



Research Article

Comparative Study on the Nutritional Composition and Bioavailability of Ndaleyi from Millet and Sorghum

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This study investigates the nutritional composition, anti-nutritional content, functional properties, and sensory characteristics of *Ndaleyi*, a traditional food product made from four varieties of millet and sorghum. The objective was to assess how different grain types impact the nutritional and functional properties of *Ndaleyi*, with the hypothesis that the variety of grain significantly influences these characteristics. Statistical one-way ANOVA analysis ($p < 0.05$) confirmed significant sample differences. Sample N1, which was made from *Jigare* red sorghum, exhibited higher moisture, fat, and nitrogen-free extract (NFE) levels. Sample N2, derived from another sorghum variety, contained the highest amounts of crude fat and NFE, making it an energy-rich option. Sample N3 was distinguished by its high crude fibre and protein content, making it an excellent choice for those seeking high-protein and high-fibre foods. Sample N4, noted for having the highest NFE, was identified as a key carbohydrate source. Regarding anti-nutritional factors, Sample N3 had the highest levels of oxalates, while Sample N4 contained the most phytates, which could affect mineral absorption. However, all anti-nutritional compounds remained within safe consumption limits. The functional properties also varied among samples; Sample N4 exhibited the highest bulk density and dispersibility, making it suitable for instant meals. Meanwhile, Sample N3 had high water solubility, which is ideal for soups and sauces. Sensory evaluations indicated that Sample N4, made from white sorghum, received the highest scores for flavour and texture, suggesting strong commercial potential. In conclusion, this study highlights the nutritional and sensory diversity of *Ndaleyi* and suggests that specific grain varieties can be optimized for better functional and commercial viability.

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INTRODUCTION

Millet and sorghum are staple grains in Nigeria, playing an essential role in food security and nutrition (Nkama *et al.*, 1994). One traditional food derived from these grains is *Ndaleyi*, a fermented, sun-dried, and agglomerated powder particularly popular among the Kanuri people of Borno State, Nigeria (Ruth *et al.*, 2022). Traditionally, *Ndaleyi* is prepared through an extended steeping process, after which it is reconstituted into a thick gruel known as "*beri ndaleyi*" and commonly consumed with soups or stews (Ikechukwu *et al.*, 2023). Despite its widespread consumption, limited scientific data is available on the nutritional profile, functional properties, and anti-nutritional factors of *Ndaleyi* (Nkama *et al.*, 1994). This information is essential for optimizing its nutritional value and exploring its potential for commercial applications (Ratnavathi CV, 2014). Prior research on other traditional Nigerian fermented foods, such as *ogi* and *tuwo*, has highlighted their nutritional and functional benefits; however, *Ndaleyi* remains understudied, even though its unique processing method may have significant health implications (Adegoke *et al.*, 1994). Moreover, the prolonged steeping process used in its preparation could influence its nutrient composition and bioavailability, warranting further investigation (Abah *et al.*, 2020; Adegoke *et al.*, 1994; Adegunwa & Alamu, 2011; ADEYEMI *et al.*, 1987; Putra *et al.*, 2022).

This study analyses the proximate composition, functional properties, and anti-nutritional factors of *Ndaleyi* made from various millet and sorghum varieties. Additionally, the study will evaluate its sugar composition, including glucose, fructose, maltose, and sucrose, to provide a comprehensive understanding of its nutritional potential. The findings will contribute to the scientific literature on traditional fermented foods and support efforts to enhance the nutritional value of *Ndaleyi*, promoting greater consumer acceptance.

MATERIALS AND METHODS

Collection of Samples:

The raw materials used in this study, millet and sorghum, were obtained from the Lake Chad Research Institute in Maiduguri (Duodu *et al.*, 2003).

Apparatus and Reagents:

The following apparatus and reagents were utilized in this study: bucket, mat, weighing balance, sieve, milling machine, spectrophotometer, volumetric flask, desiccator, graduated cylinder, test tubes, water bath, viscometer, filter paper, hydrochloric acid (HCl), sulfuric acid (H₂SO₄), sodium hydroxide (NaOH), and centrifuge tubes (AKINGBALA *et al.*, 1981; Jimoh & Abdullahi, 2017; Sulaiman *et al.*, 2020).

