosity, and lateral expansion. Bulk density was calculated based on the actual size of snacks using Thymi *et al.* (2005) method. Apparent density was tested based on Qiu *et al.* (2015) procedure method. Porosity was derived from bulk and apparent values, as specified by Qiu *et al.* (2015). Expansion laterally was determined using methods reported by Alvarez-Martinez *et al.* (1988) and Fan *et al.* (1996). Water absorption capacity of the snacks was assessed by a modified technique outlined by Malomo *et al.* (2012). Similarly, oil absorption capacity of all samples was evaluated by employing a modified technique of Beuchat (1977).

2.4 Sensory Properties of the Snacks

A preference test was conducted using a simple paired comparison. The participants on a 9-point hedonic scale, as indicated by Oluwamukomi *et al.* (2005) scored the snacks.

2.5 Statistical Analysis

The collected data were prepared in replicates and analyzed using one way Analysis of variance (ANOVA) of Statistical Package for Social Sciences (SPSS version 17.0). Means, which were significant, were separated using the Duncan's Multiple Range Test at 95% confidence interval.

Table 1: Sample Composition and Processing Methods

Sample Code	Description	Baking Code	Frying Code	Roasting Code
A	Cassava mash only	AB – Baked	AF – Fried	AR – Roasted
B	Cassava mash + 2% cocoa powder	BB – Baked	BF – Fried	BR – Roasted
C	Cassava mash + 16% desiccated coconut	CB – Baked	CF – Fried	CR – Roasted
D	Cassava mash + 2% cocoa powder + 16% desiccated coconut	DB – Baked	DF – Fried	DR – Roasted

Keys: 'A - Cassava-mash; B – Cassava-mash enriched with 2% cocoa powder; C – Cassava-mash enriched with 16% desiccated coconut; D – Cassava-mash enriched with 2% cocoa powder and 16% desiccated. AB - Baked Cassava-based extrudate; BB - Baked Cassava-based extrudate with 2% cocoa powder; CB - Baked Cassava-based extrudate with 16% desiccated. coconut; DB – Baked Cassava-based extrudate with 2% cocoa powder, 16% Desiccated Coconut Powder; AF – Fried Cassava-based extrudate; BF – Fried Cassava-based extrudate with 2% cocoa powder; CF – Fried Cassava-based extrudate with 16% desiccated coconut; DF - Fried Cassava-based extrudate with 2% cocoa powder, 16% desiccated coconut; AR - Roasted Cassava-based extrudate; CR – Roasted Cassava-based extrudate with 16% desiccated coconut; DR - Roasted Cassava-based extrudate with 2% cocoa powder and 16% desiccated Coconut.'

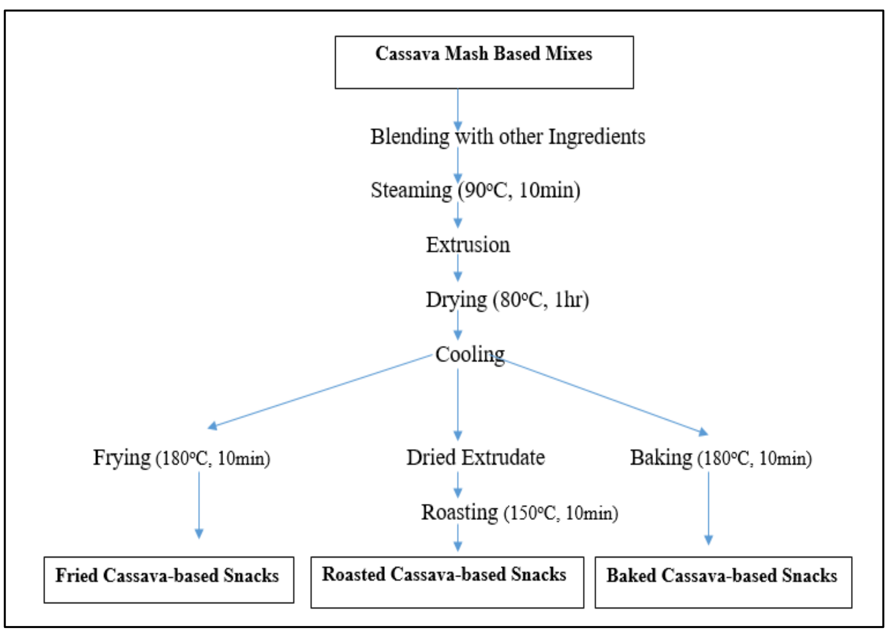

Fig. 1. Flow diagram for the production of cassava- based snacks

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3. RESULTS AND DISCUSSION

3.1 Proximate Composition of the Extruded Snacks

Proximate composition of maize and defatted coconut flour blends is presented in **Table 2**. The moisture content of the snacks varied from 3.42% to 7.46%. The moisture content of fried extruded snacks was found lower than roasted snacks. Frying decreased the moisture content considerably compared to baking and roasting ($p < 0.05$) due to the higher heat transfer coefficient. This is also due to the rapid evaporation upon frying at 180°C (Esturk *et al.*, 2000; Zhang *et al.*, 2021). The processed snacks all recorded a moisture content of less than 10%, the recommended level for flour snacks (Makinde and Ladipo, 2012), which prevents microbial growth and increases shelf life.

