



ENHANCING QUALITY AND TEXTURAL ATTRIBUTES OF BEEF PATTIES USING BLENDS OF WHEAT AND TIGERNUT (*CYPERUS ESCULENTUS*) FLOUR: A SUSTAINABLE INGREDIENT APPROACH

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Abstract: This study evaluated the use of wheat–tigernut composite flour to enhance the nutritional, textural, and sensory qualities of beef patties with an emphasis on dietary fibre improvement and sustainability. Minced beef was blended with varying ratios of wheat and tigernut flour, shaped into patties, deep-fried, and assessed for proximate composition, colour, texture, and sensory attributes using a 7-point hedonic scale. Results showed that increasing tigernut flour levels elevated fibre, fat, and carbohydrate content, with 100% tigernut patties yielding the highest fibre content. Textural analysis indicated that tigernut addition increased stickiness, chewiness, and gumminess. The blend containing 60% wheat and 40% tigernut (W60T40) achieved the highest overall sensory acceptability (scores ranging from 6.36 to 7.14). Colour changes were also observed with varying tigernut levels. The findings demonstrate that tigernut flour not only enhances the nutritional profile, particularly fibre content, but also contributes to consumer acceptability, offering a functional, sustainable ingredient for healthier meat products. This research supports the development of innovative, fibre-enriched beef patties that align with sustainable food production and healthier dietary patterns.

Keywords: beef patties, tigernut, wheat, quality evaluation

1. Introduction

Meat varieties include, but are not limited to, beef, grilled, fried, roasted, and stewed meat derived from various animal sources such as goat, sheep, ram, duck, and pheasant. The global food system currently faces significant challenges due to rapid population growth, projected to reach 10 billion by 2050, which is expected to increase food demand [1]. Among meat products, an increasing number of people are adopting a plant-based lifestyle motivated by personal health, religious beliefs, and environmental considerations. Increasing dietary fibre in beef products, especially patties, consistently impacts water-holding capacity (WHC), cooking yield, fat retention, texture profile, emulsion stability, microstructure, oxidative stability, and nutritional enhancement. The increasing demand for

products with reduced animal meat has facilitated the replacement with plant-based ingredients [2]. The tiger nut (*Cyperus esculentus* L.) is a nutrient-dense tuber rich in lipids, proteins, carbohydrates, fibre, vitamins, minerals, and bioactive compounds [3]. Proximate composition of tigernuts typically ranges (%) per 100 g, dry weight: moisture (5–10), crude protein (4–9), crude fat (20–35), ash (1.5–3.5), carbohydrate by difference (45–60). Dietary fibres extracted from tiger nuts have been incorporated into meat formulations to develop fibre-enriched products with improved physicochemical and nutritional properties. Given their polyphenol content, these by-products may also help modulate or inhibit lipid oxidation in food systems [4]. Beyond their nutritional value, dietary fibres play

important technological roles, including increasing cooking yield and rheological properties, reducing formulation costs, and enhancing the texture of meat products [5]. Studies on the physicochemical characteristics of tiger nut by-products have confirmed their high fibre content, highlighting their potential as ingredients for health-oriented foods [3]. Dietary fibre consumption is recognised for enhancing gastrointestinal function by increasing stool volume, improving gut motility, and promoting the generation of short-chain fatty acids through fermentation, which aids in metabolic and inflammatory management [6]. Meat products enhanced with fibre may attenuate postprandial glycaemic responses and enhance lipid metabolism, thereby contributing to diminished risk markers for type 2 diabetes and cardiovascular illnesses [7]. Tigernut flour served not only as a nutritional additive but also as a functional component of the meat matrix. The fibre-rich composition most likely improved water and lipid retention, resulting in lower fat content, less cooking loss, and increased firmness and chewiness via fibre-protein-water interactions. These quality enhancements indirectly promote healthier meat compositions by enhancing yield stability and decreasing fat consumption per serving. Nevertheless, since fibre values were obtained from proximate analysis, additional separation between soluble and insoluble fibre fractions is necessary. In addition, edible by-products from food industries are increasingly recognised as viable alternatives to address food security challenges in developing countries such as Nigeria. Knorr and Augustin [8] emphasised that integrating underutilised food resources and agro-industrial by-products can enhance dietary diversity and promote sustainability. These materials, which possess technological, nutritional, and functional benefits, represent a promising approach to

improving food quality and resource efficiency [8].