Production of *Ndaleyi*:

Ndaleyi was produced using millet and sorghum, following the procedure described in reference ("Official Methods of Analysis of AOAC INTERNATIONAL," 2023). For millet, the process included steeping 2 kg of millet in 2.5 litres of distilled water for 7 days at room temperature (Nina *et al.*, 2012). This was followed by washing, grinding, and mixing with water in a 1:10 weight/volume ratio (Hall & Mertens, 2023). The mixture proceeded through wet sieving, stirring, sedimentation for 1–2 days, and decantation to remove excess water. The mixture was separated into two layers: "*chir*" (the lighter layer) and "*ndaleyi*" (the denser layer), which was subsequently sun-dried (EUCAST European Committee, 2019). The same steps were followed for sorghum, with an extended steeping duration of 14 days (Sulaiman *et al.*, 2020).

Proximate Composition Analysis The proximate composition of the *Ndaleyi* samples was determined using standard methods from the Association of Official Analytical Chemists (AOAC). The following analyses were performed:

Crude Protein Determination

Crude protein content was determined using the Kjeldahl method with a Kjeltac™ 2300 analyzer (Wójcik *et al.*, 2021). Samples were digested at 420 °C for 1 hour to convert organically bound nitrogen to ammonium sulfate (Jimoh & Abdullahi, 2017). The liberated ammonia was distilled into a boric acid receiving solution and titrated with standardized hydrochloric acid. A conversion factor of 6.25 was used to convert total nitrogen to a percentage of crude protein (Zaku *et al.*, 2009).

Crude Fat Determination:

Crude fat content was determined using the AOAC (2005) method with a Soxtec System HT2 fat extractor (Abah *et al.*, 2020). Fat was extracted using hexane, and the solvent was later evaporated. The difference between the initial and final weights of the extraction cup represented the crude fat content (Hall & Mertens, 2023).

Crude Fiber Determination:

Crude fibre content was determined using defatted samples obtained from the fat analysis.

Each sample (5 g) was boiled under reflux for 30 minutes in 200 mL of 1.2% H₂SO₄ solution (Nina *et al.*, 2012), followed by washing and boiling in 200 mL of 1.2% NaOH solution for another 30 minutes (Abah *et al.*, 2020). The washed residue was dried in an oven at 105 °C for 3 hours, weighed, ashed in a muffle furnace at 550 °C for 2 hours, and reweighed (Hollmann *et al.*, 2013). Crude fibre content was calculated using the appropriate formula Eqn1.

Crude fiber (%) = [(Weight of dried residue - Weight of ash) / Weight of defatted sample]

$$\text{Crude fiber (\%)} = \frac{(\text{Weight of dried residue} - \text{Weight of ash})}{\text{Weight of defatted sample}} \times 100 \text{ or}$$

$$\% \text{ moisture content} = \frac{(W_2 - W_3)}{W_1} \times \frac{100}{1} \dots \dots \text{Eqn 1}$$

Where W₂= weight of crucible + sample after washing and drying in the oven.

W₃= weight of crucible + sampl as ash and W₁= weight of original sample.

Additional Proximate Composition Analysis**Moisture Content Determination:**

Moisture content was determined by drying to a constant weight(Thiex *et al.*, 2012). Five grams of each sample were dried at 110 °C for 3 hours,

cooled in a desiccator, and weighed at 30-minute intervals until a constant weight was achieved (Hall & Mertens, 2023). Moisture content was calculated using the appropriate formula Eqn. 2

$$\text{moisture (\%)} = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight}} \times 100 \dots \dots \dots \text{Eqn 2}$$

Ash Content Determination:

Ash content was determined by dry ashing. Five grams of each sample were ashed in a muffle furnace at 600 °C for 3 hours, cooled

in a desiccator, and weighed. Ash content was calculated using the appropriate formula Eqn. 3(EUCAST, 2024).

$$\text{Ash (\%)} = \frac{\text{weight of ash}}{\text{weight of sample}} \times 100 \dots \dots \dots \text{Eqn 3}$$

Carbohydrate Content Determination:

Carbohydrate content was estimated by difference using the formula in Equation 4.