Ash content ranged between 2.82% and 3.85%, and its considerable increase was observed in enriched snacks as compared to non-enriched samples. Desiccated coconut notably increased ash content due to its high inherent levels (Adeloye, 2020). This finding is consistent with Sekinat *et al.* (2015), who observed similar increases with tigernut flour. Frying led to a slight decrease in ash content compared to baking and roasting (Omotosho *et al.*, 2015), likely due to the higher heat transfer coefficient. Fibre content ranged from 2.04% to 3.88%, influenced by the proportions of enriched ingredients. While processing methods impacted fibre content, frying did not significantly alter fibre levels compared to baking and roasting ($p > 0.05$). However, frying caused a reduction in fibre due to nutrient loss from hot oil immersion (Corrison and Jorge, 2005; Omotosho *et al.*, 2015). Fat content varied from 4.20% to 16.17%, with frying contributing the most due to oil absorption. The increased fat content, particularly in fried snacks, was significantly higher ($p < 0.05$) compared to baked and roasted snacks (Obadina *et al.*, 2013). Desiccated coconut also increased the fat content, which supported the findings of Adeloye (2020). Protein content ranged from 4.04% to 12.43%, with significant increase observed in snacks enriched with cocoa powder and desiccated coconut. This finding aligns with Mihiranie *et al.* (2017), who reported higher protein levels in snacks with defatted coconut flour. Despite the overall increase, frying led to a slight reduction in protein content due to high temperatures affecting nutrient structure (Omotosho *et al.*, 2015; Cao *et al.*, 2022). It could also be observed that baked and roasted snacks retained higher protein levels. Carbohydrate content ranged from 62.54% to 80.77%, with unenriched cassava mash snacks, which was baked showing the highest carbohydrate levels. This supports Mihiranie *et al.* (2017), who highlighted the high energy content of cassava-based snacks.

Table 2: Proximate Composition of the Roasted, Fried and Baked Extruded Snacks

Sample	Moisture (%)	Ash (%)	Fibre (%)	Fat (%)	Protein (%)	Carbohydrate (%)
AB	$5.59{\pm}0.01^{d}$	$3.05{\pm}0.03^{e}$	$2.18{\pm}0.05^{f}$	$4.20{\pm}0.02^{k}$	$4.21{\pm}0.02^{j}$	$80.77{\pm}0.04^{a}$
BB	$5.61{\pm}0.04^{d}$	$3.10{\pm}0.04^{d}$	$2.24{\pm}0.02^{e}$	$4.25{\pm}0.01^{j}$	$4.28{\pm}0.04^{i}$	$80.52{\pm}0.03^{b}$
CB	$5.19{\pm}0.04^{f}$	$3.85{\pm}0.02^{a}$	$3.78{\pm}0.01^{c}$	$8.36{\pm}0.04^{f}$	$11.85{\pm}0.02^{d}$	$66.97{\pm}0.01^{e}$
DB	$5.23{\pm}0.03^{e}$	$3.86{\pm}0.01^{a}$	$3.83{\pm}0.02^{b}$	$8.52{\pm}0.04^{e}$	$12.43{\pm}0.00^{a}$	$66.13{\pm}0.02^{f}$
AF	3.56 ± 0.02^{h}	$2.88{\pm}0.02^{g}$	$2.04{\pm}0.01^{g}$	$8.90{\pm}0.06^{c}$	$4.04{\pm}0.01^{k}$	$78.58{\pm}0.03^{d}$
BF	3.42 ± 0.01^{h}	$2.82{\pm}0.05^{h}$	$2.04{\pm}0.02^{g}$	$8.38{\pm}0.04^{f}$	$4.08{\pm}0.02^{k}$	$79.26{\pm}0.04^{c}$
CF	3.82 ± 0.02^{g}	3.21 ± 0.03^{c}	3.08 ± 0.05^{d}	$14.84{\pm}\ 0.04^{b}$	$11.24{\pm}\ 0.05^{e}$	63.81 ± 0.01^{h}
DF	3.84 ± 0.03^{g}	3.24 ± 0.03^{c}	3.10 ± 0.05^{d}	$16.17{\pm}\ 0.05^{a}$	$11.11{\pm}\ 0.03^{f}$	62.54 ± 0.03^{j}
AR	7.12 ± 0.04^{c}	3.02 ± 0.01^{f}	2.21 ± 0.03^{ef}	$4.79{\pm}\ 0.01^{h}$	$4.38{\pm}\ 0.03^{h}$	$78.70{\pm}\ 0.04^{c}$
BR	7.16 ± 0.01^{b}	3.00 ± 0.02^{f}	2.19 ± 0.02^{f}	4.37 ± 0.02^{i}	4.48 ± 0.02^{g}	$78.76{\pm}\ 0.02^{c}$
CR	7.44 ± 0.05^{a}	3.85 ± 0.04^{a}	3.88 ± 0.01^{a}	8.34 ± 0.02^{g}	$11.93{\pm}\ 0.04^{c}$	$65.23{\pm}\ 0.03^{g}$
DR	7.46 ± 0.02^{a}	$3.81{\pm}\ 0.05^{b}$	3.85 ± 0.01^{b}	8.72 ± 0.03^{d}	$12.24{\pm}\ 0.02^{b}$	$63.61{\pm}\ 0.01^{i}$

Values are means of triplicate determinations ± standard deviation. The mean values along the same row with different superscripts are significantly different ($p < 0.05$) using Duncan multiple ranged test
KEYS: 'AB - Baked Cassava-based extrudate ; BB - Baked Cassava-based extrudate with 2% cocoa powder; CB - Baked Cassava-based extrudate with 16% desiccated coconut; DB - Baked Cassava-based extrudate with 2% cocoa powder and 16% Desiccated Coconut Powder; AF - Fried Cassava-based extrudate; BF - Fried Cassava-based extrudate with 2% cocoa powder; CF - Fried Cassava-based extrudate with 16% desiccated coconut; DF - Fried Cassava-based extrudate with 2% cocoa powder and 16% desiccated coconut; AR - Roasted Cassava-based extrudate; ; BR - Roasted Cassava-based extrudate with 2% cocoa powder; CR - Roasted Cassava-based extrudate with 16% desiccated coconut; DR - Roasted Cassava-based extrudate with 2% cocoa powder and 16% desiccated Coconut'.