Accordingly, the present study investigated the enhancement of the nutritional composition, sensory attributes, and overall acceptability of beef patties through the incorporation of novel tiger nut-wheat flour blends, while simultaneously promoting sustainable food production practices. Beef is among the most consumed meat sources worldwide and is low in fibre.

2. Materials and methods

2.1 Sample preparation

2.1.1 Source of materials

Boneless beef, fresh tiger nuts, wheat flour golden penny brand (micronutrients per 100 g: micronutrients per 100 g: approximately zinc (50 mg/kg), vitamin B3 (45 mg/kg), iron (40 mg/kg), vitamin B1 (6 mg/kg), vitamin B2 (5 mg/kg), vitamin B6 (6 mg/kg), vitamin B9 (2.6 mg/kg), vitamin A (2 mg/kg), vegetable oil, salt, and spices were purchased from Mushin market, Lagos, Nigeria. Tiger nut flour production was done according to the method outlined by Ani (2021) [9]. The process involved sorting dry brown tiger nuts to eliminate particles. After wet cleaning, tiger nut was dried in a hot air oven at 45 °C, allowed to cool to ambient temperature, milled, then tigernut flour was packaged in clean, dry plastic containers and tightly sealed to prevent moisture absorption. Seven blend formulations of wheat flour: tiger nut flour (100:0, 0:100, 90:10, 80:20, 70:30, 60:40, 50:50) were used in the study, as shown in Table 1. Simultaneously, boneless beef was washed, trimmed, cut into smaller pieces, and minced using a manual meat mincer. Salt, water, minced meat, and the composite flour mix were thoroughly blended as outlined in Table 2. The mixture was moulded into uniform 1.0 cm-thick slabs, and 70 cm in diameter. The moulded samples were deep-fried at 165 °C for 5 minutes, using the modified method of Johansson et al [10]. After frying, the patty

samples were allowed to cool at room temperature (22-25 °C) for 30 minutes

before being packed in Ziplocs for further analysis.

Table 1.

Flour blends proportion (wheat flour and tiger nut flour) using 15 g

Sample code	Flour Blend	Wheat Flour (g)	Tiger nut Flour (g)	Total (g)
W100	100	15	0	15
W90T10	90:10	13.5	1.5	15
W80T20	80:20	12.0	3.0	15
W70T30	70:30	10.5	4.5	15
W60T40	60:40	9.0	6.0	15
W50T50	50:50	7.5	7.5	15
T100	100	0	15	15

Keys: 100 = 15g of wheat flour; 90: 10 = 13.5 g of wheat flour + 1.5 g of tigernut flour; 80: 20 = 12.0 g of wheat flour + 3.0 g of tigernut flour; 70:30 = 10.5 g of wheat flour + 4.5 g of tigernut flour; 60: 40 = 9.0 g of wheat flour + 6.0 g of tigernut flour; 50: 50 = 7.5 g of wheat flour + 7.5 g of tigernut flour

Table 2.

Formulation of beef patties in this study

Components	Proportion (%)
Meat (Beef)	80
Composite Flour (filler)	15
Water	3
Salt	2

2.2 Determination of proximate composition

Moisture content, crude fat, crude fibre, and crude ash were determined according to the standard method described by the Association of Official Analytical Chemists method, 18th edition (A.O.A.C.) [11]. Protein was determined using the Kjeldahl method (AOAC, 26-12.01). The carbohydrate content was estimated by difference as shown below.

Total Carbohydrate = 100 - (Fat + Fibre + Ash + Protein + Moisture) Eq. (1)
 Replication was done in triplicate.

2.3. Texture profile analysis (TPA)

To determine the texture profile analysis. Selected moulds of beef patties samples were analysed with the aid of a textural profile analyser (Testometric material testing machine, 0500-10080) at the National Centre for Agricultural Mechanisation (NCAM), Ilorin, Kwara

State. Springiness, Stringiness, cohesiveness, gumminess, adhesiveness, and chewiness were measured using the two-cycle compression test (Magnus Taylor puncture probe test) at a depth of 5 mm, a probe diameter of 120 mm, and a speed of 102 mm/min.

2.4 Colour analysis

The lightness (*L*), redness (*a**), and yellowness (*b**) of the beef patties were measured in triplicate as described by Nadim et al. [12] after calibration of the instrument (Chroma-meter CR-410, Minolta, Japan) using a white tile. The average results were expressed using the CIELAB system.