Functional Properties of Ndaley**Bulk Density (BD) Determination:**

Bulk density was determined using a modified method. Ten grams of each sample were placed

in a 25 mL graduated cylinder and tapped ten times. The final volume was recorded, and bulk

density was calculated using the appropriate formula in Eqn. 5

$$\text{Bulk density } \left(\frac{g}{ml} \right) = \frac{\text{weight of sample (g)}}{\text{Volume of sample (ml)}} \quad \text{Eqn 5}$$

Water Absorption Capacity (WAC)

Determination Water absorption capacity was determined in triplicate (Zhang *et al.*, 2024). One gram of each sample was mixed with 10 mL of

distilled water, incubated at 30 °C for 30 minutes, centrifuged, and weighed. WAC was calculated using the appropriate formula Eqn. 6.

$$\text{WAC \%} = \frac{\text{weight of residue} - \text{initial weight of tube}}{\text{weight of sample}} \times 100 \quad \text{Eqn 6}$$

Dispersibility Determination

Dispersibility was determined using a modified method (EUCAST, 2017). Ten grams of each sample were mixed with 100 mL of distilled

water, stirred, and left to stand for 3 hours. The volume of settled particles was recorded, and dispersibility was calculated using the appropriate formula Eqn. 7.

$$\text{Dispersibility \%} = \frac{100\text{ml} - \text{Volume of settled particles (ml)}}{100 \text{ (ml)}} \times 100 \quad \dots \text{Eqn 7}$$

Anti-Nutritional Properties.

Tannin Determination

Tannin content was determined using the AOAC method ("AOAC INTERNATIONAL Methods Committee Guidelines for Validation of Microbiological Methods for Food and Environmental Surfaces," 2023; Hall & Mertens,

2023). Five grams of each sample were mixed with 50 mL of distilled water, shaken, and filtered. Two milliliters of the extract were reacted with sodium carbonate and Folin-Ciocalteu reagent, and absorbance was measured at 760 nm. Tannin content was calculated using the appropriate formula Eqn. 8.

$$\text{Tannin } \left(\frac{mg}{100g} \right) = \frac{\text{Sample absorbance} \times \text{Standard concentration} \times 100}{\text{Standard absorbance} \times \text{weight of sample (g)}} \quad \dots \text{Eqn 8}$$

Phytate Determination

Phytate content was determined using AOAC methods (Agbo *et al.*, 2017; Cornu & Delpuch, 1981). Samples were extracted with 0.5 M

HNO₃ and digested with 0.5 mL of perchloric acid (HClO₄). The digested sample was analyzed spectrophotometrically using Eqn. 9.

$$\text{phytate } \left(\frac{mg}{100g} \right) = \frac{\text{sample of absorbance} \times \text{standard concentration} \times 100}{\text{standard absorbance} \times \text{weight of the sample}} \quad \dots \text{Eqn .9}$$

RESULTS

Proximate Composition of *Ndaleyi*

The proximate composition of *Ndaleyi*, derived from four different millet and sorghum varieties, is summarized in Table 1 and Figure 1-5.

Statistical one-way ANOVA analysis revealed significant sample variations ($p < 0.05$). Sample N1 exhibited the highest moisture, fat, and nitrogen-free extract (NFE) levels. Sample N2 had the highest crude fat content and elevated

NFE levels, indicating its potential as a rich energy source. Sample N3 was notable for its increased crude fibre, protein, and NFE levels, suggesting it may serve as a high-protein, high-fibre dietary option. In contrast, Sample N4 recorded the highest NFE content, demonstrating its suitability as a primary

carbohydrate source. These findings highlight the impact of varietal diversity in millet and sorghum on the nutritional profile of *Ndaleyi*, underscoring that the choice of raw materials significantly affects the final product's composition.

Table 1: Chemical Composition of *Ndaleyi* from Millet and Sorghum Varieties

SAMPLE	MOISTURE CONTENT	ASH CONTENT	CRUDE FIBER	CRUDE FAT	CRUDE PROTEIN	NFE
N1	10.26±0.18 ^a	1.45±1.73	3.35±0.06	10.57±0.25 ^a	8.07±0.20	66.30±0.80 ^d
N2	8.73±0.20	1.52±1.73	2.88±0.06	11.38±0.27 ^{ab}	8.47±0.20	67.03±0.72 ^c
N3	9.45±0.10	1.60±1.73	3.57±0.07 ^a	8.42±0.20	8.91±0.20 ^a	68.05±0.60 ^b
N4	9.78±0.10	1.15±1.73	2.99±0.03	8.99±0.21	7.91±0.21	69.23±0.42 ^a