3.2 Mineral Composition of the Baked, Fried and Roasted Extruded Snacks

Table 3 presents the mineral composition of processed cassava-mash snacks, including potassium, zinc, iron, calcium, and magnesium, measured in mg/100g. The potassium content ranged from 4.17 to 325.45 mg/100g across baked, fried, and roasted snacks. Enrichment with desiccated coconut and cocoa powder increased potassium levels in baked, fried, and roasted snacks. Desiccated cocoa and coconut powder with 2300 mg/100g and 1060 mg/100g significantly increased potassium content ($p < 0.05$) of the snacks. Frying at 180°C for 10 minutes may be the cause for the decrease in potassium content of fried snacks, according to Omotosho *et al.* (2015) and González-Casado and Mateos (2023). Zinc content ranged from 1.40 to 3.88 mg/100g, with desiccated coconut significantly increasing zinc content ($p < 0.05$) due to the high value of zinc (41.02 mg/100g). Fried snacks had a slight decrease in zinc, likely due to lower heat transfer efficiency (Pimpaporn, 2007).

Iron content varied from 1.36 to 8.81 mg/100g. Desiccated coconut and cocoa powders contributed appreciably to the iron content ($p < 0.05$). Frying reduced the iron content compared to baking and roasting (Omotosho *et al.*, 2015). Calcium content ranged from 5.06 to 38.25 mg/100g and the addition of desiccated coconut and cocoa powder significantly raised the calcium content ($p < 0.05$) due to its high calcium content (477.412 mg/100g and 127.886 mg/100g respectively). Processing significantly affected the calcium content of the snacks. Magnesium content ranged from 1.17 to 229.71 mg/100g. It can be noted that desiccated coconut and cocoa powder had 1815.10 mg/100g and 555.34 mg/100g of magnesium respectively. Accordingly, desiccated coconut and cocoa powder increased magnesium levels significantly ($p < 0.05$). Furthermore, comparing processes, frying tended to reduce the magnesium content in general. This agrees with Omotosho *et al.*, (2015) who reported frying led to a reduction in magnesium content.

3.3 Antioxidant Properties of the Snacks

The effects of enrichment on the DPPH (2-Diphenyl-1-picryhydrazyl) radical scavenging inhibitions and TPC of processed extruded snacks (AB – DR) are presented in **Figures 2** and **3** respectively. The DPPH scavenging inhibition of the processed snacks ranged from 53.90% -60.30%, respectively. It was noted that heat treatments such as baking, frying, and roasting had effect on the DPPH of the snacks.

Enrichment with cocoa powder significantly affected ($p < 0.05$) the DPPH scavenging inhibition in the processed snacks, perhaps due to the excellent radical scavenging ability of cocoa powder (Miller *et al.*, 2008; Odunlade *et al.*, 2016). No significant difference was observed in the DPPH values of the snacks although fried snacks showed a slight decrease in DPPH radical scavenging ability compared to baked and roasted snacks. Hwang *et al.* (2012) also reported that thermal processing, like frying, reduced antioxidant radical scavenging activity in vegetables like carrots, onions, and peppers, as also observed in the present study. In addition, incorporation of ingredients like oil and sugar may also be responsible for the reduced levels of antioxidants and lower scavenging activity of the processed snacks (Patras, 2010; Dinstel, 2013).

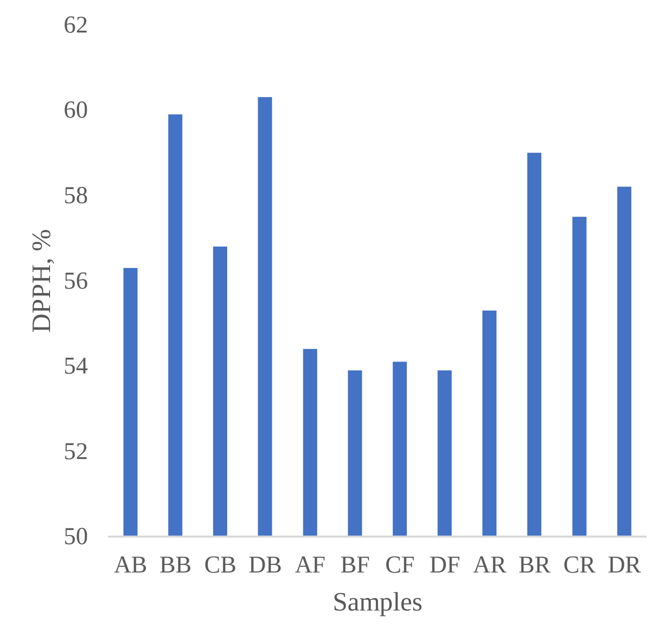

Fig. 2. DPPH of Baked, Fried and Roasted Cassava based Extruded Snacks. AB - Baked Cassava-based extrudate ; BB - Baked Cassava-based extrudate with 2% cocoa powder; CB - Baked Cassava-based extrudate with 16% desiccated coconut; DB - Baked Cassava-based extrudate with 2% cocoa powder and 16% Desiccated Coconut Powder; AF - Fried Cassava-based extrudate; BF - Fried Cassava-based extrudate with 2% cocoa powder; CF - Fried Cassava-based extrudate with 16% desiccated coconut; DF - Fried Cassava-based extrudate with 2% cocoa powder and 16% desiccated coconut; AR - Roasted Cassava-based extrudate; ; BR - Roasted Cassava-based extrudate with 2% cocoa powder; CR - Roasted Cassava-based extrudate with 16% desiccated coconut; DR - Roasted Cassava-based extrudate with 2% cocoa powder and 16% desiccated Coconut'.