2.5 Sensory analysis

Sensory evaluation was conducted in the sensory laboratory of the Department of Food Science and the Technology laboratory at Yaba College of Technology by 20 semi-trained panellists under standardised testing conditions. The

samples were scored for colour, odour, taste, texture, and overall acceptability on a 7-point hedonic scale to measure the degree of likeness for the products. Samples were presented in coded trays and assessed individually in a cubicle under illumination by thirty panellists.

2.6 Statistical Analysis

The means of the data obtained were subjected to analyses of variance (ANOVA) to determine if means are significantly different at ($p < 0.05$) using SPSS version 22. Separation of means was carried out using the Duncan multiple range test.

Table 3.

Proximate composition of beef patties

Sample	Moisture %	Protein %	Ash %	Fat %	Fibre %	Carbohydrate %
W100	59.05±0.24 ^c	21.71±1.48 ^c	2.82±0.09 ^a	11.97±0.12 ^a	0.14±0.03 ^a	4.33±1.05 ^a
W90T10	44.99±0.92 ^a	13.64±0.03 ^b	7.60±0.14 ^{bc}	13.26±0.11 ^b	1.64±0.11 ^b	18.87±0.97 ^{cd}
W80T20	45.82±0.04 ^{ab}	13.55±0.08 ^a	8.45±0.42 ^{bc}	13.86±0.11 ^{abc}	1.95±0.06 ^c	16.36±0.38 ^{bc}
W70T30	46.10±0.91 ^{ab}	12.65±0.06 ^b	8.88±0.17 ^{bc}	13.91±0.20 ^{abc}	2.04±0.08 ^c	16.42±0.11 ^c
W60T40	47.10±0.51 ^b	12.58±0.03 ^b	9.38±0.53 ^c	14.41±0.19 ^{bc}	2.67±0.02 ^d	13.86±0.86 ^b
W50T50	47.60±1.62 ^b	12.40±0.58 ^b	9.44±0.31 ^c	14.65±0.14 ^d	2.93±0.03 ^e	12.98±0.42 ^b
T100	44.74±0.12 ^a	8.05±0.29 ^a	6.99±2.22 ^b	13.34±1.11 ^{bc}	3.19±0.04 ^f	23.69±2.84 ^e

*Values are means of duplicates and (±) standard deviation

*Values with different superscripts within the same column are significantly ($p < 0.05$) different from each other

*W = Wheat flour and T = Tigernut

3. Results and discussion

3.1. Effect of tigernut-wheat composite flour on the proximate composition of beef patties.

The proximate composition of beef patties is summarised in Table 3. The results revealed significant differences ($p < 0.05$) among the samples. Moisture content ranged from 44.74% to 59.05%, with beef patties containing 100% wheat flour exhibiting the highest value, while those formulated with 100% tiger nut flour showed the lowest. The reduction in moisture content with increasing tiger nut inclusion may be attributed to the high fibre content of the flour, which tends to absorb and bind water, thereby reducing free moisture availability [13]. Protein content varied between 8.05% and 21.71%, with the highest value recorded in patties containing 100% wheat flour and the lowest in those formulated solely from tiger nut flour. The observed decrease in protein content following tiger nut substitution, in contrast to the increase associated with wheat flour, reflects the differing protein levels of the two raw materials. The

moderate protein content observed in the composite beef patties may therefore be ascribed to the combined contribution of wheat and tiger nut proteins [14].

Ash content, which reflects the mineral composition of food, ranged from 2.82% to 9.44%. Patties formulated with 100% wheat flour exhibited the lowest ash content, whereas those containing 50% tiger nut substitution recorded the highest value.

The observed increase in ash content with greater tiger nut inclusion can be attributed to the high mineral concentration of tiger nuts, notably calcium, potassium, magnesium, and phosphorus [15]. The fat, fibre, and carbohydrate contents ranged from 11.97% to 14.65%, 0.14% to 3.19%, and 4.33% to 24.42%, respectively. Beef patties prepared with a 50:50 blend of wheat and tiger nut flour exhibited the highest fat content, while those made entirely from tiger nut flour contained the highest fibre level. Increasing tiger nut substitution led to progressive rises in fat, fibre, and carbohydrate content, likely due to the naturally higher lipid and dietary fibre composition of tiger nut flour [16].