The above values are expressed as mean ± standard error of mean. The values with superscript shows the significant difference between the groups (p<0.05)(Values are expressed as mean ± standard error; superscripts indicate significant differences, N1: *Ndaleyi* from *jigare red sorghum* N2: *Ndaleyi* from *super sosat millet* N3: *Ndaleyi* from *PEO 5984 millet* N4: *Ndaleyi* from *chakalare white sorghum*

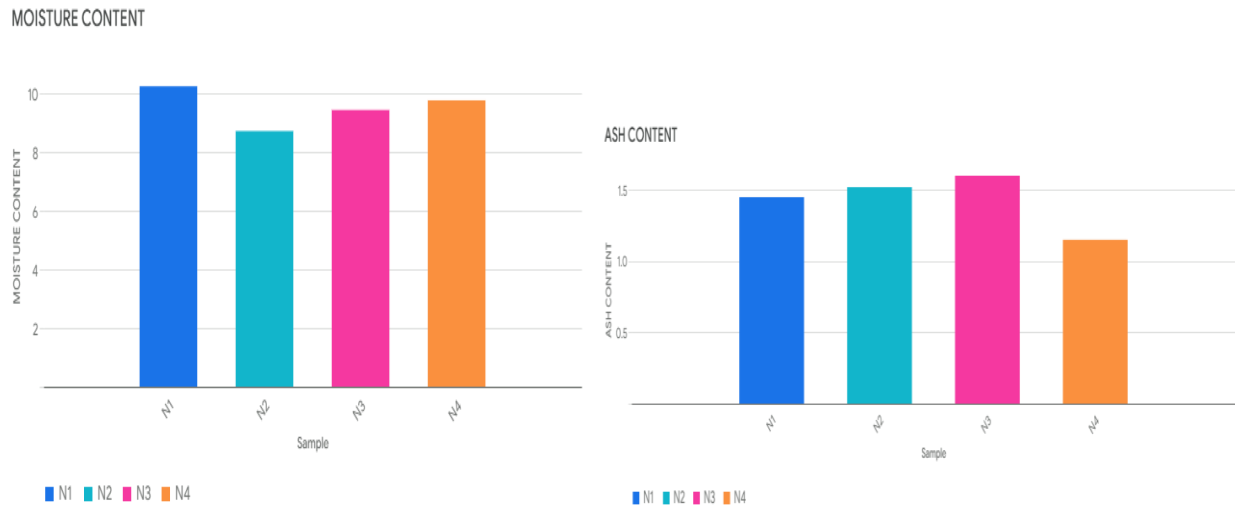


Figure 1 and 2: Chart of Moisture and Ash content

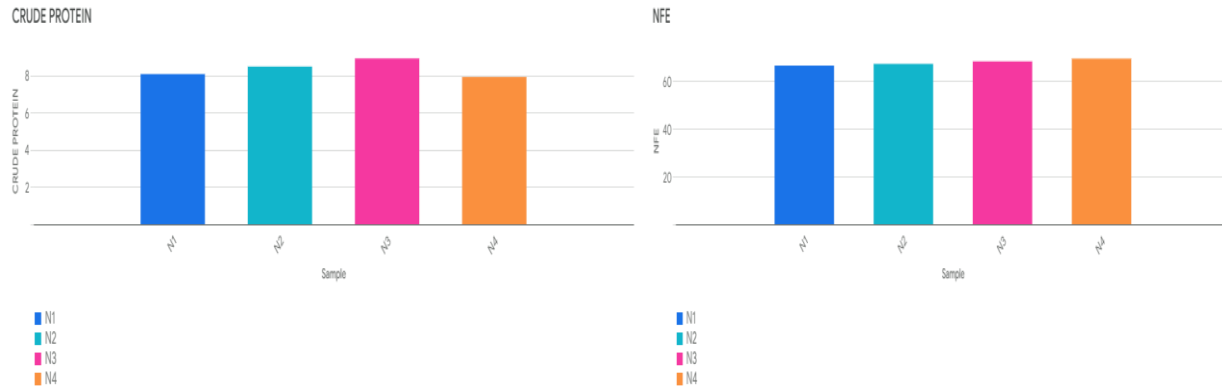


Figure 3 and 4: Chart of Crude protein and NFE

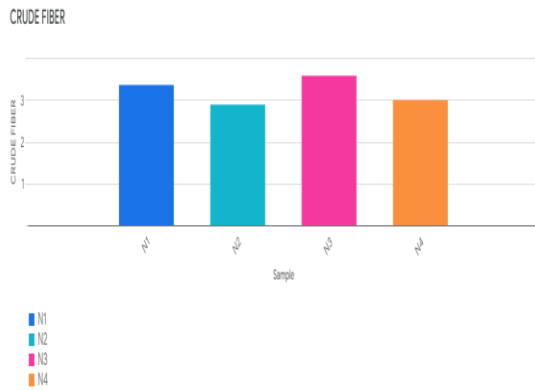


Figure 5: chart of crude fiber content

Anti-Nutritional Content

The anti-nutritional content of *Ndaleyi* is detailed in Table 2 and Figure 6-8, revealing important differences ($p < 0.05$) among the samples. Statistical analysis, including ANOVA followed by Tukey’s post-hoc test, confirmed these disparities. Sample N3 had the highest oxalate content, which may influence calcium bioavailability. Meanwhile, Sample N4 contained the highest phytate levels, a

compound known to impair mineral absorption. All samples contained measurable amounts of tannins and oxalates; however, their levels were within acceptable limits for human consumption. Previous studies have documented these acceptable limits. Further processing techniques, such as fermentation, soaking, or boiling, could help reduce these compounds while preserving the product’s nutritional value.

Table 2: Anti-nutritional content of *Ndaleyi*

SAMPLE	PHYTATE	TANNIN	OXALATE
N1	2.79±0.07	2.16±0.03	0.09±0.004
N2	1.92±0.05	1.71±0.01	0.00±0.00
N3	2.79±0.06	2.26±0.03	0.13±0.006 ^a
N4	3.44±0.08^a	2.31±0.02	0.07±0.002

The above values are expressed as mean \pm standard error of mean. The values with superscript shows the significant difference between the groups ($p < 0.05$), N1: Ndaleyi from jigare red sorghum, N2: Ndaleyi from super sosat millet, N3: Ndaleyi from PEO 5984 millet, N4: Ndaleyi from chakalare white sorghum
NFE: Nitrogen Free Extract