Effect of enrichment **(Figure 3)** on total phenolic content of processed cassava snack shows that the total phenolic content of the processed snacks (baked, fried and roasted) ranged from 15.20 to 27.90%, 14.70 to 27.40% and 14.70 to 28.90% respectively. Total phenolic content (TPC) of processed cassava-mash snacks was significantly enhanced ($p < 0.05$) by the addition of cocoa powder. This can be explained by the fact that cocoa powder contains high phenolic content (Gunathilake *et al.*, 2009; Odunlade *et al.*, 2016). Alternatively, the increase can be explained by the formation of new antioxidants in the form of Maillard reaction products due to heat processing (Pokorny, 2007). Maillard reactions, which involve condensation between amino acids and sugars, have been linked to polyphenols and strong antioxidant compounds (Jokic, 2004; Lee and Park, 2005). It was also noticed that fried snacks with cocoa powder had slightly lower TPC than baked and roasted snacks, possibly due to reduced solubility of polyphenols and flavonoids in oil (Aladedunye and Przybylski, 2009). Overall, baking and roasting processes could enhance the TPC in processed cassava-mash snacks.

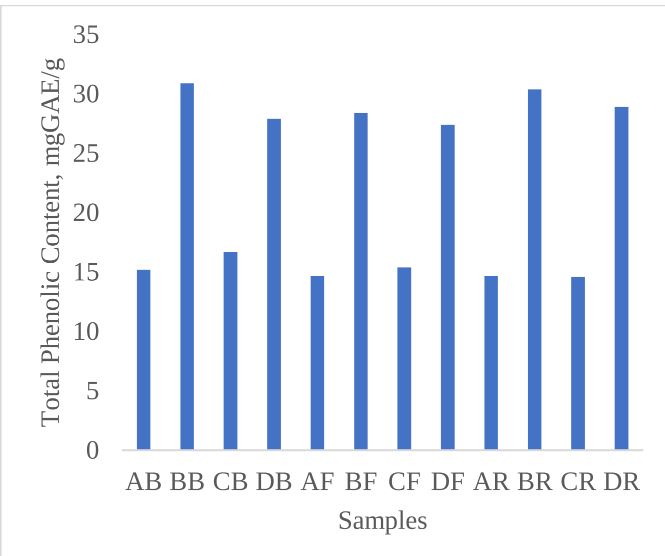

Fig. 3. Total Phenolic Content of Baked, Fried and Roasted Cassava based Extruded Snacks. AB - Baked Cassava-based extrudate ; BB - Baked Cassava-based extrudate with 2% cocoa powder; CB - Baked Cassava-based extrudate with 16% desiccated coconut; DB - Baked Cassava-based extrudate with 2% cocoa powder and 16% Desiccated Coconut Powder; AF - Fried Cassava-based extrudate; BF - Fried Cassava-based extrudate with 2% cocoa powder; CF - Fried Cassava-based extrudate with 16% desiccated coconut; DF - Fried Cassava-based extrudate with 2% cocoa powder and 16% desiccated coconut; AR - Roasted Cassava-based extrudate; ; BR - Roasted Cassava-based extrudate with 2% cocoa powder; CR - Roasted Cassava-based extrudate with 16% desiccated coconut; DR - Roasted Cassava-based extrudate with 2% cocoa powder and 16% desiccated Coconut.

3.4 Physical Properties of the Snacks

Water absorption capacity (WAC) of the snacks is indicated in **Figure 4**. WAC of the processed snacks at room temperature and at 60, 70, 80, and 90°C ranged from 154% to 282%, 180% to 290%, 210% to 349%, 234% to 392%, and 310% to 467%, respectively. WAC of the hot snacks significantly increased ($p < 0.05$) with rising temperatures. The increased WAC would likely be a result of heat treatment effects as gelatinization (Leonard *et al.*, 2015). Gelatinization also influences texture and functionality in terms of enhancing molecular breakdown (Korkerd *et al.*, 2016). Among the different processing methods, frying had a significant effect ($p < 0.05$) on WAC compared to roasting and baking. The reduced WAC in fried snacks is likely due to their higher oil absorption and retention, which limits their water absorption capacity, supporting the notion that amylose-lipid complexes can restrict water absorption (Oikonomou *et al.*, 2012).

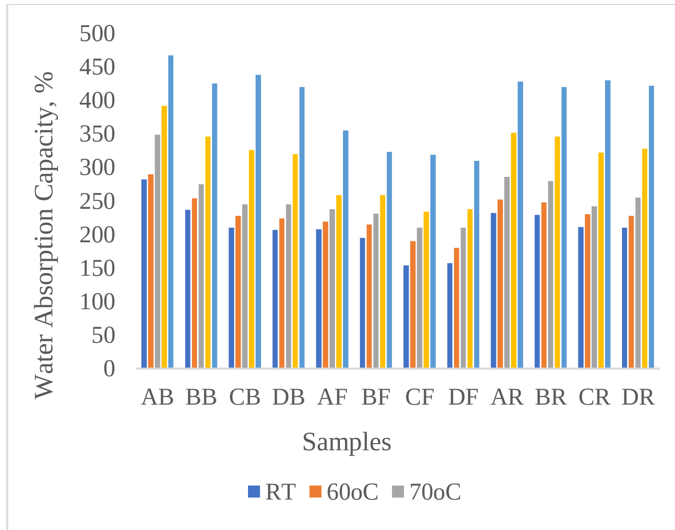

Fig. 4. Water absorption Capacity of Enriched Cassava Based Snacks. 'AB - Baked Cassava-based extrudate ;BB - Baked Cassava-based extrudate with 2% cocoa powder; CB - Baked Cassava-based extrudate with 16% desiccated coconut; DB - Baked Cassava-based extrudate with 2% cocoa powder and 16% Desiccated Coconut Powder; AF - Fried Cassava-based extrudate; BF - Fried CF -Fried Cassava-based extrudate with 16% desiccated coconut; DF - Fried Cassava-based extrudate with 2% cocoa powder and 16% desiccated coconut, AR – Roasted Cassava-based extrudate; CR - Roasted Cassava-based extrudate with desiccated coconut; DR - Roasted Cassava-based extrudate with 2% cocoa powder and 16% desiccated; RT: Room temperature'.