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This finding underscores the potential nutritional advantages of incorporating tiger nut flour into beef patties, particularly through enhanced fibre enrichment. Such formulations may improve digestive function and reduce the risk of chronic diseases, aligning with the observations of Maduka and Ire [17]. The nutritional benefits of integrating tigernut (*Cyperus esculentus*) flour into beef patties are especially evident via the increased fibre content. The inclusion of dietary fibre in meat products is consistently linked to enhanced digestive function, modification of gut microbial activity, and decreased risk markers for chronic diseases, including cardiovascular disease and type 2 diabetes [6];[7]. Tigernut flour presents a more cohesive functional profile than other fibre sources used in meat compositions, such as wheat bran, oat fibre, cellulose, and inulin. Traditional grain brans serve as efficient bulking agents but often lead to increased hardness and diminished sensory quality at

elevated inclusion levels, whilst pure fibres such as cellulose or inulin offer minimal structural reinforcement within the meat matrix [18].

Tigernut flour integrates insoluble dietary fibre with inherent starch and lipid components, enhancing water retention and fat encapsulation while augmenting fibre consumption.

This multifunctional behaviour underscores its suitability as both a nutritional enhancer and a techno-functional ingredient in meat systems, contingent on precise optimisation of inclusion levels.

3.2 Effect of tigernut-wheat composite flour on the colour attributes of beef patties

The colour of fried foods significantly influences consumer acceptance [19]. For beef patties, colour attributes such as lightness, redness, and yellowness were measured, with values ranging from 21.70 to 26.89, 8.29 to 9.69, and 8.28 to 11.03, respectively (Table 4).

Table 4.

Colour attributes of beef patties incorporated with blends of wheat and tigernut flour

Sample	Lightness (L)	Redness (a*)	Yellowness (b)	ΔE Colour Intensity	ΔC Chroma Value	Hue Angle (Tan ⁻¹ b/a)
W100	24.93±0.23 ^d	9.69±0.08 ^c	11.00±0.18 ^d	64.22±0.03 ^c	12.09±0.08 ^a	Control
W90T10	26.89±0.21 ^f	8.81±0.05 ^c	11.03±0.13 ^d	63.19±0.03 ^d	10.91±0.05 ^b	51.36
W80T20	24.87±0.13 ^d	8.47±0.06 ^b	9.85±0.10 ^b	64.86±0.08 ^c	9.31±0.03 ^d	49.31
W70T30	21.70±0.03 ^a	8.72±0.11 ^c	8.28±0.04 ^a	67.97±0.11 ^a	9.07±0.02 ^c	43.53
W60T40	26.40±0.02 ^c	8.53±0.01 ^b	10.30±0.04 ^c	63.38±0.02 ^d	9.54±0.02 ^d	50.38
W50T50	23.18±0.13 ^b	9.44±0.05 ^d	9.83±0.15 ^b	66.67±0.05 ^b	10.21±0.08 ^c	46.15
T100	24.17±0.23 ^c	8.29±0.08 ^a	9.99±0.23 ^{bc}	65.54±0.03 ^{ab}	9.21±0.05 ^c	50.31

*Values are means of duplicates and standard deviation

*Values with different superscripts within the same column are significantly ($p < 0.05$) different from each other

W = Wheat flour

T = Tigernut flour

Notably, beef patties formulated with 100% wheat flour and 100% tiger nut flour differed significantly ($p < 0.05$) from those produced with other flour blends. However, patties containing 80% wheat flour and 20% tiger nut flour showed no significant difference ($p > 0.05$) compared to the control sample prepared exclusively with

wheat flour [19]. The inclusion of tiger nut flour at 20% and 40% levels increased the lightness (L^* value) of the beef patties, an effect attributed to the high dietary fibre content of tiger nut, which enhances water-holding capacity [20]. The improved moisture retention likely promoted greater light reflection, yielding a lighter

appearance. In contrast, with 30% and 50% replacement of tiger nuts, a reduction in lightness was observed. This decrease may be attributed to interactions between tiger nut constituents and meat proteins, which influence surface colour by reducing light reflectance and imparting a darker tone to the patties [13]. Redness is a critical attribute of beef patties, strongly associated with quality perception and consumer acceptability. It is primarily determined by the concentration and oxidative state of myoglobin, the protein responsible for oxygen binding and storage in muscle tissues [21]. A significant difference ($p < 0.05$) in redness (a^* value) was observed

among the samples, suggesting possible variations in myoglobin levels or distribution [21]. These colour differences highlight the influence of flour composition on the visual quality and overall consumer appeal of beef patties.

3.3 Effect of tigernut-wheat composite flour on the textural attributes of beef patties

The textural properties of processed foods influence their perception and acceptability. The table of textural properties of beef patties is presented in Table 5 and includes attributes such as adhesiveness, cohesiveness, chewiness, gumminess, springiness, and stringiness.