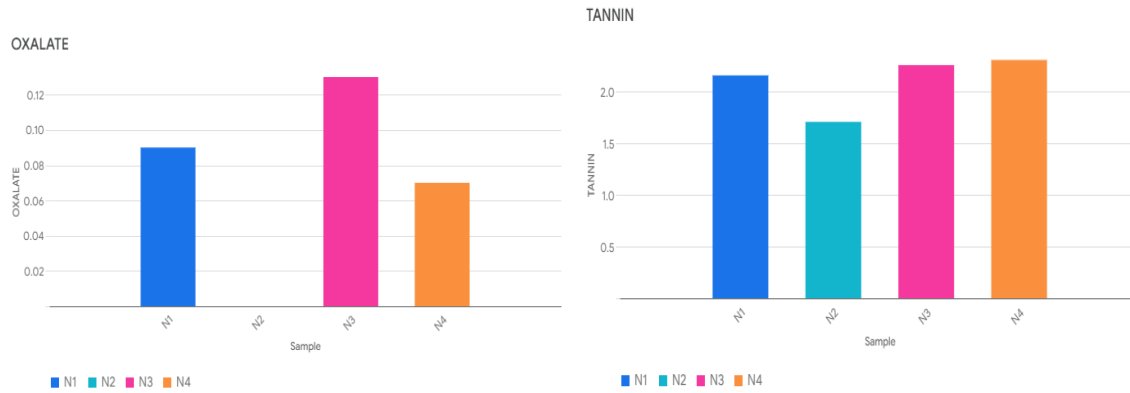


Figure 6 and 7: Oxalate and Tannin chart

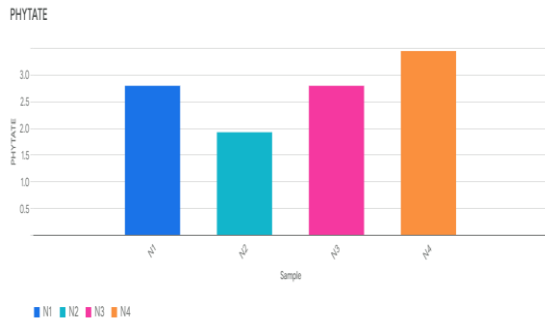


Figure 8: Phytate

Functional Properties

The functional properties of *Ndaleyi*—such as bulk density, dispersibility, water absorption capacity, water solubility, and swelling power—are summarized in Table 3 and Figures 9-13. As confirmed by ANOVA, significant differences ($p < 0.05$) were observed among the samples. Sample N4 exhibited the highest bulk density and dispersibility, making it suitable for food products that require good reconstitution properties, such as instant meals or beverages. Sample N3 showed the highest water solubility,

which would benefit food applications like soups and sauces that require enhanced solubility. These functional properties are crucial in determining the suitability of *Ndaleyi* for various food formulations. Bulk density affects packaging and storage efficiency, water solubility influences product dispersion in liquid-based food systems, and swelling power contributes to texture and mouthfeel, which are essential for product development and consumer acceptance.

Table 3: functional properties of *Ndaleyi*

SAMPLE	BULK DENSITY	DISPERSIBILITY	WATER ABSORPTION	WATER SOLUBILITY	SWELLING POWDER
N1	0.62±0.001	68.0±0.57	277.7±1.48	5.83±0.009	2.60±0.008
N2	0.67±0.003	67.43±0.23	202.3±0.30	4.46±1.33	3.20±0.009
N3	0.64±0.002	68.33±0.33	205.3±1.31	16.18±0.01	2.90±0.012
N4	0.72±0.002	81.00±0.58	186.7±0.08	4.42±0.009	4.32±0.009

| Sample | Bulk Density (g/cm³) | Dispersibility (%) | Water Absorption (g/g) | Water Solubility (%) | Swelling Power (%)

