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*Original Research Article*

# Nutritional Potential of Low-Carbohydrate Nigerian Staple Meal Alternatives for Improving Dietary Compliance in Starch-Restricted Populations

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ABSTRACT

The increasing prevalence of obesity and Type 2 Diabetes Mellitus (T2DM) has prompted interest in low-carbohydrate dietary alternatives for better metabolic control. This study aimed to evaluate the nutrients and sensory properties of alternative meals formulated from cabbage, coconut, eggplant, and rolled oats flours, with psyllium husk added as a binder. Food materials were processed into flour, and the nutrients properties were analyzed using standard AOAC methods, while sensory attributes were assessed using a 9-point hedonic scale. Results showed that the carbohydrate content of the meals ranged from 14.66 to 15.85%, with appreciable levels of protein (1.05 – 1.90%), crude fibre (10.80 – 11.50%), and fat (32.48 – 34.50%). Vitamin analysis showed appreciable amounts of vitamin A (1192.24 – 2376.24 µg/g), vitamin C (8.79 – 22.08 µg/g), vitamin E (113.82 – 207.31 µg/g), and vitamin K (56.93 – 86.20 µg/g). Considerable amount of vitamins $B_1$, $B_6$, and $B_9$ were also present. Mineral analysis of the meals revealed potassium (10.25 – 24.70 mg/100 g) as the most abundant element, followed by sodium, calcium, and magnesium. Sensory evaluation revealed that all meals were generally acceptable, with meal made from cabbage flour rated the highest for taste (7.87), texture (7.27), flavour/aroma (7.40), appearance (7.27), and overall acceptability (7.13). Beyond low carbohydrate, the relatively low sodium content across samples suggests suitability for low sodium diets as well. The study concludes that these locally developed low-carbohydrate meals are nutrient-dense, and potentially beneficial for the dietary management of diabetes and other chronic diseases that need modification in carbohydrate consumption.

***Keywords:*** Low-Carbohydrate meal, Metabolic control, Chronic diseases, Swallow, Nutrient-dense, Low sodium diets.

## Introduction

Chronic diseases such as diabetes mellitus, cardiovascular diseases, stroke, and some forms of cancers are some of the major causes of morbidity and mortality globally.[1,2] A shift from infectious to non-communicable diseases began in the early 1900s as a results of advancements in public health and has continued till the present day.[1,3] According to the World Health Organization (WHO), chronic non-communicable disease is the leading cause of death worldwide, and remain eight of the ten leading causes of death in the United States.[4,5] Unhealthy lifestyle such as physical inactivity, poor nutrition, smoking, and excessive alcohol are key risk factors to the development of these conditions.[6]

In Nigeria, as in many developing countries, chronic diseases are on the increase, with reported occurrence in 64.9% of Nigeria population.[7] Chronic disease accounts for the overwhelming percentage of preventable deaths of about 63% of global deaths in 2008, and disabilities around the world.[8].

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The global economic burden of chronic diseases is projected to rise to approximately $47 trillion by 2030, with potentially higher impacts in developing countries due to the emergence and re-emergence of these conditions.[1] Yet investment in addressing key risk factors, such as access to healthy foods, opportunities for physical activity, smoking cessation, and cancer screening, remains insufficient.

A balanced diet with appropriate macronutrient proportions helps prevent lifestyle-related chronic diseases.[9] However, a significant challenge in Nigeria is that many commonly consumed staple foods and their processed products, such as rice dough *(Tuwonshinkafa)*, maize dough *(tuwonmasara)*, millet dough *(tuwongero)*, yam/cassava flour *(amala)*, pounded fermented cassava *(fufu, akpu)*, *garri (eba)*, etc, have been reported to have a high-glycemic index (GI) between 75.0% to 97.0%.[10,11]Regular consumption of high-GI foods, often in large portions, increases the risk of developing chronic diseases, while replacing them with low-GI alternatives improves health outcomes in individuals with chronic diseases.[11]

Low carbohydrate diets, defined as those providing less than 45% of total energy from carbohydrates,[12] devised to restrict the amount of energy obtained from carbohydrates, with compensation by increasing the remaining macronutrients (either fat or protein intakes, or both).[13,14] Low carbohydrate diets have been associated with improved weight control and reduced risk of metabolic disorders.[15] While some vegetables, legumes, and cereals have been identified as having lower carbohydrate values, there is a clear gap in the availability and evaluation of modified staple meal alternatives that are palatable, culturally acceptable, and nutritionally adequate for the Nigerian population. The present study aimed to exclusively investigate the nutritional potential of low-carbohydrate alternatives developed from Nigerian staple meals, to address a gap in culturally relevant dietary options for starch-restricted populations. By utilizing locally available



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foods formulated from traditional ingredients such as cabbage, coconut, eggplant, and rolled oats instead of Western diets, this approach provides practical evidence for improving dietary compliance among individuals with metabolic disorders.

## Materials and Methods

*Collection and identification of plant material*
Eggplant (*Solanum melongena*), Cabbage (*Brassica oleracea*), and Coconut (*Cocos nucifera*) were purchased from Wuse market, FCT Abuja, Nigeria in February, 2025, while psyllium husk and rolled oat were purchased from a store in Abuja, Nigeria in February, 2025. The plants were identified at the National Institute for Pharmaceutical Research and Development (NIPRD), Abuja, where the following voucher numbers were assigned; NIPRD/H/7456, NIPRD/H/7455, and NIPRD/H/7457, for Eggplant (*Solanum melongena*), Cabbage (*Brassica oleracea*) and Coconut (*Cocos nucifera*), respectively.

