FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 1, January, 2026, pp 175 – 184
DOI: https://doi.org/10.33003/fjs-2026-1001-4538

ASSESSMENT OF NON-FIBER CARBOHYDRATES, Β-GLUCANS, PECTIN, AND ANTINUTRIENTS IN INDIGENOUS NIGERIAN EDIBLE CROPS FOR FUNCTIONAL FOOD APPLICATIONS

[1]Maimuna Muhammad Salihu, [1]Emmanuel Haruna, [2]Hassan Bala Salihu, [3]Agu Perpetual Nkemdilim, [1]Amos Alvan and *[1,4]Samson Baranzan Wayah

[1]Department of Biochemistry, Faculty of Life Sciences, Kaduna State University, Nigeria.
[2]Federal Neuropsychiatric Hospital, Kaduna State, Nigeria.
[3]Department of Chemistry, Faculty of Science, Airforce Institute of Technology, Nigeria.
[4]Faculty of Environmental, Life, Natural Science, and Technology, Okayama University, Japan.

*Corresponding authors' email: samson.wayah@kasu.edu.ng

ABSTRACT

Dietary fibers such as soluble fiber, beta-glucan, and pectin play crucial roles in gut health and glycemic regulation, offering potential benefits for managing type 2 diabetes mellitus. Despite this, many indigenous Nigerian crops remain underexplored for their fiber composition and antinutrient contents. By employing standard biochemical assays, this study quantified soluble fiber, beta-glucan, and pectin levels, alongside saponin, tannin, and oxalate contents, in nineteen selected crops. It further assessed total short-chain fatty acid (TSCFA) production following fermentation with *Lactobacillus* species to evaluate fermentability and functional value. The highest non-fiber carbohydrates content was observed in *Monodora myristica* (20.28%), *Piper nigrum* (19.21%), and *Moringa oleifera* (13.14%). *Helianthus annuus* showed the highest beta-glucan (3.14%) and pectin (10.32%) levels, followed by *Sorghum spontanea* and *Monodora myristica*. Antinutrient analysis revealed *Moringa oleifera* contained the highest saponin (2.48 mg/100 g), tannin (1.12 mg/100 g), and oxalate (1.98 mg/100 g) levels. Fermentation results indicated significant TSCFA production in *Hibiscus sabdariffa* (0.09 M), *Cyperus esculentus* (large seed) (0.08 M), and *Piper guineense* (0.078 M), demonstrating good fermentability and prebiotic potential, whereas *Sorghum durra* and *Eleusine coracana* produced lower values. In conclusion, several underutilized Nigerian crops possess high levels of beneficial dietary fibers with promising fermentability, highlighting their potential as functional foods for glycemic control and gut microbiota modulation. However, their elevated antinutrient levels underscore the need for effective processing and detoxification strategies. Future research should investigate *in vivo* effects, microbial interactions, and crop improvement to optimize health benefits.

Keywords: Antinutrients, Beta-Glucan, Pectin, Soluble Fiber, Short-Chain Fatty Acids

INTRODUCTION

Dietary fibers have gained increasing recognition for their roles in human health, particularly in the prevention and management of metabolic disorders such as type 2 diabetes mellitus (T2DM) (Opperman *et al.*, 2025). Soluble fibers are a type of dietary fibers. Soluble fibers including beta-glucan and pectin, have been shown to modulate postprandial glycemia, improve insulin sensitivity, and promote satiety through delayed gastric emptying and reduced glucose absorption (Wu *et al.*, 2021).. Beyond glycemic regulation, these fibers serve as substrates for gut microbiota fermentation, leading to the production of short-chain fatty acids (SCFAs) such as acetate, propionate, and butyrate, which exert beneficial effects on gut integrity, lipid metabolism, and immune regulation (Portincasa *et al.*, 2022). Consequently, dietary fibers are increasingly recognized as key components of functional foods with therapeutic potential (Ghavami *et al.*, 2023).

Nigeria is endowed with a wide diversity of indigenous and underutilized crops that may serve as sustainable sources of dietary fibers (Onawo and Egboduku, 2025). However, research on the fiber composition of these crops remains limited, with most studies focusing on widely consumed cereals such as maize, rice, and wheat. Many traditional crops including *Sorghum*, *Cyperus*, *Digitaria*, *Piper*, *Aframomum*, and *Monodora* species are underexplored despite their potential nutritional and medicinal value. Moreover, the presence of antinutrients such as tannins, saponins, and oxalates in these crops may influence nutrient bioavailability, palatability, and safety, underscoring the need for detailed evaluation (Onawo and Egboduku, 2025).

In addition, the fermentability of these indigenous crops by beneficial microbes such as *Lactobacillus* species, one the most important probiotic bacteria of human gut microbiota, remains largely uncharacterized. Fermentation potential is a critical indicator of prebiotic activity, as it determines the extent to which dietary fibers can support gut microbiota functions and SCFA production (Rastogi *et al*., 2022; Vinelli *et al.*, 2022).

This study, therefore, aimed to quantify non-fiber carbohydrates (which includes soluble fiber), beta-glucan, and pectin contents, as well as key antinutrients, in nineteen selected Nigerian crops. It also evaluated their fermentability by *Lactobacillus* species through measurement of total SCFA production. Findings from this work are expected to provide insights into the nutritional and functional value of underutilized indigenous crops, with implications for diabetes management, gut health promotion, and the development of novel functional foods.

MATERIALS AND METHODS

Sample Collection and Identification

Plants used in this study are shown in Table 1. Plant samples were collected from markets within Kaduna metropolis and identified by a taxonomist at biological science department Kaduna state university. Thereafter, samples were washed and dried at room temperature and processed into powder using mortar and pestle.