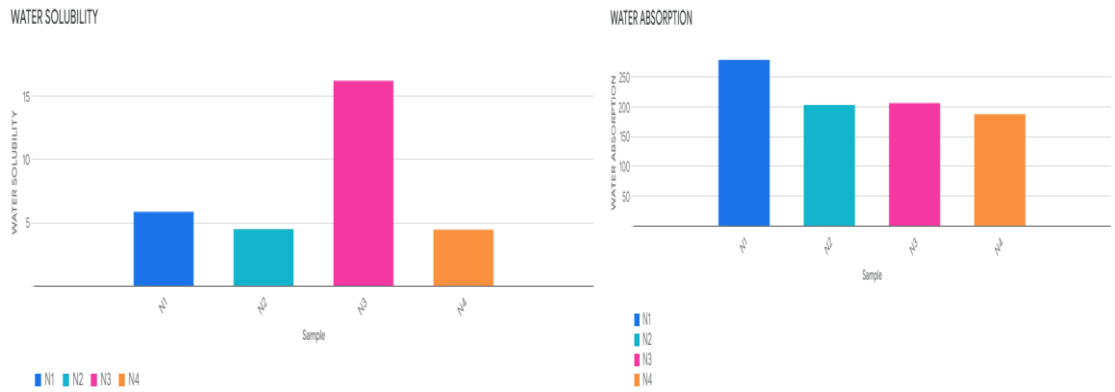


Figure 9 and 10: water solubility and water adsorption

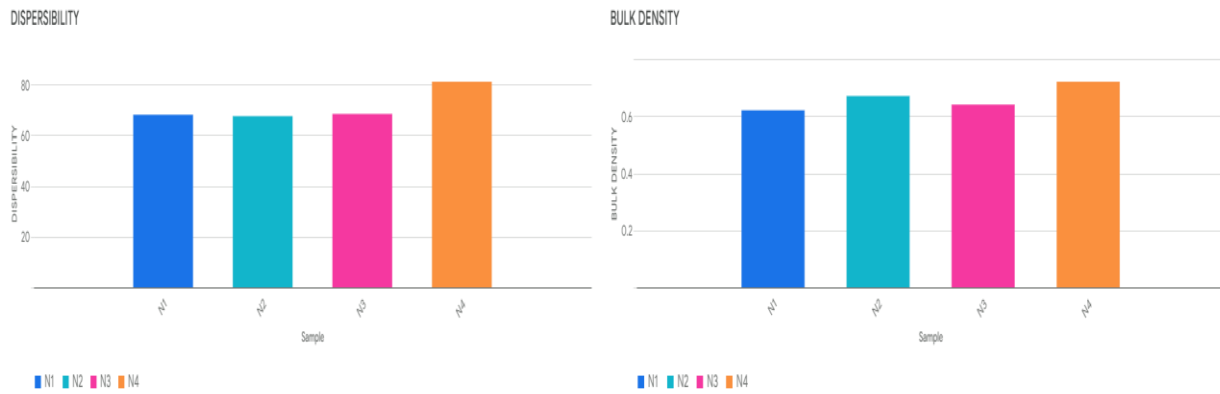


Figure 11 and 12: Dispersibility and Bulk Density

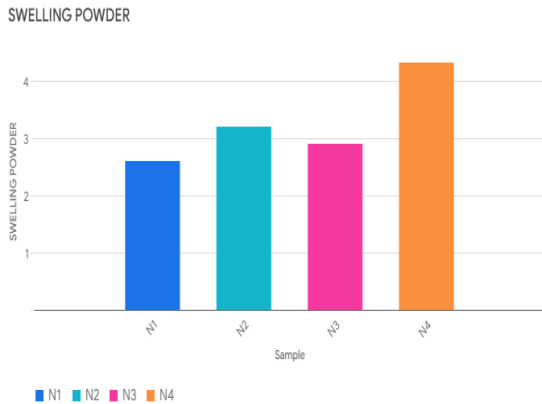


Figure 13: Swelling powder

Sensory Characteristics

The sensory evaluation results, shown in Table 4 and Figure 14-16, indicated significant differences ($p < 0.05$) in flavor, texture, color, and overall acceptability among the samples, as analyzed using ANOVA and Tukey’s post-hoc test. Sample N4, produced from white sorghum, received the highest scores for flavor, texture, and overall acceptability, indicating that it was the most preferred product. In contrast, Sample