*Processing of vegetables into flours*
Fresh mature eggplants were sorted, washed, sliced thinly, and oven-dried at 55°C for 6 hours. The dried slices were milled, sieved, and stored in airtight containers. Fresh cabbage heads were similarly prepared, damaged leaves were removed, washed, cut, oven-dried at 55°C for 8–12 hours, milled, sieved, and stored. Mature coconuts were de-husked, cracked, washed, sliced, and blended into a smooth consistency, then drained, oven-dried at 55°C for 6 hours, milled into flour, and stored. All milling was performed using a Chinese-made electric grinder.

*Preparation of low carbohydrate meals (swallows)*
*Ingredients*: Four flours (cabbage, coconut, eggplant, and Rolled oat) were used in the formulation of low-carbohydrate meals. Psyllium husk was incorporated as a binding agent.
*Methods of meal preparation:* About 250 g (1 cup) of each of the flours was measured and mixed with 5 g of psyllium husk separately in four different bowls. To prepare each meal, water was added to a pan and brought to a boil. Mixed flour was added and stirred continuously until thoroughly mixed. More water was added to maintain consistency, and the mixture was cooked for 4-5 minutes.

*Proximate analysis*
*Determination of moisture content:* Moisture content was determined using the oven-drying method (AOAC, 2019).[16] A known weight (5 g) of the sample was placed in a pre-weighed crucible and dried in a hot air oven at 105°C for 24 hours until a constant weight was obtained. The crucible was then cooled in a desiccator and reweighed. Percentage moisture was calculated using the following formula (Equation 1):

$$\text{Moisture content (\%)} = \frac{W1 - W2}{W1} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 1)}$$

Where:
$W_1$ = weight of sample before drying (g)
$W_2$ = weight of sample after drying (g)

*Determination of crude fat:* Fat content was determined using the Soxhlet extraction method.[16] A pre-weighed, dry sample (2 g) was placed in a thimble and extracted with petroleum ether as the solvent for 4–6 hours. After extraction, the solvent was removed by evaporation on a heating mantle, and the extracted lipid residue was dried in an oven at 100 – 105ºC for 30 minutes, cooled in a desiccator and weighed. The lipid content was calculated using the following formula (Equation 2):

$$\text{Crude fat content (\%)} = \frac{\text{Weight of extracted fat}}{\text{Weight of sample (g)}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 2)}$$

*Determination of crude protein:* Crude protein content was determined using the Kjeldahl method.[16] The sample (1 g) was digested with concentrated sulfuric acid ($H_2SO_4$) and a 10:1 mixture of potassium sulfate ($K_2SO_4$) and copper sulfate ($CuSO_4$) as catalyst in a digestion flask until a clear solution was obtained. The digest was neutralized with sodium hydroxide (40%) and distilled into 4% boric acid solution, followed by titration with standard hydrochloric acid (HCl). The total nitrogen content was determined, and protein content was calculated using a conversion factor of 6.25 (Equation 3):

$$\text{Crude protein (\%)} = \text{Total Nitrogen} \times 6.25 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 3)}$$

*Determination of total ash content*: Total ash content was determined by incinerating the sample in a muffle furnace at 550°C for 4 –6 hours.[16] A pre-weighed crucible containing the sample (5 g) was placed in the furnace until all organic matter was burnt off, leaving a white or grayish residue. The crucible was cooled in a desiccator and reweighed. The ash content was determined as follows (Equation 4):

$$\text{Total ash content (\%)} = \frac{W3 - W1}{W2 - W1} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 4)}$$

Where:
$W_1$ = Weight of empty crucible (g)
$W_2$ = Weight of crucible + sample before ashing (g)
$W_3$ = Weight of crucible + ash after ashing (g)
*Determination of crude fibre*: Crude fiber was determined using the acid and alkali digestion method.[16] The sample (2 g) was defatted using petroleum ether and then digested sequentially with 1.25% sulfuric acid and 1.25% sodium hydroxide solution under controlled conditions. The insoluble residue was filtered, dried, incinerated in a muffle furnace at 550°C, and weighed. The crude fiber content was calculated as follows (Equation 5):

$$\text{Crude fibre (\%)} = \frac{\text{Loss in weight on ignition}}{\text{Sample weight}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 5)}$$

*Determination of carbohydrate content*: Carbohydrate content of the samples was determined by difference using FAO[17] method as shown below (Equation 6):

$$\%\, Carbohydrate = 100 - (\%\, ash + \%moisture + \%protein + \%\, fat + \%\, fiber) \text{ (Eq. 6)}$$

*Vitamins analysis*
*Determination of vitamin A (β-carotene):* Vitamin A content was determined using the Koche method.[18] One gram of the sample was macerated with 200 mL of petroleum ether for 10 min, then allowed to stand for 1 h, during which intermittent shaking was performed every minute. The solution was centrifuged at 4000 rpm for 10 min, after which 3 mL of the resulting supernatant was carefully allocated into three separate test tubes. The supernatant in each test tube was evaporated to dryness, then the residue was reconstituted in 0.2 mL of a 1:1 mixture of acetic anhydride and chloroform, along with 2 mL of 50% trichloroacetic acid (TCA) in chloroform. The absorbance of the resultant solution was subsequently measured at a wavelength of 620 nm at intervals of 15 and 30 seconds, using the corresponding blank as a reference. The vitamin A concentration of the samples was calculated using the following formula (Equation 7):

$$Vitamin\ A\ content = \frac{\text{Absorbance of test x Concentration of standard}}{\text{Absorbance of standard x weight of sample}} \quad \ldots\ldots\ldots\ldots\ldots \text{(Eq. 7)}$$