Table 5.

Textural properties of beef patties

Sample	Adhesiveness (N.s.)	Cohesiveness	Chewiness (N)	Gumminess (N)	Springiness	Stringiness (mm)
W100	0.44±0.02 ^a	0.31±0.04 ^a	280.50±4.95 ^a	978.00±25.46 ^a	0.28±0.02 ^a	0.58±0.09 ^a
W90T10	6.79±0.13 ^d	0.27±0.04 ^a	426.50±16.26 ^c	1182.00±18.39 ^b	0.35±0.02 ^a	3.37±0.43 ^d
W80T20	3.41±0.25 ^b	0.38±0.02 ^a	667.50±6.36 ^d	1720.50±10.61 ^c	0.35±0.06 ^a	2.52±0.35 ^c
W70T30	3.48±0.02 ^b	0.32±0.04 ^a	670.50±34.65 ^d	1822.00±8.49 ^f	0.35±0.05 ^a	2.61±0.54 ^c
W60T40	7.61±0.16 ^c	0.36±0.02 ^a	644.50±36.06 ^d	1339.50±45.96 ^c	0.35±0.06 ^a	1.47±0.18 ^b
W50T50	3.14±0.07 ^b	0.33±0.07 ^a	428.00±26.87 ^c	1520.00±78.49 ^d	0.35±0.06 ^a	2.22±0.01 ^c
T100	4.32±0.38 ^c	0.33±0.02 ^a	354.00±19.80 ^b	1348.00±26.87 ^c	0.33±0.01 ^a	0.15±0.14 ^a

*Values are means of duplicates and (\pm) standard deviation

*Values with different superscripts within the same column are significantly ($p < 0.05$) different from each other
 W = Wheat flour, T = Tigernut flour

A textural profile analysis provides a rapid and objective means of assessing product performance and consumer perception [22]. All the patty samples in this study remained cohesive for all treatments. Substitution of tigernuts did not reveal a significant difference in sample cohesiveness ($p > 0.05$) in this study. Cohesiveness, which is crucial for maintaining the structural integrity of patties during cooking and consumption [23], ranged from 0.27 to 0.38, with no significant variation among the samples. The improvement in dough stickiness upon blending wheat and tiger nut flours may be attributed to the high dietary fibre content of tiger nut flour [13] and the gluten network contributed by wheat flour [24]. Tiger nut flour

significantly influenced adhesion of all samples ($p < 0.05$), likely due to its strong water-binding capacity and the formation of a robust gluten network from wheat proteins [25]. Adhesiveness and Cohesiveness improved with moderate tigernut inclusion, suggesting better resistance to deformation of patties. The chewiness of beef patties is essential in determining the overall mouthfeel, texture, and perceived quality of a burger, serving as a crucial indicator of moisture. Chewiness values ranged from 280.50 to 670.50, increasing with higher levels of wheat and tiger nut flour. This trend may result from the combined effects of tigernut fibre and gluten flour, which together form a gel-like matrix that enhances structural

strength. Chewiness was observed to increase significantly from the control (W100) compared with W80T20 and W70T30, suggesting that moderate substitution with tigernuts enhances chewiness. Inclusion of tigernut flour above 30% results in a decline in chewiness. Samples W80T20 and W70T30 gave the highest chewiness score. Moderate levels of tigernut flour substitution (20-30%) produced the chewiest texture. Stringiness occurs when the level of substitution is too high, thereby weakening the matrix due to a low level of elastic network formation. Stringiness was observed at low levels of tigernut substitution (10-30%), then declined as the tigernut content increased beyond 40%.

Sample T100 had the lowest stringiness value, similar to W100. W90T10 was observed to be the stringiest sample ($p > 0.05$). The observed increase in stringiness could be linked to the absence of gluten in tiger nut flour. Overall, the interaction between the two flours contributed to a

more cohesive, tender, and elastic texture in the beef patties [26].

3.4. Sensory evaluation of deep-fat-fried beef patties

Table 6 presents the scores for sensory characteristics, including colour, taste, texture, and odour, which varied from 6.3 to 7.8, 5.81 to 7.26, 6.06 to 6.72, and 5.86 to 7.02, respectively. The results suggest that using tiger nut flour at modest replacement levels may enhance the sensory quality of beef patties without negatively impacting customer acceptance. Tenderness, flavour, and colour play major roles in consumer preference and purchase intent [27]. Colour scores ranged between 6.30 and 7.80. Patties made with 100% tiger nut flour received lower colour acceptability scores compared to those produced with 100% wheat flour. Nonetheless, the incorporation of tiger nut flour enhanced overall appearance and colour uniformity. Significant differences ($p < 0.05$) were observed across all colour parameters.