Table 1: Plants That Were Investigated in This Research

S/No	Indigenous Name	English Name	Scientific Name
1.	Jar dawa	Red sorghum	*Sorghum durra*
2.	Kaura	Yellow sorghum	*Sorghum exertum*
3.	Launin ƙasa dawa	Brown sorghum	*Sorghum spontanea*
4.	Farar dawa	White sorghum	*Sorghum bicolor*
5.	Uzziza	African black pepper	*Piper guineense*
6.	Gero	Millet	*Pennisetum typhoides*
7.	Ehuru	African nutmeg	*Monodora myristica*
8.	Aya rigiza	Tigernut seed small variety	*Cyperus esculentus*
9.	Aya	Tigernut seed large variety	*Cyperus esculentus*
10.	Acca	Hungry rice	*Digitaria exilis*
11.	Magarya	Jujube	*Ziziphus abyssinica*
12.	Alkama	Wheat	*Triticum aestivum*
13.	Masoro	Black pepper	*Piper nigrum*
14.	Barekata	Roselle, white	*Hibiscus sabdariffa*
15.	San filawa	Sunflower seed	*Helianthus annuus*
16.	Tamba	Finger millet	*Eleusine coracana*
17.	Dauro	Pearl millet	*Pennisetum glaucum*
18.	Zogale	Moringa seed	*Moringa oleifera*
19.	Citta mai koko	Alligator pepper	*Aframomum* daniellii

Determination of Non-Fiber Carbohydrates

In this study, non-fiber carbohydrates which comprise of soluble fibers, starch, sugars, organic acids and fructans was used as indirect approach to estimate the soluble fiber content of the crops (Villalba *et al*., 2021). A sample of 1 g was added to 600 ml beakers, followed by the addition of 100 mL of neutral detergent solution and 0.5 g sodium sulfite (Na_2SO_4). The mixture was boiled for one hour in a refluxing apparatus, meanwhile, weight of an oven dried glass crucible was recorded. After boiling, the solution was poured through the glass crucible, and a vacuum was applied. The sample was rinsed with acetone repeatedly until the drained liquid is clear. It was then dried at 105 °C overnight. Once dried, the sample was allowed to cool to room temperature in a desiccator. The sample and crucible were weighed again. The percentage of neutral detergent fiber (NDF) was calculated as:

%NDF = (Weight of crucible + Weight of residue) - Weight of crucible/Weight of sample ×100

To determine the soluble fibers:

Non-fiber carbohydrates (%) = 100− NDF (Van Soest *et al.*, 1991)

Determination of Beta-glucan

The Neogen β-glucan assay kit (K-BGLU) was used as described by the manufacturer. A flour sample (80-120 mg, accurately weighed) was added to a glass centrifuge tube (16 x 120 mm; 17 mL capacity). The tube was tapped to ensure that the entire sample settles at the bottom. To assist in dispersion, 0.2 mL of 50% (v/v) aqueous ethanol was added. Next, 4.0 mL of 20 mM sodium phosphate buffer (pH 6.5) was added, and the mixture was stirred using a vortex mixer. The tube was then placed immediately into a boiling water bath for 60 seconds. After that, the contents were stirred vigorously on a vortex mixer, incubated further at 100°C for 2 minutes, and stirred again.

The tube and its contents were incubated at 50°C for 5 minutes to allow them to equilibrate. Following this, 0.2 mL of solution 1 (diluted lichenase) was added, and the contents were stirred. The tube was sealed with parafilm and incubated at 50°C for 1 hour, with periodic stirring (3-4 times) on a vortex mixer, or continuously if possible. Then, 5.0 mL of 200 mM sodium acetate buffer (pH 4.0) was added, and the mixture was vigorously stirred. After allowing the tube to equilibrate to room temperature for 5 minutes, the sample was centrifuged at 1,000 g for 10 minutes.

Accurate aliquots (0.1 mL) were transferred from the supernatant into three test tubes (12 mL capacity). In two tubes (the reaction tubes), 0.1 mL of solution 2 (diluted β-glucosidase) was added, while in the third tube (the reaction blank), 0.1 mL of 50 mM sodium acetate buffer (pH 4.0) was added. All tubes were incubated at 50°C for 10 minutes. Following this, 3.0 mL of GOPOD Reagent was added to each tube, and they were incubated at 50°C for an additional 20 minutes. The tubes were removed from the water bath, and the absorbance was measured at 510 nm against a reagent blank within 1 hour. The absorbance value was used to determine the amount of β-glucan using Mega-Calc™ from megazyme website (Held and Fox, 2023).

Determination of Pectin

Aqueous Extraction

About 20 g powder of sample was mixed in water at a temperature of 25°C for a duration of 30 minutes. Filtration was employed to separate the residue. The supernatants were concentrated under vacuum conditions (Marcon *et al.*, 2005).

Acid Extraction

The residue obtained from the aqueous extraction was subjected to extraction with 5% (w/v) citric acid at 100 ^{0}C for 80 minutes. The sample was cooled, followed by the separation of its residue through filtration. The supernatants underwent precipitation using ethanol at a ratio of 2 volumes (2 vol ethanol:1 vol sample). Following an incubation period of 12 hours at 4°C, the pectin was separated through filtration and subsequently dried at a temperature range of 35-40°C (Marcon *et al.*, 2005).

Quantification of Pectin

To a 0.5 g sample of pectin, 5 ml of 96% ethanol, 1 g of sodium chloride, and 100 ml of deionized water were incorporated. The solution was agitated until the pectin completely dissolved, followed by titration using 0.1 M NaOH, with phenolphthalein serving as the indicator (Grassino *et al.*, 2018).

Pectin content (mg/g) =V×N×176.1×1000/W

Where:

V = Volume of NaOH used (in mL)
N = Normality of NaOH solution (in this case, 0.1 N)
176.1 = Equivalent weight of pectin (g/mol)
W = Weight of the sample used for pectin extraction (in grams)

Determination of Saponin

In accordance with the gravimetric method described in AOAC (1990), a Soxhlet extractor and two distinct organic solvents was be utilized. Precisely 2.0 g of the specimen was weighed into a thimble and introduced into a Soxhlet extractor equipped with a condenser. Extraction was conducted using acetone in a 250 ml round-bottom flask for a duration of three hours. Afterward, the sample was weighed in a 250 ml round-bottom flask containing methanol. Extraction continued for an additional three hours using the same apparatus fitted with an extractor. Upon completion of the second extraction, the methanol was extracted via distillation, and the sample was oven-dried to eliminate any residual solvent in the flask. Once cooled in desiccators, the flask was weighed (AOAC, 1990).
Calculation:

$$\% \text{ Saponin} = \frac{A - B \times 100}{W}$$

Where:
A = weight of flask and extract saponin
B = weight of empty flask
W = weight of sample

Determination of Tannins

The tannin content of the samples was analyzed in accordance with the method described in the International Pharmacopoeia and AOAC, with certain adjustments (Manoshree and Devangi, 2019). In a conical flask, 5 mL of the extract, 5 g of indigo solution, and 150 mL of deionized water (ddH_2O) were combined. For titration, a 0.1 N aqueous solution of potassium permanganate was employed until the solution transitions from blue to green. Afterward, a few drops were added to the solution at a time until it turned golden yellow.