The oil absorption capacities (OAC) of the snacks are presented in **Figure 5.** The values ranged from 84.0% to 96.0% for baked snacks, 60.0% to 70.0% for fried snacks, and 79.0% to 94.0% for roasted snacks. Statistically significant ($p < 0.05$) differences were observed in the OAC between fried and dry-heated (baked, roasted) samples. No statistically significant ($p > 0.05$) difference was observed in the oil absorption capacity between roasted and baked snacks. This result concurs with Lima *et al.* (2024), who

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noted a reduction in oil absorption capacity for fried snacks as a function of pretreatment, frying conditions, and material properties. The ability of the sample snacks and blends to absorb a lot is because they are lipophilic in nature (Kaushal *et al.*, 2012).

Table 3: Mineral Composition the Baked, Fried and Roasted Extruded Snacks

Sample	Potassium (mg/100g)	Zinc (mg/100g)	Iron (mg/100g)	Calcium (mg/100g)	Magnesium (mg/100g)
AB	4.19±0.03^{j}	1.43±0.02^{gh}	1.36±0.01^{k}	5.47±0.00^{h}	11.33±0.01^{j}
BB	4.49±0.03^{h}	1.46±0.01^{f}	1.74±0.00^{g}	5.63±0.04^{g}	11.97±0.03^{g}
CB	321.65±0.02^{d}	3.70±0.02^{c}	8.22±0.03^{d}	35.42±0.01^{c}	217.30±0.02^{d}
DB	323.60±0.01^{b}	3.73±0.03^{b}	8.63±0.02^{b}	38.25±0.02^{a}	229.71±0.02^{a}
AF	4.18± 0.00^{j}	1.39±0.03^{i}	1.28±0.01^{l}	5.06±0.05^{k}	11.17±0.04^{j}
BF	4.34 ± 0.02^{i}	1.40±0.02^{hi}	1.61±0.03^{i}	5.26±0.06^{j}	11.75±0.02^{h}
CF	316.35±0.05^{e}	3.17 ± 0.05^{d}	5.64 ± 0.04^{f}	33.45± 0.03^{d}	205.82± 0.03^{f}
DF	311.15±0.05^{f}	3.13 ± 0.01^{e}	5.83± 0.01^{e}	33.11± 0.02^{e}	207.11± 0.01^{e}
AR	4.17 ± 0.03^{j}	1.40 ± 0.02^{i}	1.47 ± 0.04^{j}	5.34± 0.02^{i}	11.54± 0.00^{i}
BR	4.61 ± 0.02^{g}	1.44 ± 0.04^{fg}	1.70 ± 0.03^{h}	5.46 ± 0.00^{h}	11.98± 0.01^{g}
CR	325.45±0.04^{a}	3.86 ± 0.05^{a}	8.42 ± 0.01^{c}	36.26 ± 0.01^{b}	222.52± 0.03^{c}
DR	321.13±0.01^{c}	3.88± 0.03^{a}	8.81 ± 0.02^{a}	32.46± 0.04^{f}	226.12± 0.01^{b}

Values are means of triplicate determinations ± standard deviation. The mean values along the same row with different superscripts are significantly different ($p < 0.05$) using Duncan multiple ranged test. AB - Baked Cassava-based extrudate ; BB - Baked Cassava-based extrudate with 2% cocoa powder; CB - Baked Cassava-based extrudate with 16% desiccated coconut; DB - Baked Cassava-based extrudate with 2% cocoa powder and 16% Desiccated Coconut Powder; AF - Fried Cassava-based extrudate; BF - Fried Cassava-based extrudate with 2% cocoa powder; CF - Fried Cassava-based extrudate with 16% desiccated coconut; DF - Fried Cassava-based extrudate with 2% cocoa powder and 16% desiccated coconut; AR - Roasted Cassava-based extrudate; ; BR - Roasted Cassava-based extrudate with 2% cocoa powder; CR - Roasted Cassava-based extrudate with 16% desiccated coconut; DR - Roasted Cassava-based extrudate with 2% cocoa powder and 16% desiccated Coconut. E: 100% Cocoa powder; F: 100% Desiccated coconut powder'.