N1, made from *Jigare* red sorghum, was distinguished by its appealing color profile. It is important to acknowledge the subjective nature of sensory evaluation, which can be influenced by individual preferences and potential biases in the assessment process. Future studies could utilize blind sensory tests or larger consumer panels to minimize bias and enhance the reliability of the results.

Table 4: Sensory characteristic of *Ndaleyi*

SAMPLE	TASTE	FLAVOUR	COLOR	TEXTURE	O.A
N1	8.50±0.41	7.85±0.23	6.70±0.18 ^a	8.15±0.23	8.10±0.29
N2	8.45±0.21	8.10±0.16	8.50±0.20	8.25±0.16	8.80±0.28
N3	8.90±0.17	8.40±0.22	8.23±0.19	8.25±0.24	8.40±0.22
N4	8.95±0.05	8.60±0.17 ^a	8.85±0.08	8.80±0.12 ^a	8.95±0.42 ^a

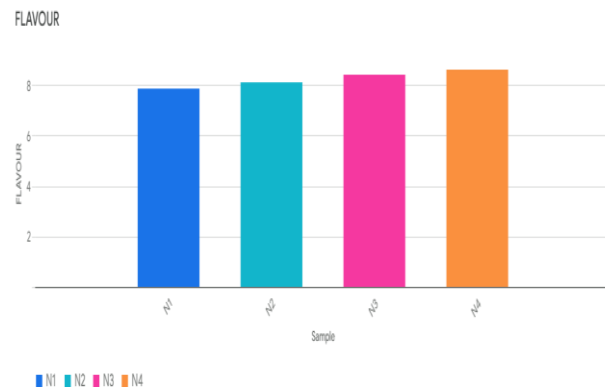
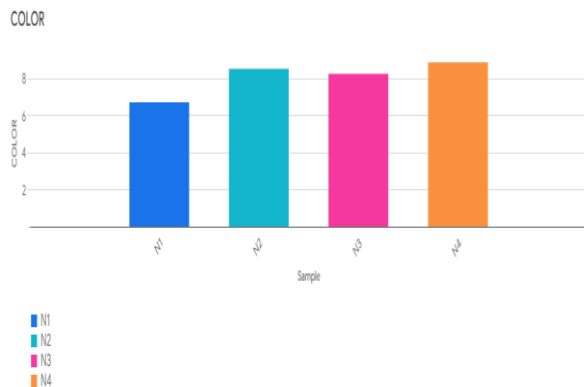