The standard solution of indigo carmine was prepared as follows: after heating and cooling 500 ml of ddH_2O to dissolve 6 g of indigo carmine, 50 ml of 95-97% sulfuric acid was added. The solution will then be diluted to 1L and passed through a filter. Each individual plant sample was examined in triplicate. The standard graph of tannic acid was generated by titrating a mixture of 5 mL of indigo solution with varying amounts of a 0.001 M solution of standard tannic acid (AOAC, 1990).

Determination of Oxalate

The methodology employed in this study followed the procedure described earlier by Adeniyi et al. (2009). A 2 g sample underwent digestion with 10 ml of 6 M HCl for one hour and was then diluted to 250 ml in a volumetric flask. The pH of the filtrate was adjusted with concentrated NH_4OH solution, causing the color of the solution to change from salmon pink to pale yellow. Following this, 10 ml of a 5% $CaCl_2$ solution was added to the filtrate to precipitate the insoluble oxalate. The suspension was centrifuged at 2500 rpm, and the supernatant was decanted. The precipitate was fully dissolved in 10 ml of 20% (v/v) H_2SO_4, resulting in a total filtrate volume of 300 mL.

An aliquot of 125 ml of the filtrate were titrated against a 0.05 M standardized $KMnO_4$ solution until a faint pink color persisted for approximately 30 seconds. The aliquot was heated to a temperature close to the boiling point. The titer value was used to assess the oxalate content (AOAC, 1990). This is the overall redox reaction:

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 8H_2O + 10CO_2$$

Determination of Total Short Chain Fatty Acids in the Selected Crops

Isolation of Lactobacillus sp. from Yoghurt Sample

To 9 mL DeMan Rogosa Sharpe (MRS) broth in a test tube 1 mL of the yogurt sample was added. The inoculated broth was incubated at 37 °C for 24 hours to allow the organism to multiply and enrich the sample. The enriched broth was then serially diluted using sterile normal saline. Aliquots of these dilutions were plated onto MRS agar plates using pour plating method. The plates were incubated under anaerobic conditions at 37 °C for 48 hours. This ensures that LAB, which are often facultative anaerobes or obligate anaerobes, have the optimal conditions to grow and form colonies.

After incubation, individual colonies that appeared on the agar plates were selected and transferred to fresh MRS broth for 24 hours for further growth. Pure cultures were further identified using biochemical tests such as; methyl red Voges Proskauer test, indole test, oxidase test, catalase test (Modasiya *et al.,* 2024).

Evaluation of Total Short Chain Fatty Acids

The inoculum (Lactobacillus sp.) was prepared growing the strain in MRS broth for 24 hours at 37 °C under anaerobic conditions. Soluble fiber source was dissolved in a basal medium at a concentration of 2% (w/v). And inoculated with Lactobacillus at 10% (v/v). The medium was Incubated at 37 °C for 48 hours for fermentation to take place. After fermentation, the broth was collected, and centrifuged at 10,000 rpm for 10 minutes to remove microbial cells. The supernatant was filtered through a 0.2 µm filter paper. To 10 mL of the filtered sample, 1 mL of 0.1 M HCl was added to adjust the pH to go below 2. The acidified sample was slowly titrated by slowly adding 0.1 M NaOH while stirring, continuously measuring the pH and recording the volume of NaOH used in bringing the sample to pH 7 (AOAC, 1990).

Calculation

The total SCFA concentration was calculated based on the amount of NaOH used:
Total SCFA (mM) = Volume of NaOH (L)×Molarity of NaOH (mol/L)/Sample volume (L)

Data Analysis

Data were cleaned, coded, and entered into the IBM SPSS statistics software version 29 for analysis. Numerical variables were expressed as means of triplicate measurements. Standard deviation was used as a measure of dispersion. One-way analysis of variance (ANOVA) was used to compare mean values for statistically significant difference at 95% confidence level. Crop species was used as the factor for the one-way ANOVA. Post hoc analysis was carried out using Tukey's honestly significant difference test (Turkey’s HSD).

RESULTS AND DISCUSSION

Non-Fiber Carbohydrates content of the Selected Crops

In this study, non-fiber carbohydrates which includes soluble fibers, starch, sugars, organic acids and fructans was used to estimate soluble fiber content of the crops (Villalba *et al.*, 2021). Among the samples analyzed, *Monodora myristica* (20.28 g/100g) and *Piper nigrum* (19.21 g/100g) exhibited the highest soluble fiber concentrations (Figure 1). This is noteworthy because soluble fibers play an essential role in modulating postprandial blood glucose levels by forming viscous gels in the gastrointestinal tract, delaying gastric emptying, and slowing carbohydrate absorption (Cassidy *et al.*, 2018). These effects are beneficial in the dietary management of type 2 diabetes mellitus. Therefore, the consumption of these spices could contribute meaningfully to glycemic control when incorporated into traditional diets (Chen *et al.*, 2022).

Aframomum daniellii (12.33 g/100g), *Hibiscus sabdariffa* (12.43 g/100g), *Piper guineense* (10.08 g/100g), and *Cyperus esculentus* (small) (10.07 g/100g) also showed appreciably high soluble fibre levels. These plants are commonly underutilized despite their availability in Nigeria. Their inclusion in daily meals, either as spices, condiments, or whole foods, could enhance fiber intake among the population, offering an affordable and culturally acceptable strategy for improving metabolic health and preventing the onset of diabetes (Wu *et al.*, 2023).