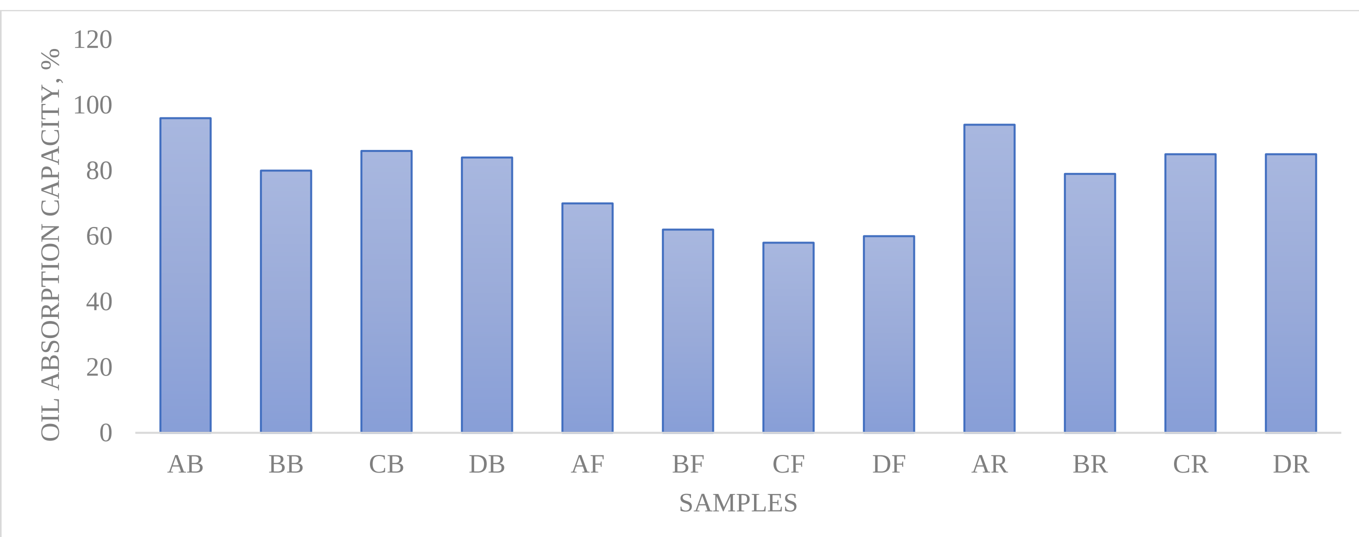

Fig. 5. Oil Absorption Capacity of Enriched Cassava Based Snacks. AB - Baked Cassava-based extrudate ;BB - Baked Cassava-based extrudate with 2% cocoa powder; CB - Baked Cassava-based extrudate with 16% desiccated coconut; DB - Baked Cassava-based extrudate with 2% cocoa powder and 16% Desiccated Coconut Powder; AF - Fried Cassava-based extrudate; BF - Fried CF -Fried Cassava-based extrudate with 16% desiccated coconut; DF - Fried Cassava-based extrudate with 2% cocoa powder and 16% desiccated coconut, AR – Roasted Cassava-based extrudate; CR - Roasted Cassava-based extrudate with desiccated coconut; DR - Roasted Cassava-based extrudate with 2% cocoa powder and 16% desiccated.

3.5 Physical Properties of the Snacks

Tables 4 and **5** show a detailed comparison of raw extruded and processed cassava-mash snack physical features including thickness, length, weight per length, lateral expansion, bulk density, apparent density, and porosity respectively. Raw extruded snacks ranged from 3.20 to 3.30 mm, whereas processed snacks ranged from 3.11 to 3.18 mm. Desiccated coconut and cocoa powder enrichment significantly affects thickness ($p < 0.05$). The amount of cassava-mash used influenced thickness, which is in line with studies by Okafor and Uwgu (2014) who documented thickness ranges of 7.51-8.04 mm for breadfruit blend snacks. The raw and processed snacks actual length ranged between 148-175 mm and 147-173 mm/g, respectively. Snacks fortified with desiccated coconut and cocoa powder showed significant decrease in size and weight for size ($p < 0.05$) due to lower starch availability for expansion (Wang *et al.*, 2015; Liu *et al.*, 2021). Lateral expansion ranged between 6.60% to 10% for raw extruded snacks and 6.20% to 9.80% for processed extruded snacks.

Incorporation of other flours such as desiccated coconut and cocoa powder inhibited lateral expansion significantly ($p < 0.05$) which can affect the starch properties and this finding agrees with the finding of Korkerd *et al.* (2016). In addition to this, Jisha *et al.*, (2010) added that lower bulk density samples exhibit higher expansion ratio and our finding agrees with the earlier findings.

Bulk density was between 0.67 to 0.84 g/cm³ for unprocessed extruded snack foods and 0.67 to 0.85 g/cm³ for processed extruded snack foods. The values were higher than (0.32 – 0.51 g/cm3) reported by Okafor and Ugwu (2014) for cold extruded snack food bulk from breadfruit mixtures. It was further noted in the current study that bulkiness increased with the addition of other flours, as also supported by the work of Okafor and Ugwu (2014). Chandra (2016) further commented that the inclusion of sugars and acid would have contributed and given rise to an increase in Bulk density. Apparent density was 0.62 to 0.78 g/cm³ and 0.65 to 0.78 g/cm³ for raw extruded snack and processed extruded snack respectively, and lower densities were observed in the extruded snack having added ingredients ($p < 0.05$), confirming results by Ajanaku *et al.* (2012). Porosity was between -0.35 and 0.14 and -0.34 and 0.13 for raw extruded snacks and processed extruded snacks, respectively, with significant reductions in porosity for cocoa powder-added snacks as a result of reduced starch availability (Okafor and Uwgu, 2014; Giannini *et al.*, 2011).