*Determination of vitamin $B_1$ (thiamine) concentration:* Vitamin $B_1$ concentration was determined using the Koche method.[18] Briefly, 1 g of the sample was homogenized with 50 mL of ethanolic sodium hydroxide solution and filtered into a 100 mL flask. The filtrate (10 mL) was pipetted into a beaker and 10 mL potassium dichromate (0.05 M) was added for colour development. A blank sample was prepared, and the absorbance was taken at 560 nm. The vitamin $B_1$ concentration of


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the sample was extrapolated from a standard curve (Equation 8):

$$Vitamin\ B1\ content = \frac{\text{Absorbance of test x Concentration of standard}}{\text{Absorbance of standard x weight of sample}}$$ ……. (Eq. 8)

*Determination of vitamin $B_6$ (pyridoxine) concentration:* Vitamin $B_6$ concentration was determined using the AOAC method.[16] Sample powder (1 g) was extracted with 500 mL of distilled water for 1 h and filtered. Then 2 mL of distilled water, 0.4 mL of 50% sodium acetate, 0.1 mL of diazotized reagent (0.5% p-nitrobenzaldehyde) and 0.2 mL of 5.5% sodium carbonate were added to 1 mL of the filtrate and mixed thoroughly. The absorbance of the solution was read at a wavelength of 540 nm. The vitamin $B_6$ concentration was calculated as follows (Equation 9):

$$\text{Concentration of vitamin B6} = \frac{\text{Abs.of sample x Df x volume of cuvette}}{\varepsilon}$$ ……. (Eq. 9)

Where:
Abs. = Absorbance of sample
Df = Dilution factor
Ɛ = Extinction coefficient

*Determination of vitamin $B_9$ (folic acid) concentration*: Vitamin $B_9$ concentration was determined using the AOAC method.[16] Briefly, 1 g of sample powder was measured and placed into a beaker, and subsequently extracted with 100 mL of distilled water with gentle heating. The amalgamation was rigorously agitated, cooled, and then filtered. The absorbance of the filtrate was measured at a wavelength of 325 nm using a UV-Visible spectrophotometer. The vitamin $B_9$ concentration was calculated using the following formula (Equation 10):

$$\text{Vitamin B9 content} = \frac{\text{Absorbance of sample x gradient factor x dilution factor}}{\text{weight of sample}}$$ …… (Eq. 10)

*Determination of vitamin C (ascorbic acid) concentration:* Vitamin C concentration was determined using the AOAC method.[16] Briefly, 1 g of the sample was macerated with 20 mL of 0.4% oxalic acid for 10 min, followed by centrifugation at 4000 rpm for 10 min. The supernatant (1 mL) was allocated into three separate test tubes, each containing 9 mL of 2,6-dichlorophenol indophenol (12 mg/L), followed by thorough mixing through shaking. The absorbance of the resultant solution was measured at 520 nm at intervals of 15 and 30 seconds, using the corresponding blank as a reference. The concentration of vitamin C in the samples was calculated using the following formula (Equation 11):

$$\text{Concentration of vitamin C} = \frac{\text{Abs.x Df x volume of cuvette}}{\varepsilon}$$ …… (Eq. 11)

Where:
Abs. = Absorbance of sample
Df = Dilution factor
Ɛ = Extinction factor

*Determination of vitamin E (α-tocopherol) concentration:* Vitamin E concentration was determined using the AOAC method.[16] Briefly, 1 g of the sample was macerated with 20 mL of petroleum ether for 10 min, and allowed to stand for 1 h with intermittent shaking every 1 min, then centrifuged at 4000 rpm for 10 min. Supernatant (3 mL) was transferred into triplicate test tubes, evaporated to dryness, and the residue was redissolved in 2 mL ethanol and shaken. A known volume, 1 mL of 0.2% ferric chloride in ethanol and 1 mL of 0.5% α-dipyridyl in ethanol, was added to the resulting solution and then made up to 5 mL with ethanol. The mixture was thoroughly shaken and the absorbance of the resulting solution was taken at a wavelength of 520 nm against the corresponding blank. The vitamin E concentration of the sample was calculated as follows (Equation 12):

$$\text{Concentration of vitamin E} = \frac{\text{Abs.x Df x volume of cuvette}}{\varepsilon}$$ …… (Eq. 12)

Where:
Abs. = Absorbance of sample
Df = Dilution factor
Ɛ = Extinction factor

*Determination of vitamin K:* Vitamin K content was determined using a modified AOAC method.[16] About 5 g of the sample was saponified with ethanolic potassium hydroxide (60%) under reflux for 30 min to release the fat-soluble vitamins. The mixture was cooled, and vitamin K was extracted with hexane. The extract was centrifuged at 4000 rpm for 10 min to separate the organic layer. The supernatant was collected, washed with distilled water, and dried over anhydrous sodium sulfate. The solvent was then evaporated under a nitrogen stream to prevent oxidation. The extract was purified using a silica gel column, and vitamin K was quantified by HPLC with UV detection at 248 nm. Standard phylloquinone (K1) solutions were used for calibration. All procedures were performed under minimal light and oxygen exposure.

*Mineral analysis*
Mineral profile was analyzed using atomic absorption spectrometry with a Hitachi-Z8200 spectrometer connected to a Hitachi graphite furnace. Sample preparation and analysis followed AOAC method.[19] The food samples were placed in a sample cup, where the solvent was evaporated in the furnace. The dried residue was then vaporized into gas or fine droplets, and the heated graphite chamber converted the components of the vaporized sample into free atoms.