Figure 14 and 15: Color and flavor

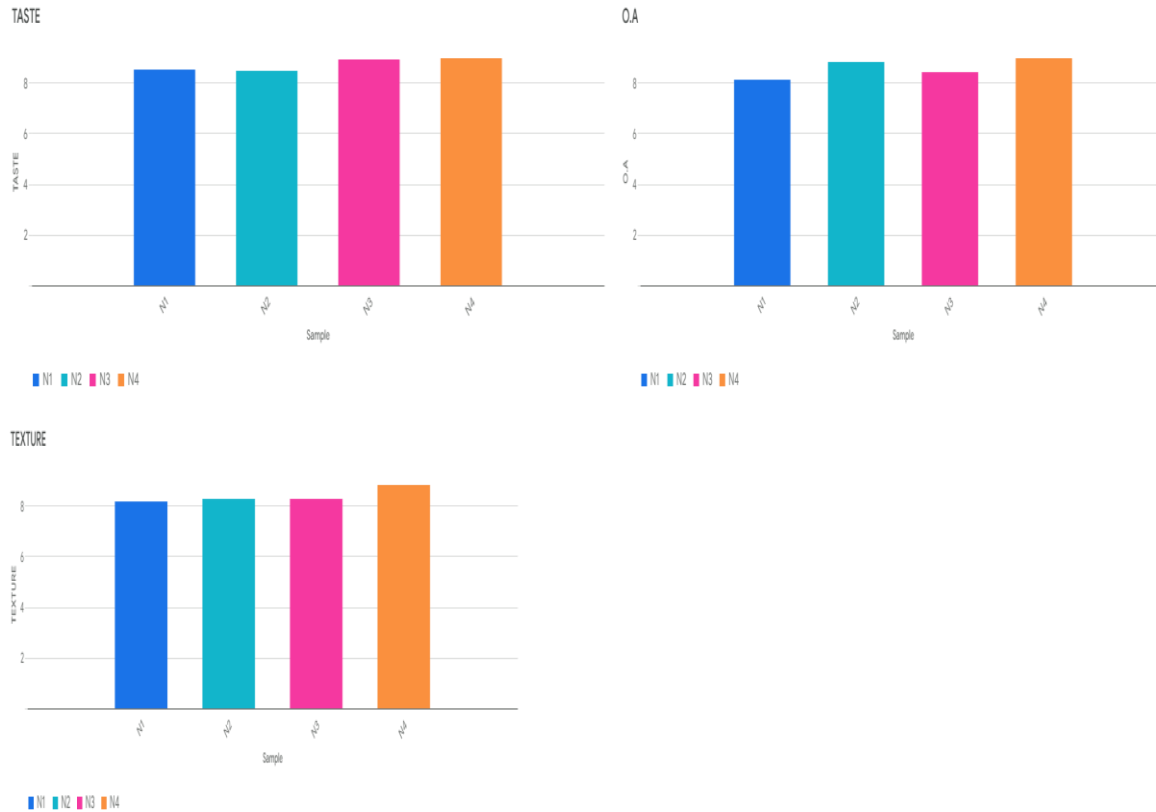


Figure 16, 17 and 18: Taste, O.A and Texture chart

CONCLUSION

The results of this study reveal the nutritional, functional, and sensory diversity of *Ndaleyi* produced from various millet and sorghum varieties. Statistical analysis confirmed significant differences among the samples. The study highlight the potential for optimizing *Ndaleyi's* nutritional profile, with samples N3 and N4 offering distinct macronutrient benefits. The presence of anti-nutritional factors indicates a need for further exploration of processing techniques to improve the product's nutritional quality. Additionally, the functional properties suggest that *Ndaleyi* can be tailored for diverse food applications, while sensory evaluation indicates that the white sorghum-based *Ndaleyi* has strong commercial potential. These findings provide valuable insights into the field of traditional foods and offer pathways for developing *Ndaleyi* into a more nutritionally optimized and commercially viable product.

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