Table 6.

Sensory evaluation of deep-fat-fried beef patties

Samples	Colour	Taste	Texture	Odour	Overall Acceptability
W100	7.80±1.63 ^b	7.26±1.65 ^b	6.64±1.67 ^a	7.02±1.43 ^c	6.68±1.49 ^{ab}
W90T10	6.30±1.36 ^a	5.81±1.45 ^a	6.46±1.63 ^a	5.86±1.87 ^a	6.42±1.67 ^{ab}
W80T20	6.36±1.75 ^a	5.88±1.56 ^a	6.20±2.07 ^a	5.96±2.15 ^a	6.36±1.85 ^{ab}
W70T30	6.40±1.71 ^a	5.94±2.09 ^a	6.44±1.79 ^a	6.18±1.77 ^{ab}	6.38±1.93 ^{ab}
W60T40	6.46±1.80 ^a	6.20±1.90 ^{ab}	6.06±1.83 ^a	6.10±2.16 ^{ab}	7.14±1.78 ^b
W50T50	6.70±1.83 ^a	6.08±1.79 ^{ab}	6.42±1.81 ^a	6.04±1.82 ^{ab}	6.46±1.83 ^{ab}
T100	6.80±1.71 ^{ab}	6.62±1.62 ^{ab}	6.72±1.58 ^a	6.78±1.42 ^{bc}	7.06±1.50 ^{bc}

*Values are means of duplicates and standard deviation

*Values with different superscripts within the same column are significantly ($p < 0.05$) different from each other
 W = Wheat flour, T = Tigernut flour

Beef patties with 100% tiger nut flour inclusion recorded the highest score (T100) for colour, for taste and odour values, while patties with 100% wheat flour (T100) inclusion had the highest scores for taste. Sample T100 with 100 per cent tigernut flour inclusion received the highest score of

6.72 for textural attributes. The control W 100 received the highest odour score. Although significant ($p < 0.05$) differences were noted in colour, taste, and odour and overall general acceptability for all beef patties samples, no significant ($p > 0.05$) difference was observed in textural

properties. Overall acceptability mean score values for beef patties with wheat and tiger nut flour blends ranged from 6.36 to 7.14. Panellists preferred patties with 40% tiger nut inclusion to the control with 100% wheat flour. Significant ($p < 0.05$) differences were observed in the overall acceptability of all beef patties. The findings were similar to those of the findings of Douglas et al. [27]

4. Conclusion

This study found that tigernut-wheat composite flour blends improve the nutritional quality of beef patties while maintaining product quality. Tigernut flour's high fibre content makes it a sustainable meat enhancer, enriching meat products and making them healthier. The findings demonstrate the technological and nutritional potential of underutilised commodities, such as tigernut, as functional ingredients in meat processing, highlighting their importance in modern food formulation. Tigernut flour offers both economic and environmental advantages, particularly for developing nations, in addition to its nutritional and technological benefits. In a balanced diet, these fibre-enriched beef patties can help enhance digestive health and reduce risk factors for non-communicable diseases, such as cardiovascular disease and type 2 diabetes. In a balanced diet, these fibre-enriched beef patties may contribute to improved digestive health and reduce risk factors linked to non-communicable diseases such as cardiovascular disease and type 2 diabetes. The W60T40 wheat–tigernut combination had the best nutritional and sensory balance. This implies that minimal substitution is preferable for balancing health benefits and product quality. Beyond product-level improvements, the work promotes sustainable food systems, especially in underdeveloped nations. Tigernut, an underutilised, locally accessible crop with little agronomic

inputs, is perfect for value-added food products, particularly in developing countries. It can boost agricultural diversification, reduce dependency on refined components, and strengthen local agro-processing value chains. This formulation approach directly supports SDG 2 (Zero Hunger) by promoting food security and nutrition, SDG 3 (Good Health and Well-being) by promoting healthier diets, and SDG 12 (Responsible Consumption and Production) by promoting sustainable ingredient use. The findings support utilising indigenous crops to reformulate animal products for healthier and more sustainable food production.

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Ethics declaration:

This study received approval from the Ethics Committee of Yaba College of Technology, Yaba, Lagos, Nigeria. Confirms that all experiments were performed according to the relevant guidelines and regulations.