*Sensory evaluation*
Fifteen panelists from Bingham University, Karu, Nasarawa State, Nigeria were selected to evaluate the sensory attributes of the formulated samples. The participants were chosen based on their prior knowledge and experience in assessing sensory characteristics of food products. Consumer acceptability of the meals was determined using a 9-point hedonic scale questionnaire, where 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, and 1 = dislike extremely. About 2 g of each sample was presented to the panelists, each coded differently to prevent bias. The samples were evaluated for taste, texture, flavour, appearance, and overall acceptability. Clean drinking water was provided to the panelists to rinse their palates before and after tasting each sample.
All panelists were informed about the study purpose and procedures and provided written informed consent prior to participation. Participation was voluntary, no personal identifiers were collected, and confidentiality was maintained throughout the study.

*Statistical analysis*
Data were analyzed using SPSS version 21.0 (SPSS Inc., Chicago, IL) and expressed as mean ± standard deviation (SD). Differences between the mean values were analyzed using one-way analysis of variance (ANOVA) followed by Tukey's Honestly Significant Difference (HSD) post-hoc test. Significance level of 5% ($P < 0.05$) was considered statistically significant.

## Results and Discussion

*Proximate composition of low-carbohydrate flours and meals*
The rising prevalence of chronic diseases in Nigeria is a growing public health concern that may further increase healthcare costs if not properly addressed. Dietary habits remain one of the major risk factor, as Nigerian staples are predominantly plant-based and carbohydrate-

flours, meals and psyllium husks. From the findings, carbohydrate was the dominant macronutrient in all samples, ranging from 41.07 - 55.52%


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in alternative flours and 14.66 - 15.85% in meals. The lower carbohydrate content observed in meals prepared from the flours makes them suitable alternatives to meals made from staple grains and tubers such as *garri, tuwonmasara, fufu, amala* consumed in Nigeria. The level of carbohydrate found in this study indicates that these dishes are not particularly rich sources of carbohydrates, and could play a vital role in management and prevention of metabolic disorders.[15]Hence, their use by population with or at risk of chronic diseases such as diabetic mellitus may therefore be encouraged. The carbohydrate content observed in this study is similar to the findings of Nnedinso (2023),[21] who recorded available carbohydrate in some traditional dishes in south eastern part of Nigeria to be 16.31%, 20.33%, and 31.22% for *ayarayaoka*, *okpa* (pudding made from bambara groundnut) and *achicha*and*agbugbu* (a popular cocoyam-based traditional dish), respectively. In addition, the carbohydrate contents of the meals were below that reported by Okareh *et al*. (2021)[20] for banana (28.36%), jollof rice (24.17%), and wheat flour (21.88%)

Crude protein content ranged from 3.64% in cabbage flour to 4.52% in coconut flour and from 1.05% in cabbage meal to 1.90% in eggplant meal. The crude protein content observed in this study for both flours and meals were similar to that reported in the work of Okareh *et al*. (2021)[20] who found protein contents of ranging from 0.67% in pineapple to 5.4% in wheat flour, and also similar to the findings of Awogbenja and Ugwuona (2012)[22], who reported protein content of 3.10 - 5.07% in traditional dishes consumed in Nasarawa State, Nigeria.

Dietary fiber is the edible parts of plants, which can be completely or partially fermented in the large intestine but undigested and unabsorbable in the human small intestine, and this is important in glycemic control and improved metabolic function.[23] Crude fibre content was generally high across the low carbohydrate flours (20.52 - 23.13%), with the highest value (23.13%) found in cabbage flour, which could explain the lower carbohydrate content in the flours. In contrast, the meal samples had much lower fibre contents (10.8 - 11.5%), which might be attributed to the higher moisture and fat contents observed in the meals, and the fact that psyllium husks, which also has reasonable amount of fiber was added to the meals as a binding agent. This suggests that drying and milling processes enhance the concentration of fibre, making the flours potentially valuable for digestive health and cholesterol regulation.[24] Fibre-rich flours such as cabbage and eggplant may therefore be useful as functional ingredients for weight management and glycaemic control.[24,25]

Lipid content was observed to be highest in both coconut flour (26.49%) and meal (34.50%), reflecting the naturally high oil content of coconut. However, other samples, particularly cabbage, eggplant and rolled oat flours, showed relatively low-fat contents (8.06%, 5.80%, and 7.09%, respectively). The fat contents in the flours were above that previously reported for pineapple, banana, jollof rice, and wheat flour, with values ranging from 0.05% - 3.70%. [20]

Moisture content was significantly lower in flours (2.93–12.80%) than in meals (36.05–38.25%). The reduced moisture content observed in the low carbohydrate flours is expected, as drying is a key step in flour production. Consequently, the low moisture levels reported in this study are typical of flours. Low moisture content enhances shelf life by minimizing the risk of mould growth and microbial spoilage, since microorganisms require water for survival.[26] Therefore, flours with reduced moisture are more stable and suitable for long-term storage. The relatively high moisture content observed in the meal samples, particularly eggplant (38.10%) and rolled oats (38.25%), indicates a higher water presence within the foods.

The findings show that ash content (a measure of total mineral content) ranged from 4.47 - 6.83% in flours and 1.30–1.71% in meals. The higher ash content observed in the flours indicate a higher concentration of mineral elements in the flours than in the meals.[27] Cabbage flour (6.83%) and eggplant flour (6.51%) were particularly high in ash, suggesting they may serve as good mineral sources. The ash contents found in this study were higher than that reported by Obahiagbon and Erhamwenetiemwomon (2016)[28] for ten commonly consumed flours in Nigeria.