Interestingly, *Moringa oleifera* leaves widely regarded for their medicinal and nutritional value also demonstrated a high soluble fibre content (13.14 g/100g), supporting previous reports of its hypoglycaemic properties. Its use in teas, soups, and food fortification may therefore provide dual benefits: nutritional enhancement and functional support for diabetes management (Pareek *et al.*, 2023). Conversely, the grains *Digitaria exilis* (0.78 g/100g) and *Sorghum bicolor* (1.52 g/100g) exhibited the lowest soluble fiber contents. This suggests that although these grains are staple foods in various regions, they may offer limited functional benefits in terms of soluble fiber-mediated glycemic control compared to other studied crops. Nonetheless, these grains may still contribute to overall dietary fiber intake when consumed as part of a mixed diet. The three wild sorghum species analyzed, *Sorghum durra* (4.85 g/100g), *Sorghum exertum* (4.61 g/100g), and *Sorghum spontanea* (4.96 g/100g) contained moderate amounts of soluble fibre. This indicates that certain sorghum landraces may have better potential for breeding programs targeting high-fiber cereal cultivars suitable for functional food development aimed at diabetes prevention (Khoddami *et al.*, 2023).

Furthermore, *Eleusine coracana* (5.52 g/100g) and *Cyperus esculentus* (large) (7.65 g/100g) recorded moderate fibre levels, reinforcing their potential as alternative cereal and tuber crops, respectively, that could contribute to dietary diversification with functional benefits. A study assessed the concentration of soluble fiber in several food plants. The results indicated the following fiber content: wheat bran (4.6 g/100 g), oat fiber (1.5 g/100 g), rice bran (4.7 g/100 g), apple fiber (13.9 g/100 g), tomato fiber (8.3 g/100 g), dried raw white beans (4.3 g/100 g), and cooked asparagus (0.5 g/100 g) (Chawla and Patil, 2010).

From a nutritional and public health perspective, these findings have several important implications. Crops with high soluble fiber content such as *Monodora myristica*, *Piper nigrum*, and *Ziziphus abyssinica* can be harnessed to formulate fiber-enriched foods aimed at improving glycemic control and gut health. The observed soluble fiber levels also indicate potential for prebiotic effects, as these fibers can be fermented by gut microbiota to produce short-chain fatty acids (SCFAs), which are beneficial for insulin sensitivity and overall metabolic health (Nitzke *et al.*, 2024).

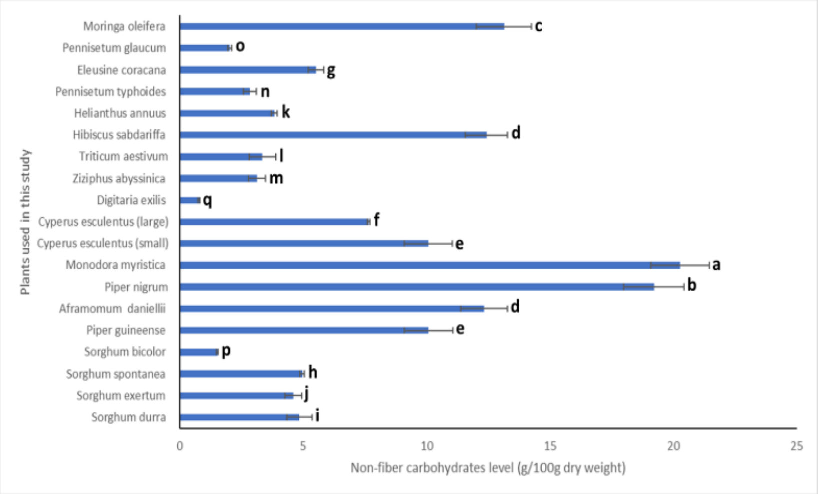

Figure 1: Non-fiber Carbohydrates Content of the Selected Crops. Values are Means of 3 Replications ± Standard Deviation; Means that differ Significantly at 95% Confidence Level were Assigned Different Alphabet

Beta-glucan Levels in the Selected Crops

Beta-glucan, a soluble dietary fiber known for its viscosity and ability to attenuate postprandial blood glucose levels, has been extensively studied for its hypoglycemic and cholesterol-lowering properties (Hossain *et al.*, 2025). The differential levels of beta-glucan across the crops examined (Figure 2) underscore both the nutritional diversity of indigenous and cultivated Nigerian plant resources and their possible utilization in functional foods or nutraceutical development.

Among all the crops analyzed, *Helianthus annuus* (sunflower) recorded the highest beta-glucan concentration at 3.14%. This is significant, as sunflower seeds are not commonly consumed in large quantities in Nigeria, yet they hold immense potential as a source of functional fiber. Their high beta-glucan content could be harnessed in the formulation of fiber-rich dietary products targeted at diabetic populations, especially if coupled with public health awareness on their nutritional benefits (Ojo *et al.*, 2021).

Closely following in beta-glucan richness were *Sorghum spontanea* (3.12%) and *Monodora myristica* (2.71%). These results highlight the remarkable fiber content in some wild and underutilized plant species. *Sorghum spontanea*, a wild sorghum variety, exhibited higher beta-glucan levels than commonly cultivated sorghum species such as *Sorghum durra* (2.37%) and *Sorghum bicolor* (1.94%), suggesting that wild varieties may possess superior health-promoting attributes due to their genetic and environmental adaptations. This finding supports the conservation and promotion of wild sorghum species not just for biodiversity but also for their nutritional and medicinal potentials. Similarly, *Monodora myristica*, often used as a spice in traditional Nigerian cuisine, showed high beta-glucan content, indicating that culinary spices could also contribute meaningfully to dietary fiber intake (Edo *et al.*, 2024). This opens up avenues for further research into the health benefits of other indigenous spices and condiments that are often overlooked in mainstream nutritional assessments.

Other crops with relatively high beta-glucan content include *Sorghum exertum* (2.65%), *Pennisetum typhoides* (2.62%), and Piper nigrum (2.54%). These crops, particularly *Pennisetum typhoides* (commonly known as pearl millet), are already part of traditional diets in parts of Nigeria and sub-Saharan Africa. Their moderate-to-high beta-glucan content makes them suitable for formulation into low-glycemic index meals. *Piper nigrum* (black pepper), also a commonly used spice, showed considerable beta-glucan content, which again emphasizes the potential contribution of small-volume, high-impact ingredients to overall fiber intake (Edo *et al.*, 2024).