3.6 Sensory Properties of the Extruded Snacks

Table 6 and **Plate 1** presents the mean sensory scores and picture of cassava-mash extruded snacks respectively. Baked snacks received mean scores between 6.23 and 6.26 for appearance, indicating a slight preference. Roasted snacks scored between 4.30 and 5.40, reflecting a range from "dislike slightly" to "neither like nor dislike." Fried snacks, however, received higher scores, from 8.52 to 8.56, showing a strong preference. Fried snacks consistently outperformed baked and roasted ones, which scored lower, possibly due to uneven colour development in roasting. For texture, baked snacks scored between 6.26 and 6.63, showing a slight preference, while roasted snacks had scores between 4.53 and 4.76, indicating a slight dislike. Fried snacks scored between 8.46 and 8.76, reflecting a strong preference for their crispiness. Significant differences were noted in texture, with fried snacks preferred for their crispness except for samples AF and BF. In terms of flavour, baked snacks received scores of 6.20 to 7.10, and roasted snacks scored between 6.20 and 7.03, suggesting slight to moderate liking. Fried snacks scored between 8.10 and 8.50, showing a strong preference. The flavour enhancement is attributed to oil, desiccated coconut, and cocoa powder, with fried snacks enriched with desiccated coconut achieving the highest scores. For taste, baked snacks ranged from 6.23 to 7.80, roasted from 6.18 to 7.88, and fried from 8.12 to 8.60. Fried snacks, particularly those with desiccated coconut, received the highest scores, indicating strong preference. Roasted snacks had the lowest scores, suggesting neutrality. Overall acceptability scores ranged from 6.53 to 7.10 for baked, 7.80 to 8.80 for fried and 6.43 to 7.03 for roasted snacks. Fried snacks with desiccated coconut received the highest overall scores (8.54 to 8.75), indicating a strong preference. Snacks without enrichment had lower scores, suggesting low preference. Cocoa powder might have masked the coconut flavor, impacting the scores of snacks with both cocoa and desiccated coconut.

Table 4: Physical properties of the Raw Extruded Cassava-mash Snacks

Sample	Thickness (mm)	Specific length (mm)	Lateral Expansion (%)	Bulk Density (g/cm³)	Apparent Density (g/cm³)	Porosity
A	3.30±0.03^a	175±0.01^a	10.00±0.02^a	0.67±0.03^b	0.78 ±0.01^a	0.14±0.01^a
B	3.30±0.02^a	172±0.02^b	10.00±0.00^a	0.68±0.02^b	0.76 ±0.02^b	0.11±0.02^b
C	3.20±0.01^b	150±0.00^c	6.60±0.01^b	0.83±0.01^a	0.65 ±0.01^c	-0.27±0.01^c
D	3.20±0.01^b	148±0.00^d	6.60±0.01^b	0.84±0.01^a	0.62 ±0.01^d	-0.35±0.01^d

Values are means of triplicate determinations ± standard deviation. The mean values along the same row with different superscripts are significantly different ($p < 0.05$) using Duncan multiple ranged test. 'A – Extruded Cassava-mash; B – Extruded Cassava-mash enriched with 2% cocoa powder; C – Extruded Cassava-mash enriched with 16% desiccated coconut; D – Extruded Cassava-mash enriched with 2% cocoa powder and 16% desiccated coconut'.

Table 5: Physical properties of the Processed Cassava-mash Snacks

Sample	Thickness (mm)	Specific length (mm)	Lateral Expansion (%)	Bulk Density (g/cm^3)	Apparent Density (g/cm^3)	Porosity
AB	$3.14±0.01^{bc}$	$171±0.00^{b}$	$9.80±0.01^{a}$	$0.67±0.03^{d}$	$0.75 ±0.01^{b}$	$0.11±0.00^{b}$
BB	$3.12±0.01^{de}$	$168±0.01^{c}$	$9.80±0.00^{a}$	$0.68±0.02^{d}$	$0.75 ±0.01^{b}$	$0.10±0.01^{c}$
CB	$3.12±0.02^{de}$	$150±0.01^{d}$	$6.50±0.02^{c}$	$0.83±0.01^{b}$	$0.65 ±0.01^{f}$	$-0.31±0.00^{h}$
DB	$3.18±0.02^{a}$	$147±0.02^{e}$	$6.40±0.03^{c}$	$0.85±0.01^{a}$	$0.66 ±0.00^{e}$	$-0.34±0.00^{j}$
AF	$3.13 ± 0.00^{cd}$	$168±0.03^{c}$	$9.60±0.01^{b}$	$0.70±0.02^{c}$	$0.75 ±0.02^{b}$	$0.07±0.01^{d}$
BF	$3.13 ± 0.00^{cd}$	$168±0.03^{c}$	$9.60±0.03^{b}$	$0.70±0.01^{c}$	$0.78 ±0.03^{a}$	$0.11±0.01^{b}$
CF	$3.12 ± 0.01^{e}$	$150 ± 0.02^{d}$	$6.20 ± 0.04^{d}$	$0.83± 0.03^{b}$	$0.67 ± 0.03^{de}$	$-0.24 ± 0.02^{f}$
DF	$3.17 ± 0.01^{a}$	$146 ± 0.01^{e}$	$6.20 ± 0.03^{d}$	$0.85± 0.03^{a}$	$0.67 ± 0.01^{de}$	$-0.27 ± 0.02^{g}$
AR	$3.15 ± 0.02^{b}$	$172 ± 0.01^{ab}$	$9.80 ± 0.02^{a}$	$0.68± 0.03^{d}$	$0.78 ± 0.01^{a}$	$0.13± 0.03^{a}$
BR	$3.18 ± 0.03^{a}$	$173 ± 0.00^{a}$	$9.80 ± 0.00^{a}$	$0.68 ± 0.02^{d}$	$0.78 ± 0.01^{a}$	$0.13± 0.01^{a}$
CR	$3.11 ± 0.03^{e}$	$152 ± 0.01^{d}$	$6.40 ± 0.03^{cd}$	$0.82 ± 0.01^{b}$	$0.68 ± 0.03^{cd}$	$-0.20± 0.02^{e}$
DR	$3.12 ± 0.01^{de}$	$147 ± 0.02^{e}$	$6.40 ± 0.02^{c}$	$0.85 ± 0.03^{a}$	$0.68 ± 0.04^{c}$	$-0.33± 0.01^{i}$

Values are means of triplicate determinations ± standard deviation. The mean values along the same row with different superscripts are significantly different ($p < 0.05$) using Duncan multiple ranged test. AB - Baked Cassava-based extrudate ;BB - Baked Cassava-based extrudate with 2% cocoa powder; CB - Baked Cassava-based extrudate with 16% desiccated coconut; DB - Baked Cassava-based extrudate with 2% cocoa powder and 16% Desiccated Coconut Powder; AF - Fried Cassava-based extrudate; BF - Fried CF -Fried Cassava-based extrudate with 16% desiccated coconut; DF - Fried Cassava-based extrudate with 2% cocoa powder and 16% desiccated coconut, AR – Roasted Cassava-based extrudate; CR - Roasted Cassava-based extrudate with desiccated coconut; DR - Roasted Cassava-based extrudate with 2% cocoa powder and 16% desiccated.