**Table 1:** Proximate *composition of low-carbohydrate flours, meals and Psyllium Husk*

| Sample | Crude protein (%) | Crude fibre (%) | Fat (%) | Moisture (%) | Ash (%) | Carbohydrate (%) |
|---|---|---|---|---|---|---|
| Cabbage Flour | 3.64 ± 0.04$^{d}$ | 23.13 ± 0.10$^{a}$ | 8.06 ± 0.05$^{e}$ | 12.80 ± 0.02$^{c}$ | 6.83 ± 0.02$^{a}$ | 45.55 ± 0.15$^{c}$ |
| Coconut Flour | 4.52 ± 0.03$^{b}$ | 20.52 ± 0.03$^{c}$ | 26.49 ± 0.01$^{d}$ | 2.93 ± 0.03$^{g}$ | 4.47 ± 0.03$^{c}$ | 41.07 ± 0.03$^{d}$ |
| Eggplant Flour | 3.95 ± 0.04$^{c}$ | 22.47 ± 0.03$^{b}$ | 5.80 ± 0.01$^{f}$ | 10.82 ± 0.02$^{d}$ | 6.51 ± 0.01$^{b}$ | 50.45 ± 0.02$^{b}$ |
| Rolled Oats Flour | 4.07 ± 0.03$^{c}$ | 21.75 ± 0.05$^{bc}$ | 7.09 ± 0.04$^{e}$ | 6.09 ± 0.04$^{f}$ | 5.48 ± 0.04$^{c}$ | 55.52 ± 0.06$^{a}$ |
| Cabbage Meal | 1.05 ± 0.01$^{f}$ | 11.50 ± 0.04$^{e}$ | 33.60 ± 0.03$^{b}$ | 37.44 ± 0.01$^{b}$ | 1.65 ± 0.01$^{e}$ | 14.76 ± 0.03$^{f}$ |
| Coconut Meal | 1.50 ± 0.05$^{e}$ | 10.80 ± 0.03$^{f}$ | 34.50 ± 0.04$^{a}$ | 36.05 ± 0.03$^{c}$ | 1.30 ± 0.03$^{f}$ | 15.85 ± 0.05$^{e}$ |
| Eggplant Meal | 1.90 ± 0.02$^{e}$ | 11.20 ± 0.02$^{e}$ | 32.80 ± 0.02$^{c}$ | 38.10 ± 0.02$^{a}$ | 1.33 ± 0.04$^{f}$ | 14.67 ± 0.02$^{f}$ |
| Rolled Oats Meal | 1.40 ± 0.08$^{e}$ | 11.50 ± 0.02$^{e}$ | 32.48 ± 0.02$^{c}$ | 38.25 ±0.05$^{a}$ | 1.71 ± 0.09$^{f}$ | 14.66 ± 0.16$^{f}$ |
| Psyllium Husks | 4.90 ± 0.02$^{a}$ | 21.50 ± 0.01$^{bc}$ | 6.28 ± 0.07$^{f}$ | 5.90 ± 0.01$^{f}$ | 4.80 ± 0.03$^{c}$ | 56.62 ± 0.11$^{a}$ |

Values are mean ± SD (n = 3). Means within the same column with different superscript letters are significantly different ($p < 0.05$).

*Vitamin contents of low-carbohydrate flours and meals*

Table 2 presents the vitamin contents of low-carbohydrate flours and meals made from cabbage, coconut, eggplant and rolled oats. The vitamins analysed in both flours and meals were vitamin A as *β*-carotene, $B_1$, $B_6$, $B_9$, C, E, and K. Vitamin A, a fat-soluble vitamin present in both plant and animal foods is crucial for maintaining healthy vision, immune function, and cellular differentiation.[29] All the flours had considerable amount of *β*-carotene, with cabbage flour exhibiting the highest vitamin A content (2016.50 µg/g), followed by rolled oats flour (1588.28 µg/g), while coconut flour had the lowest vitamin A content (310.23 µg/g). The vitamin A contents of the meals were slightly higher, with values ranging from 1192.24 µg/g to 2376.24 µg/g. The slightly lower vitamin A content in the flours compared to the meals may be due to minimum loss of the vitamin from processing of



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the ingredients into flour. Although, the addition of psyllium husks to the meals may also contribute to the vitamin A content of the meals. The vitamin A content observed in the flours in this study are higher than the values (1.05 mg/100 g – 2.50 mg/100 g) observed in five low-glycemic index flours formulated from finger millet, soybeans, unriped plantain, carrot, and pumpkin.[30] It is noteworthy that vegetables are generally recognized as richer in vitamins than most other foods.[31]