At the middle of the spectrum were crops such as *Piper guineense* (1.35%), *Aframomum daniellii* (1.11%), *Moringa oleifera* (1.14%), and *Hibiscus sabdariffa* (1.74%). While these values are not as high as those of sunflower or wild sorghum, they still offer a reasonable contribution to daily fiber intake, particularly in combination with other foods. Moringa oleifera, in particular, is widely known for its rich micronutrient profile and antioxidant properties; the additional presence of beta-glucan reinforces its value as a functional food for managing metabolic disorders (Pareek *et al.*, 2023).

Cyperus esculentus, represented by two seed size varieties, exhibited notable differences in beta-glucan content. The small-seeded variety had 1.43%, whereas the large-seeded variety had only 0.92%. This suggests that intra-species variation, possibly due to environmental factors or genotype, significantly influences fiber composition. Such findings can guide selective breeding or targeted cultivation strategies for enhancing beta-glucan yield. In contrast, the lowest beta-glucan levels were observed in *Triticum aestivum* (0.32%), Digitaria exilis (0.51%), Ziziphus abyssinica (0.71%), *Eleusine coracana* (0.79%), and *Pennisetum glaucum* (0.96%). While these crops are widely consumed and often praised for their energy and mineral content, their relatively low beta-glucan levels suggest they may not independently provide the fiber levels necessary for effective glycemic control. However, they could still play complementary roles in multi-cereal or mixed-diet formulations (Chen *et al.*, 2022).

Triticum aestivum (common wheat) presenting the lowest beta-glucan content was particularly surprising, given that oats and barley other cereals in the Poaceae family are typically recognized for high beta-glucan content (Chen *et al.*, 2022). This result may reflect differences in wheat varieties, growing conditions, or post-harvest processing methods. It also highlights the need for detailed profiling of Nigerian wheat varieties to identify higher-fiber genotypes suitable for dietary management of chronic diseases.

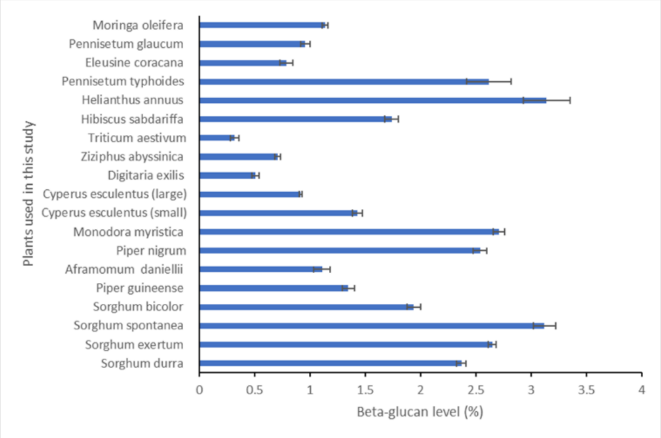

Figure 2: Beta-glucan Levels in the Selected Crops. Values are Means of 3 Replications ± Standard Deviation; Means that Differ Significantly at 95% Confidence Level were Assigned Different Alphabet

Pectin Levels in the Selected Crops

The results of the pectin content in the analyzed underutilized Nigerian crops reveal substantial variations across species (Figure 3), underscoring the diverse potential of these plants in both nutritional and industrial applications. Pectin, a soluble dietary fiber primarily composed of galacturonic acid units, plays a crucial role in gut health by acting as a prebiotic and contributing to the viscosity and gel-forming ability of intestinal contents. It is also extensively used in the food, pharmaceutical, and cosmetic industries due to its gelling, stabilizing, and emulsifying properties (Ren *et al.*, 2025).

Among the studied crops, *Helianthus annuus* (sunflower) stood out distinctly with the highest pectin content of 10.32%. This level is significantly higher than those observed in the other crops and positions sunflower as an excellent candidate for pectin extraction and industrial exploitation. The high pectin content in sunflower may be attributed to its structural composition, particularly its robust cell wall matrix, which is rich in polysaccharides. This exceptional value makes it a promising alternative to traditional pectin sources such as citrus peels and apple pomace, especially in regions where sunflower is cultivated but underutilized for its fiber content (Kalita *et al.*, 2025).

Sorghum spontanea also recorded a relatively high pectin level of 5.05%, followed by *Moringa oleifera* with 4.76% and *Sorghum exertum* with 3.98%. These values are notable and suggest that certain wild and indigenous sorghum varieties, as well as moringa, could serve as valuable dietary sources of soluble fiber. Moringa, in particular, is already celebrated for its rich nutritional profile and medicinal properties; the added benefit of high pectin content further enhances its potential in functional food development, particularly in the formulation of prebiotic-rich or blood glucose-lowering products (Sultana, 2023).

Moderate levels of pectin were observed in *Triticum aestivum* (3.11%), *Pennisetum typhoides* (3.43%), and *Hibiscus sabdariffa* (2.56%). These values indicate that commonly cultivated cereals and traditional plants could contribute meaningfully to the daily intake of pectin when consumed regularly. The relatively high pectin content of *Hibiscus sabdariffa*, known for its antioxidant-rich calyces, supports its use in the production of therapeutic beverages and functional foods. It suggests that hibiscus could offer dual health benefits antioxidant protection and improved digestive health when incorporated into diets.

Several other crops, including *Cyperus esculentus* (both small and large variants), *Ziziphus abyssinica*, and *Eleusine coracana*, showed pectin contents ranging between 1.9% and 2.7%. These levels, while not as high as those of the top-performing crops, are still significant, especially considering their wide availability, adaptability to local growing conditions, and cultural acceptance. Their inclusion in composite flour formulations, snacks, or traditional meals could help improve dietary fiber intake, particularly among populations that rely on starchy staples low in soluble fiber.