Table 6: Sensory Properties of the Snacks

Sample	Appearance	Texture	Flavour	Taste	Acceptability
AB	$6.26±0.10^{c}$	$6.60±0.20^{e}$	$6.20±0.10^{j}$	$6.30±0.15^{g}$	$6.53±0.15^{h}$
BB	$6.26±0.10^{c}$	$6.63±0.25^{d}$	$6.28±0.15^{h}$	$6.23±0.25^{h}$	$6.33±0.10^{k}$
CB	$6.23±0.10^{d}$	$6.43±0.10^{f}$	$7.08±0.17^{f}$	$7.80±0.15^{f}$	$7.10±0.12^{e}$
DB	$6.26±0.10^{c}$	$6.26±0.25^{g}$	$7.10±0.18^{e}$	$7.80±0.10^{f}$	$7.03±0.10^{f}$
AF	$8.52 ± 0.10^{b}$	$8.76±0.18^{a}$	$8.27±0.16^{b}$	$8.20±0.15^{c}$	$7.86±0.17^{c}$
BF	$8.56 ± 0.10^{a}$	$8.76±0.16^{a}$	$8.20±0.16^{c}$	$8.23±0.10^{b}$	$7.80±0.15^{d}$
CF	$8.56 ± 0.15^{a}$	$8.56 ± 0.15^{b}$	$8.50 ± 0.18^{a}$	$8.60± 0.05^{a}$	$8.80± 0.15^{a}$
DF	$8.55 ± 0.10^{a}$	$8.46 ± 0.17^{c}$	$8.10 ± 0.18^{d}$	$8.12± 0.10^{d}$	$8.35± 0.16^{b}$
AR	$5.33 ± 0.10^{f}$	$4.53 ± 0.15^{j}$	$6.20 ± 0.15^{j}$	$6.20± 0.10^{i}$	$6.50± 0.17^{i}$
BR	$5.40 ± 0.10^{e}$	$4.76 ± 0.10^{h}$	$6.26 ± 0.10^{i}$	$6.18 ± 0.10^{i}$	$6.43 ± 0.15^{j}$
CR	$4.40 ± 0.20^{g}$	$4.56 ± 0.13^{i}$	$7.03 ± 0.18^{g}$	$7.88 ± 0.20^{e}$	$7.03± 0.12^{f}$
DR	$4.30 ± 0.20^{h}$	$4.76± 0.10^{h}$	$7.01 ± 0.18^{g}$	$7.80 ± 0.20^{f}$	$7.00± 0.12^{g}$

Values are means of triplicate determinations ± standard deviation. The mean values along the same row with different superscripts are significantly different ($p < 0.05$) using Duncan multiple ranged test. AB - Baked Cassava-based extrudate ;BB - Baked Cassava-based extrudate with 2% cocoa powder; CB - Baked Cassava-based extrudate with 16% desiccated coconut; DB - Baked Cassava-based extrudate with 2% cocoa powder and 16% Desiccated Coconut Powder; AF - Fried Cassava-based extrudate; BF - Fried CF -Fried Cassava-based extrudate with 16% desiccated coconut; DF - Fried Cassava-based extrudate with 2% cocoa powder and 16% desiccated coconut, AR – Roasted Cassava-based extrudate; CR - Roasted Cassava-based extrudate with desiccated coconut; DR - Roasted Cassava-based extrudate with 2% cocoa powder and 16% desiccated.

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Plate 1: Cassava-mash Snacks (a) Processed Cassava-Mash Extrudate (b) Processed Cassava-Mash Extrudate with Cocoa Powder (c) Processed Cassava-Mash Extrudate with Desiccated Coconut (d) Processed Cassava-Mash Extrudate with Desiccated Coconut and Cocoa Powder.

CONCLUSION

This study shows that adding desiccated coconut and cocoa powder to cassava-mash snacks boosts their nutritional value, enhancing protein, fiber, and minerals. Desiccated coconut was especially effective due to its nutrient density. Processing methods impacted nutrient retention; frying increased fat but led to losses in fiber, potassium, and magnesium, while baking and roasting preserved more nutrients and antioxidants. Cocoa powder enriched snacks with higher phenolic content and antioxidant activity, though frying slightly reduced these benefits. Fried snacks with desiccated coconut scored highest in sensory evaluations for appearance, texture, and flavor. Overall, baking and roasting are better for nutrient retention, while enrichment and processing methods significantly influence snack quality and consumer preference. Future research should refine these factors to optimize snack attributes.

ETHICAL APPROVAL STATEMENT

This research was approved by the Department of Food Science and Technology, Obafemi Awolowo University. The same department also supervised all the taste tests. The study adhered to important ethical standards, including the Declaration of Helsinki, for the safety of participants and their just treatment. External ethics approval was not necessary since the tests were low-risk and involved no need for any medical intervention. All participants were informed of any sensitivity-inducing ingredients and they gave consent prior to starting.

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CONFLICT OF INTEREST
The authors declare that there are no conflicts of interest in this work.

DATA AVAILABILITY
The data used to support the findings of this study are available upon request from the corresponding author.

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