Vitamin $B_1$ or thiamine is a water soluble vitamin essential for glucose metabolism, nerve, muscle, and heart function. In this study, flours had thiamine content ranging from 337.78 µg/g to 522.22 µg/g, with coconut flour having the highest thiamine content (596.19 µg/g), while rolled oats meal showed the lowest thiamine content. Vitamin $B_6$ acts as a versatile coenzyme involved in over 100 enzymatic reactions, mainly in protein metabolism.[32] It also supports carbohydrate, lipid, and one-carbon metabolism; aids neurotransmitter synthesis, maintains normal homocysteine levels, and contributes to immune function and hemoglobin formation.[33] From the results of the study, all samples had relatively low vitamin $B_6$ content. For the flours, vitamin $B_6$ content ranged from 0.50 µg/g in rolled oat flour to 2.57 µg/g in coconut flour, while for the meals, vitamin $B_6$ content ranged from 0.26 µg/g in coconut meal to 0.64 µg/g in cabbage meal. Vitamin $B_9$ is known for its various bodily functions, including production of Red Blood Cells (RBCs), DNA synthesis, and it is especially important in preventing neural tube defects in the developing fetus.[29] Vitamin $B_9$ content was highest in eggplant flour (15.51 µg/g) and lowest in psyllium husk (7.62 µg/g), while the meals had vitamin $B_9$ content ranging from 8.59 µg/g (eggplant meal) to 45.17 µg/g (cabbage meal). Studies have shown that a deficiency in B-complex vitamins can lead to complications associated with chronic diseases, particularly diabetes as they play crucial roles in carbohydrate metabolism, and the potential benefits of B-complex vitamins in the management of diabetes has been demonstrated.[34].

Vitamin C content was consistently highest in coconut flour and meal, with concentrations of 39.83 µg/g and 22.08 µg/g, respectively, while rolled oats flour and meal had the lowest concentrations of vitamin C of 13.83 µg/g and 9.96 µg/g, respectively. Vitamin C intake aids in collagen synthesis, enhances iron absorption, and supports immune function. The vitamin C contents observed in this study are similar to values obtained in a previously by Ikese *et al*. (2025)[30] who reported vitamin C contents of 9.06 mg/100 g, 12.75 mg/100 g, and 10.27 mg/100g for soybeans, unripe plantain, and carrots flours, respectively. However, these values were higher than values obtained for finger millet and pumpkin flours, in which vitamin C contents were found to be 1.84 mg/100 g and 1.85 mg/100 g, respectively.[30] On the other hand, vitamin E, a fat-soluble antioxidant vitamin which protects cell membranes from oxidative damage and enhances immune function,[35] was found to be highest in eggplant flour and meal (268.44 µg/g and 213.93 µg/g, respectively), while the binding agent psyllium husk had the lowest vitamin E content of 63.47 µg/g (Table 2). Vitamins E and C function as antioxidants that help protect cells from damage, thereby reducing the risk of chronic conditions such as cardiovascular diseases, cancers, and age-related disorders.[36]

Vitamin K is a fat-soluble vitamin essential in various physiological functions such as blood coagulation, bone metabolism, cardiovascular health, glucose regulation, immune function, neuroprotection, and vascular health.[37,38] In the present study, vitamin K was found to be abundant in coconut flour and meal, cabbage meal, and rolled oats meal, with values of 98.96, 85.10, 76.67, and 86.20 µg/g, respectively, while psyllium husk had the lowest vitamin K content of 0.35 µg/g.

**Table 2:** Vitamin content of the low-carbohydrate flours, meals, and Psyllium husk

| Sample | Vitamin content (µg/g) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Vitamin A** | **Vitamin $B_1$** | **Vitamin $B_6$** | **Vitamin $B_9$** | **Vitamin C** | **Vitamin E** | **Vitamin K** |
| Cabbage Flour | 2016.50 ± 27.15$^{b}$ | 522.22 ± 13.00$^{b}$ | 0.62 ± 0.05$^{d}$ | 12.28 ± 0.68$^{d}$ | 25.28 ± 0.07$^{b}$ | 203.85 ± 4.39$^{c}$ | 35.13 ± 0.12$^{g}$ |
| Coconut Flour | 310.23 ± 5.15$^{f}$ | 596.19 ± 19.21$^{a}$ | 2.57 ± 0.01$^{a}$ | 16.44 ± 0.08$^{b}$ | 39.83 ± 0.10$^{a}$ | 229.55 ± 11.68$^{b}$ | 98.96 ± 0.02$^{a}$ |
| Eggplant Flour | 617.16 ± 12.21$^{e}$ | 522.85 ± 20.07$^{b}$ | 1.29 ± 0.02$^{b}$ | 15.51 ± 0.42$^{c}$ | 19.69 ± 0.54$^{c}$ | 268.44 ± 53.55$^{a}$ | 61.30 ± 0.52$^{e}$ |
| Rolled Oats Flour | 1588.28 ± 15.92$^{c}$ | 337.78 ± 5.58$^{c}$ | 0.50 ± 0.01$^{e}$ | 19.49 ± 0.09$^{a}$ | 13.82 ± 0.04$^{d}$ | 207.31 ± 3.75$^{c}$ | 46.27 ± 0.46$^{f}$ |
| Cabbage Meal | 1603.14 ± 8.69$^{c}$ | 449.86 ± 26.04$^{b}$ | 0.64 ± 0.01$^{d}$ | 45.17 ± 2.51$^{a}$ | 8.79 ± 0.14$^{e}$ | 207.59 ± 3.25$^{c}$ | 85.10 ± 3.15$^{b}$ |
| Coconut Meal | 1192.24 ± 16.11$^{d}$ | 343.81 ± 32.17$^{c}$ | 0.26 ± 0.01$^{f}$ | 12.80 ± 0.02$^{d}$ | 22.08 ± 0.04$^{c}$ | 113.82 ± 0.47$^{e}$ | 76.67 ± 1.45$^{c}$ |
| Eggplant Meal | 1264.03 ± 25.41$^{d}$ | 352.38 ± 0.95$^{c}$ | 0.48 ± 0.00$^{e}$ | 8.59 ± 0.06$^{e}$ | 17.16 ± 0.02$^{d}$ | 213.93 ± 3.39$^{c}$ | 56.93 ± 0.31$^{e}$ |
| Rolled Oats Meal | 2376.24 ± 64.02$^{a}$ | 318.73 ± 15.19$^{c}$ | 0.38 ± 0.00$^{e}$ | 18.84 ± 0.05$^{b}$ | 9.96 ± 0.04$^{e}$ | 130.56 ± 2.63$^{d}$ | 86.20 ± 0.40$^{b}$ |
| Psyllium husk | 1348.18 ± 20.01$^{d}$ | 647.93 ± 14.87$^{a}$ | 0.59 ± 0.02$^{d}$ | 10.74 ± 0.10$^{e}$ | 7.62 ± 0.25$^{f}$ | 63.47 ± 0.23$^{f}$ | 0.35 ± 0.02$^{h}$ |

Values are mean ± SD (n = 3). Means within the same column with different superscript letters are significantly different ($p < 0.05$).