Lower pectin levels were recorded in *Piper nigrum* (0.85%), *Digitaria exilis* (0.71%), and *Pennisetum glaucum* (0.57%). While these crops may not be ideal primary sources of pectin, they still offer potential as complementary components in fiber-enriched diets, especially when blended with other high-pectin ingredients. The presence of pectin in small amounts also suggests that even minimal consumption of these plants can contribute to overall gut health when part of a diverse diet. The percentage of dry matter in pectin found in apple pomace typically ranges from 10% to 15%. Citrus peel contains a notably greater concentration of pectin (20-30%) when contrasted with apple peel (Srivastava and Malviya, 2011).

What emerges clearly from this analysis is that indigenous and underutilized crops in Nigeria possess varying degrees of pectin content, with some such as *Helianthus annuus*, *Sorghum spontanea*, and *Moringa oleifera* offering especially high values. These findings have several implications. From a nutritional standpoint, increasing the consumption of these crops could significantly enhance the intake of soluble fiber among the Nigerian population, contributing to the management of conditions such as constipation, hypercholesterolemia, and type 2 diabetes mellitus (Sultana, 2023). From an economic perspective, crops with high pectin content could be developed into raw materials for local pectin extraction industries, reducing dependence on imports and promoting value addition within the agricultural sector.

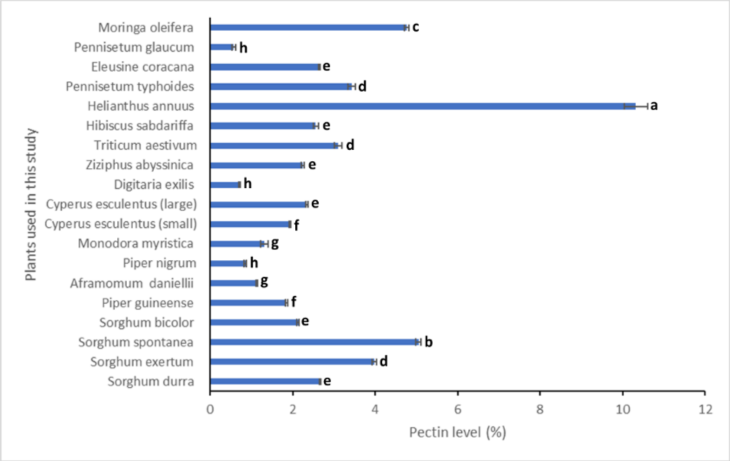

Figure 3: Pectin Levels in the Selected Crops. Values are means of 3 Replications ± Standard Deviation; means that Differ Significantly at 95% Confidence Level were Assigned Different Alphabet

Antinutrients (Saponin, Tannin and Saponin) Content of the Selected Crops

The results of the antinutrient analysis specifically saponins (Table 2), tannins (Table 2), and oxalates (Table 2) in the selected underutilized Nigerian crops highlight both nutritional concerns and potential health-promoting properties, depending on their concentrations and the dietary context. While traditionally considered undesirable due to their potential to interfere with nutrient absorption and metabolism, recent research has shown that antinutrients may also exert beneficial physiological effects when present in moderate quantities (Arsov *et al.*, 2024).

Saponins, a class of glycosidic compounds known for their soap-like foaming properties, were found in varying concentrations across the studied crops. *Moringa oleifera* had the highest saponin content at 2.48 mg/100g, which is significantly elevated compared to all other crops. This level suggests that while moringa is highly regarded for its nutritional and medicinal value, its high saponin concentration might warrant caution in individuals with gastrointestinal sensitivity or those at risk of nutrient malabsorption, particularly for minerals like iron and zinc (Oakenfull and Sidhu, 2023). However, saponins also possess desirable bioactivities, such as cholesterol-lowering, antimicrobial, and anticancer effects (Jiang *et al.*, 2024), suggesting that the presence of saponins in moringa could contribute to its therapeutic properties if consumed in appropriate quantities or after processing to reduce their levels (Akangbe *et al.*, 2024).

Ziziphus abyssinica followed with a notable saponin content of 1.24 mg/100g, which also suggests potential for both nutraceutical and pharmacological applications. The other crops had relatively low saponin levels, mostly ranging between 0.08 mg/100g and 0.27 mg/100g. Crops like *Aframomum daniellii*, *Monodora myristica*, and *Hibiscus sabdariffa* exhibited modest saponin content, indicating a reduced risk of adverse nutritional effects while still retaining some of the beneficial bioactivity. On the other hand, grains such as *Pennisetum typhoides* and *Eleusine coracana* had the lowest levels (0.08 mg/100g and 0.05 mg/100g, respectively), suggesting these crops could be suitable for individuals requiring low-saponin diets, such as children, the elderly, or those with sensitive digestion (Kaur *et al.*, 2021).

Tannin content, which is often associated with astringency and the potential to inhibit protein digestibility and iron absorption (Zhang *et al.*, 2023), also varied considerably across the studied crops. *Moringa oleifera* again recorded the highest tannin concentration at 1.12 mg/100g, followed by *Sorghum durra* (0.79 mg/100g) and *Sorghum spontanea* (0.64 mg/100g). These values, while moderate, may have nutritional implications, particularly in populations at risk of iron deficiency anemia. However, it is important to recognize that tannins also exhibit antimicrobial and antioxidant properties and may offer protection against certain diseases, including cancers and cardiovascular disorders. Crops such as *Ziziphus abyssinica* (0.07 mg/100g) and *Triticum aestivum* (0.09 mg/100g) showed minimal tannin content, suggesting that they are more bioavailable in terms of protein and iron absorption and could be valuable dietary staples, especially when consumed with other nutrient-dense foods (Hoque *et al.*, 2025).

Most of the other crops had tannin levels ranging from 0.11 mg/100g to 0.45 mg/100g, which falls within the acceptable range for human consumption and suggests that these crops may be consumed safely without significant risk of adverse effects. Notably, *Cyperus esculentus* (small and large varieties) had tannin levels of 0.24 mg/100g and 0.45 mg/100g, respectively, indicating moderate tannin presence that may contribute to the crop's natural defense mechanisms while still being nutritionally manageable in a balanced diet (Hoque *et al.*, 2025).