*Mineral contents of low-carbohydrate flours and meals*

Table 3 shows the mineral contents of the low carbohydrate flours and meals. Minerals are vital in preventing and managing chronic diseases through their roles in immune function, antioxidant defense, and enzymatic activity. Imbalances of minerals such as calcium, magnesium, zinc, and iron have been associated with conditions like Calcium plays crucial roles in the dietary management of diabetes, for instance, it is essential for pancreatic beta-cell function, which is vital for insulin secretion. The results of the mineral content analysis as presented in Table 3 show that calcium content was high in cabbage flour and meal (5.60 mg/100 g and 2.84 mg/100 g, respectively), followed by eggplant flour and meal (2.32 mg/100 g and 1.30 mg/100 g, respectively). This relatively high calcium content in these plant materials, suggests that they are good sources of calcium that could cardiovascular diseases, diabetes, osteoporosis, and cancer.[38,39] Maintaining adequate mineral levels through a balanced diet is therefore essential for disease prevention. The mineral content analysis of the various low-carbohydrate flours and meals formulated in this study revealed notable differences, reflecting the diverse nutritional compositions of the samples analyzed.

contribute to bone health. The considerably higher calcium content in the flours compared to the meals, indicates that drying concentrated the mineral, while the higher moisture in the later reduces the mineral concentration. Iron (Fe) plays an essential role in various physiologic processes, including haemoglobin formation,[40] however, it is important to add that excessive iron concentration can lead to oxidative stress, which has been linked to insulin resistance and other complications of diabetes.[41] In this study, iron concentrations ranged from 0.08 mg/100


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g in cabbage meal to 0.119 mg/100 g in rolled oat meal. Interestingly, eggplant flour exhibited a relatively higher iron content (0.20 mg/100 g), which is beneficial in the prevention of anemia. The higher iron concentration in flours compared to their respective meals may result from nutrient concentration after drying of the flour. Potassium was found to be the most abundant mineral across all samples, particularly in eggplant flour (106.4 mg/100 g) and cabbage flour (72.8 mg/100 g), indicating their potential as rich dietary sources of potassium, which is vital for fluid balance and nerve function. Sodium concentrations were generally moderate, with cabbage flour showing the highest value (18.20 mg/100 g), while rolled oats and coconut-based products had comparatively lower sodium concentrations. Magnesium and manganese were present in small but nutritionally relevant quantities. Magnesium content varied from 0.316 mg/100 g in coconut meal to 0.593 mg/100 g in cabbage flour. Magnesium is important for glucose metabolism and insulin sensitivity as it aids the activation of enzymes involved in glucose utilization and insulin action.[42] The generally low-sodium content observed across all samples indicates that these products are suitable for inclusion in low-sodium diets, making them beneficial for individuals managing hypertension. Manganese concentration was highest in rolled oats flour (0.105 mg/100 g) and lowest in eggplant meal (0.010 mg/100 g).

Substantial evidence indicates that zinc supports glucose metabolism by participating in insulin synthesis and secretion, thereby improving glycemic control and reducing oxidative stress in individuals with diabetes.[43] Zinc concentration was lowest in eggplant meal (0.017 mg/100 g). Flours generally exhibited higher zinc contents than the corresponding meals, this is likely due to the concentration effect of drying. The concentrations of all mineral elements in this study were far below what was observed by Ikese *et al*. (2025)[30] in their study on formulation and nutritional characterization of a multipurpose food flour blend for people living with diabetes. In another study by Obahiagbon and Erhamwenetiemwomon (2016),[28] slightly higher mineral concentrations were also recorded in ten powdered adult foods (flours) made from various cereals, tubers, and plantain.

*Sensory attributes of low-carbohydrate meals*

Sensory evaluation is an important tool for assessing consumer preferences in food selection. The mean sensory scores for taste, texture, flavour/aroma, appearance, and overall acceptability of the low-carbohydrate meals are presented in Table 4. Taste was the most liked attribute in the cabbage, coconut, and rolled oats meals, which received mean scores of 7.87, 7.53, and 7.53, respectively, on a 9-point hedonic scale. Among the meals, cabbage meal was rated highest across all attributes, indicating better overall consumer acceptance, as reflected in its scores for taste (7.87), texture (7.27), flavour (7.40), appearance (7.27), and overall acceptability (7.13). This was followed closely by coconut and rolled oats meals, which showed comparable levels of preference. Conversely, the eggplant meal received the lowest scores across all attributes; however, the values were still above the midpoint of the scale, indicating a generally acceptable level of consumer satisfaction.