The oxalate content of the crops revealed another important dimension of the antinutritional profile. Oxalates are known to chelate calcium and form insoluble calcium oxalate crystals, which can contribute to kidney stone formation and hinder calcium bioavailability (Salgado *et al.*, 2023). Among the studied crops, *Moringa oleifera* again exhibited the highest oxalate concentration at 1.98 mg/100g, followed closely by *Sorghum bicolor* (1.95 mg/100g) and *Pennisetum glaucum* (1.86 mg/100g). These high values imply that regular consumption of these crops in large quantities may pose a risk for individuals predisposed to oxalate-related health issues, such as renal calculi. However, these crops can still be safely consumed if appropriately processed through boiling, fermentation, or soaking which can substantially reduce oxalate levels (Huynh *et al.*, 2022).

Other crops, such as *Eleusine coracana* (1.74 mg/100g) and *Pennisetum typhoides* (1.39 mg/100g), also showed elevated oxalate levels. *Cyperus esculentus* (small variety) had a moderately high oxalate content of 1.25 mg/100g, while its large variety contained 0.72 mg/100g. In contrast, several crops had low oxalate concentrations, including *Triticum aestivum* (0.18 mg/100g), *Digitaria exilis* (0.26 mg/100g), and *Piper nigrum* (0.27 mg/100g), making them suitable for individuals requiring diets low in oxalates. The relatively low oxalate contents observed in these crops, combined with their nutritional value, suggest they could serve as safer alternatives in dietary planning, especially for populations at risk of oxalate accumulation (Huynh *et al.*, 2022).

Table 2: Saponin Content of the Selected Crops

Plant	Saponin (mg/100g)	Tannin (mg/100g)	Oxalate (mg/100g)
Sorghum durra (Red sorghum)	0.11 ± 0.042^{c}	0.79 ± 0.022^{a}	0.84 ± 0.016^{c}
Sorghum exertum (Yellow sorghum)	0.23 ± 0.013^{c}	0.43 ± 0.029^{b}	1.23 ± 0.014^{b}
Sorghum spontanea (Brown sorghum)	0.19 ± 0.031^{c}	0.64 ± 0.018^{b}	0.57 ± 0.026^{c}
Sorghum bicolor (White sorghum)	0.16 ± 0.016^{c}	0.31 ± 0.027^{b}	1.95 ± 0.063^{a}
Piper guineense (African black pepper)	0.20 ± 0.021^{c}	0.32 ± 0.042^{b}	0.67 ± 0.072^{c}
Aframomum daniellii (Alligator pepper)	0.27 ± 0.017^{c}	0.61 ± 0.051^{b}	0.23 ± 0.041^{d}
Piper nigrum (Black pepper)	0.22 ± 0.036^{c}	0.27 ± 0.063^{b}	0.27 ± 0.059^{d}
Monodora myristica (African nutmeg)	0.24 ± 0.062^{c}	0.12 ± 0.071^{c}	0.48 ± 0.072^{c}
Cyperus esculentus (Tigernut small seed variety)	0.09 ± 0.012^{d}	0.24 ± 0.036^{b}	1.25 ± 0.041^{b}
Cyperus esculentus (Tigernut large seed variety)	0.15 ± 0.019^{c}	0.45 ± 0.024^{b}	0.72 ± 0.037^{c}
Digitaria exilis (Hungry rice)	0.12 ± 0.051^{c}	0.16 ± 0.081^{c}	0.26 ± 0.062^{d}
Ziziphus abyssinica (Jujube)	1.24 ± 0.038^{b}	0.07 ± 0.073^{c}	0.52 ± 0.071^{c}
Triticum aestivum (Wheat)	0.18 ± 0.072^{c}	0.09 ± 0.011^{c}	0.18 ± 0.043^{d}
Hibiscus sabdariffa (Roselle, white)	0.26 ± 0.053^{c}	0.36 ± 0.057^{b}	0.61 ± 0.038^{c}
Helianthus annuus (Sunflower seed)	0.25 ± 0.041^{c}	0.28 ± 0.014^{b}	0.53 ± 0.061^{c}
Pennisetum typhoides (Millet)	0.08 ± 0.011^{d}	0.11 ± 0.053^{c}	1.39 ± 0.035^{b}
Eleusine coracana (Finger millet)	0.05 ± 0.012^{d}	0.25 ± 0.038^{b}	1.74 ± 0.018^{a}
Pennisetum glaucum (Pearl millet)	0.18 ± 0.046^{c}	0.31 ± 0.062^{b}	1.86 ± 0.057^{a}
Moringa oleifera (Moringa seed)	2.48 ± 0.015^{a}	1.12 ± 0.056^{a}	1.98 ± 0.064^{a}

Values are presented as means ± Standard Deviation; n=3; means within each column, that differ significantly at 95% confidence level were assigned different superscripts.

Total Short-chain Fatty Acids Produced from Fermentation of the Selected Crops using Lactobacillus sp

Among the crops analyzed, *Hibiscus sabdariffa* produced the highest amount of total short-chain fatty acids (TSCFAs) at 0.09 M (Figure 4), indicating it is highly fermentable by *Lactobacillus* species. This suggests a robust presence of fermentable substrates, possibly including a mixture of soluble fiber, pectin, and polyphenolic compounds that favor the growth and metabolic activity of probiotics. The high TSCFA production by *Hibiscus sabdariffa* enhances its value as a functional food with potential prebiotic properties that could support a healthy gut microbiota (Ashaolu *et al.*, 2021). Following closely behind are *Cyperus esculentus* (large variety) with 0.08 M, and both *Piper guineense* and *Piper nigrum*, each with 0.078 M and 0.07 M respectively. These values are also indicative of significant fermentability. *Cyperus esculentus*, commonly known as tiger nut, is known to be rich in resistant starch and certain oligosaccharides, which are ideal substrates for lactic acid bacteria. The high TSCFA production from its fermentation supports its traditional use as a health food and a natural prebiotic. Similarly, the substantial TSCFA levels produced from *Piper* species suggest that these spices contain not only antimicrobial and antioxidant phytochemicals but also components that support probiotic metabolism. This dual functionality enhances their relevance in functional food formulation, especially in the development of synbiotic products that combine probiotics and fermentable prebiotics (Vinelli *et al.*, 2022).