**Table 3:** Mineral content of the low-carbohydrate flours, meals, and psyllium husk

| Sample | Mineral content (mg/100 g) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Calcium | Iron | Potassium | Magnesium | Manganese | Sodium | Zinc |
| Cabbage Flour | 5.60 ± 0.01$^{a}$ | 0.19 ± 0.01$^{b}$ | 72.80 ± 1.34$^{b}$ | 0.59 ± 0.00$^{a}$ | 0.10 ± 0.00$^{b}$ | 18.20 ± 0.04$^{a}$ | 0.11 ± 0.07$^{b}$ |
| Coconut Flour | 0.65 ± 0.04$^{f}$ | 0.18 ± 0.01$^{b}$ | 14.38 ± 0.02$^{f}$ | 0.46 ± 0.00$^{c}$ | 0.08 ± 0.00$^{c}$ | 5.17 ± 0.12$^{c}$ | 0.06 ± 0.00$^{c}$ |
| Eggplant Flour | 2.32 ± 0.01$^{c}$ | 0.20 ± 0.00$^{a}$ | 106.40 ± 2.86$^{a}$ | 0.58 ± 0.00$^{a}$ | 0.07 ± 0.00$^{d}$ | 6.05 ± 0.04$^{c}$ | 0.12 ± 0.00$^{b}$ |
| Rolled Oats Flour | 0.88 ± 0.01$^{e}$ | 0.17 ± 0.00$^{c}$ | 15.57 ± 0.13$^{f}$ | 0.51 ± 0.00$^{b}$ | 0.11 ± 0.01$^{a}$ | 4.45 ± 0.00$^{d}$ | 0.08 ± 0.00$^{c}$ |
| Cabbage Meal | 2.84 ± 0.02$^{c}$ | 0.08 ± 0.00$^{f}$ | 23.09 ± 0.13$^{e}$ | 0.41 ± 0.00$^{d}$ | 0.02 ± 0.00$^{f}$ | 8.26 ± 0.04$^{b}$ | 0.03 ± 0.00$^{e}$ |
| Coconut Meal | 0.94 ± 0.00$^{e}$ | 0.12 ± 0.00$^{d}$ | 6.64 ± 0.09$^{g}$ | 0.32 ± 0.00$^{e}$ | 0.03 ± 0.00$^{e}$ | 4.98 ± 0.04$^{c}$ | 0.04 ± 0.00$^{d}$ |
| Eggplant Meal | 1.30 ± 0.00$^{d}$ | 0.08 ± 0.00$^{f}$ | 24.70 ± 0.11$^{e}$ | 0.38 ± 0.00$^{e}$ | 0.01 ± 0.00$^{g}$ | 5.39 ± 0.02$^{c}$ | 0.02 ± 0.00$^{f}$ |
| Rolled Oats Meal | 0.72 ± 0.00$^{f}$ | 0.12 ± 0.00$^{d}$ | 10.25 ± 0.11$^{f}$ | 0.41 ± 0.00$^{d}$ | 0.06 ± 0.00$^{d}$ | 4.43 ± 0.01$^{d}$ | 0.05 ± 0.00$^{d}$ |
| Psyllium Husk | 2.74 ± 0.02$^{b}$ | 0.31 ± 0.01$^{a}$ | 25.19 ± 0.11$^{d}$ | 0.35 ± 0.00$^{e}$ | 0.07 ± 0.00$^{c}$ | 6.70 ± 0.05$^{c}$ | 0.17 ± 0.04$^{a}$ |

Values are mean ± SD (n = 3). Means within the same column with different superscript letters are significantly different ($p < 0.05$).

**Table 4:** Sensory attributes of the low-carbohydrate meals

| Sample | Sensory attributes | | | | |
|---|---|---|---|---|---|
| | Taste | Texture | Flavour | Appearance | Overall Acceptability |
| **Cabbage Meal** | 7.87 ± 1.13$^{a}$ | 7.27 ± 0.96$^{a}$ | 7.40 ± 1.06$^{a}$ | 7.27 ± 1.16$^{a}$ | 7.13 ± 1.13$^{a}$ |
| **Coconut Meal** | 7.53 ± 1.19$^{b}$ | 7.27 ± 1.03$^{a}$ | 7.27 ± 1.16$^{b}$ | 7.13 ± 1.19$^{b}$ | 6.67 ± 1.23$^{c}$ |
| **Eggplant Meal** | 6.40 ± 1.50$^{d}$ | 7.07 ± 1.39$^{b}$ | 5.87 ± 2.07$^{c}$ | 6.53 ± 1.19$^{c}$ | 6.80 ± 1.78$^{b}$ |
| **Rolled Oat Meal** | 7.53 ± 1.13$^{b}$ | 7.13 ± 1.13$^{b}$ | 7.40 ± 0.99$^{a}$ | 7.20 ± 0.86$^{b}$ | 7.00 ± 0.94$^{b}$ |

Values are mean ± SD (n = 15). Means within the same column with different superscript letters are significantly different ($p < 0.05$).

## Conclusion

The findings from this study have shown that low-carbohydrate meals prepared from cabbage, coconut, eggplant, and rolled oats flours are nutritionally rich and suitable for carbohydrate-restricted diets. These meals contained lower carbohydrate content with appreciable fibre, protein, and mineral contents. Cabbage and eggplant meals were particularly high in fibre and minerals, while coconut products had more of lipids and vitamins. These formulations may support glycaemic control and serve as healthier alternatives for managing chronic diseases


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that require modification in carbohydrate intake. Future studies should evaluate the glycemic index, long-term metabolic effects of low-carbohydrate Nigerian staple meal alternatives and expand nutrient profiling for a more comprehensive understanding of the nutritional values of these meals.

## Conflict of Interest
The authors declare no conflict of interest.

## Authors' Declaration
The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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