Aframomum daniellii and *Moringa oleifera* each produced TSCFAs at a concentration of 0.065 M, reflecting moderate fermentability. While not as high as *Hibiscus sabdariffa*, the values still indicate a supportive environment for probiotic growth and metabolic activity (Peng *et al.*, 2017). *Aframomum daniellii*, a spice with known antioxidant and antimicrobial properties, seems to offer suitable fermentable substrates, possibly in the form of dietary fiber and polyphenols. *Moringa oleifera*, often highlighted for its rich nutrient and phytochemical profile, also contributes to SCFA production, adding to its recognized value as a medicinal and nutraceutical plant. Despite its relatively high antinutrient levels, the ability of *Moringa* to support SCFA production strengthens its role in managing gastrointestinal health when used appropriately.

Cyperus esculentus (small variety) also yielded 0.07 M TSCFAs, mirroring the performance of the large variety, although slightly lower. This consistency between both varieties indicates that their fermentable fiber content is relatively uniform and efficient in supporting *Lactobacillus*-mediated fermentation. This result further supports the inclusion of tiger nut varieties in dietary interventions aimed at improving gut microbial balance.

Sorghum spontanea produced 0.062 M TSCFAs, a relatively good yield among the cereals assessed. This suggests that, despite the presence of moderate antinutrients like tannins and oxalates, the crop possesses fermentable polysaccharides that *Lactobacillus* species can utilize effectively. Its performance indicates potential as a base for probiotic-enriched food products or beverages, especially in rural and resource-limited communities where sorghum is traditionally consumed.

The lowest producers of TSCFAs were *Eleusine coracana* and *Sorghum durra*, yielding 0.055 M and 0.035 M respectively. While still capable of supporting some SCFA production, these values suggest limited fermentable fiber availability or the presence of inhibitory compounds that may have restricted *Lactobacillus* activity. *Sorghum durra*'s relatively low SCFA production may be related to its higher tannin content, which can interfere with microbial growth and metabolism. Similarly, *Eleusine coracana*, despite its popularity as a staple grain, may contain fibers that are less accessible to the microbial enzymes of *Lactobacillus*, or may require specific pretreatments such as malting or fermentation to improve digestibility and fermentability. A study indicated that elevated quantities of soluble dietary fiber may promote the development of fibrolytic bacteria, which subsequently decompose soluble fibers to generate organic acids and monosaccharides (Tao *et al.*, 2019). In another study, soluble fiber-rich wheat bran and oat bran were fermented by intestinal microorganisms to produce short chain fatty acids (Bai *et al.*, 2020).

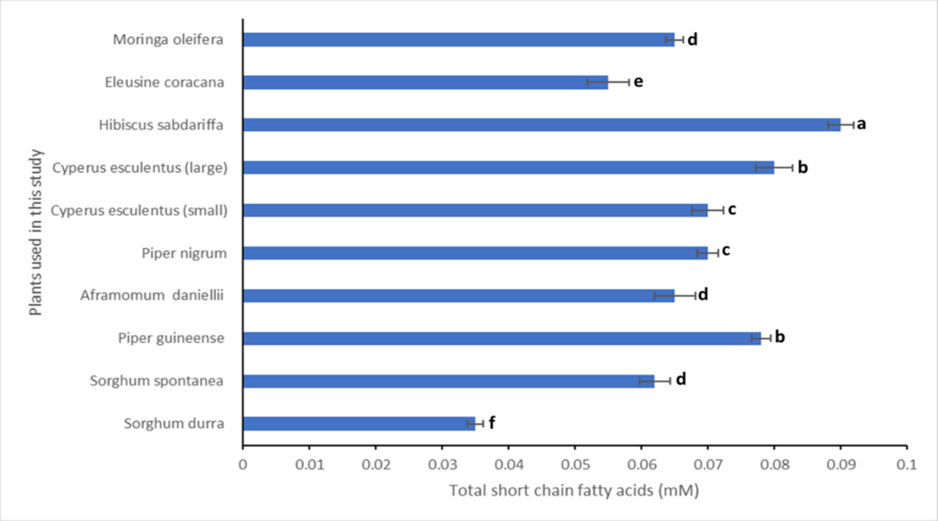

Figure 4: Total Short Chain Fatty Acids Produced from Fermentation of the Selected Crops using Lactobacillus sp. Values are Means of 3 Replications ± Standard Deviation; means that Differ Significantly at 95% Confidence Level were Assigned Different Alphabet

CONCLUSION

The overall conclusions of the study highlight the significant nutritional and functional potentials of selected underutilized Nigerian crops, particularly in relation to their dietary fiber, bioactive compound content, and fermentability by *Lactobacillus* species to produce health-promoting short-chain fatty acids (SCFAs). The study demonstrated that crops such as *Moringa oleifera*, *Cyperus esculentus*, *Hibiscus sabdariffa*, and *Piper* species are rich in non-fiber carbohydrates (by extension, soluble fiber), beta-glucan, and pectin important dietary components that contribute to glycemic control, improved lipid profiles, and enhanced gut health. These crops also supported high levels of SCFA production during fermentation, indicating their prebiotic potential and suitability for synbiotic applications.

Moreover, the antinutrient analysis revealed varying levels of saponins, tannins, and oxalates, with some crops like *Moringa oleifera* and *Ziziphus abyssinica* exhibiting relatively high levels. While these compounds can pose nutritional concerns, their presence does not negate the overall health benefits of the crops, especially when appropriate processing methods are employed to reduce antinutrient concentrations. The data also underscore the importance of balancing nutrient density and antinutrient content in selecting crops for functional food development.

Importantly, the ability of these crops to support the metabolic activity of probiotic *Lactobacillus* species, as evidenced by the production of total short-chain fatty acids, further emphasizes their value in promoting intestinal health and mitigating metabolic disorders such as type 2 diabetes mellitus. The findings collectively suggest that these underutilized crops could be integrated into dietary interventions and functional food products aimed at enhancing nutritional status, managing chronic diseases, and supporting the gut microbiome. Future studies should employ more specific methods for soluble fiber quantification, investigate in vivo effects, and develop optimal processing techniques to reduce antinutrients while preserving bioactive compounds.

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