Impact of Fermentation Periods on the Nutritional Composition and Antioxidant Activities of Ogi (Gruel) From Two Sorghum (Sorghum bicolor (L.) Moench) Varieties

Adebowale O.M.[1], Chinma C.E.[1,2,3] Adebo O.A.[3] & Makun H.A.[1]

1. Africa Centre of Excellence for Mycotoxin and Food Safety, Federal University of Technology, Minna, Nigeria
2. Department of Food Science and Technology, Federal University of Technology, Minna, Nigeria
3. Centre for Innovative Food Research (CIFR), Department of Biotechnology and Food Technology, Faculty of Science, University of Johannesburg, Doornfontein, Johannesburg, Gauteng, South Africa.

Corresponding Author: ademolatoyin123@gmail.com

ABSTRACT

Background: *The nutrient composition of sorghum makes it a healthy meal for human consumption. However, the presence of antinutritional factors hinders the bioavailability of protein and minerals in humans. Therefore, a processing method that will retain vital nutrients in food products is required to provide better health benefits to consumers.*

Objective: *The impact of fermentation on the nutritional composition and antioxidant properties of ogi (gruel) from two sorghum varieties was assessed*

Method: Two sorghum varieties (red and white) were purchased in Kure Market, Minna, Niger State. The grains were sorted, cleaned, washed, and fermented for (24, 48, 72, and 96 h) duration. Market samples (red and white sorghum ogi) were used as controls. The samples were evaluated for chemical properties and antioxidative activities.

Results: *Proximate composition varied significantly ($p<0.05$) based on sorghum type and fermentation duration. Moisture content, ash content, fat content, fibre content, protein content, and carbohydrate of red and white sorghum ranged between (9.75 and 48.00%), (1.15 and 2.67%), (1.33 and 2.83%), (0.03 and 1.85%), (5.85 and 10.50%), and (36.90 and 78.41%), respectively. Antioxidant values obtained ranged as follows: DPPH (51.72 and 74.10mg/mL) and FRAP (73.08 and 81.18 mgTE/100g), respectively. For mineral content, zinc, calcium, and iron were significantly ($p<0.05$) higher in white sorghum compared to red sorghum. Antinutrients such as oxalate, phytate, saponin, and tannin ranged between (0.32 and 2.5mg/g), (0.12 and 1.19mg/g), (2.63 and 8.90mg/g), and (0.00 and 2.47mg/g).*

Conclusion: *Fermentation significantly reduced the levels of antinutrients in ogi, leading to improved mineral bioavailability, enhanced protein digestibility, and increased nutritional value.*

Keywords: Sorghum, gruel, fermentation, nutritional composition, antioxidant properties

Doi: https://dx.doi.org/10.4314/njns.v46i2.11

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) re-emergence in the world market and increased use as a raw material for human and animal consumption is quite encouraging. Due to its nature as a drought-tolerant crop and its ability to make good use of water, sorghum is an ideal crop that contributes to food security in regions that are drought-stricken (1).

Sorghum is a good source of calories, proteins, carbohydrates, minerals, and vitamins. It plays a vital function in the human diet and contributes to nutrient intake for millions of consumers. It also contains essential and non-essential amino acids, minerals, and vitamins, all of which constitute part of the essential nutrients required by humans to perform the functions necessary to sustain life (2). Sorghum contains dietary polyphenols with high antioxidant capacity; they have free radical scavenging activity, associated with anti-diabetic, anti-inflammatory, anti-viral, immune-modulatory, and anti-cancer capacities. These health benefits of sorghum grains could thus make it an important source of ingredients for use in functional foods and other applications.

Despite the nutrient composition of sorghum, which makes it a healthy meal for human consumption, the presence of antinutritional factors such as tannin, phytic acid, saponin, and oxalate hinders nutrient bioavailability and mineral absorption and causes low protein digestibility in its consumption by humans (3). Sorghum can be consumed in different forms, such as bread, pudding, drinks, biscuits, etc. Sorghum can also be used to produce ogi – a Nigerian traditional fermented cereal gruel which serves as an important food for infants, young, and adults.

Fermentation is basically achieved through the use of Lactic Acid Bacteria (LAB), a dominant microorganism that helps to impact the safety and nutritional value of food (4). It is an efficient food processing method that inhibits the activity of antinutritients, increases nutrient bioavailability, improves digestibility as well, and promotes the shelf life of food products (5). In order to have safe, nutritious, and nutrient bioavailability products from locally sourced raw material, there is a need to explore effective methods to achieve this. Thus, the processing of sorghum to gruel that would give a desirable product and ensure its safety can be achieved through fermentation by lactic acid bacteria (LAB) (4). The study evaluated the impact of fermentation on the antioxidant activities and nutritional composition of ogi (gruel) from two sorghum varieties.

MATERIALS AND METHODS

Procurement of raw materials

Two varieties of sorghum (Sorghum bicolor (L.) Moench) grains, i.e., red and white, were identified by a crop specialist and were purchased in Kure Market, Minna, Niger State.

Chemicals and reagents

All chemicals and reagents used in the study were of analytical grade.

Production of sorghum gruel

The production of gruel from the grains was performed by adopting the method described by (5) with slight modifications. The grains were sorted, cleaned, and batched (750 g per batch) into various groups based on fermentation duration (24, 48, 72, and 96 h). The grains were steeped in clean water (approximately 2,000 mL) in a large plastic bowl with lids at room temperature (33 °C) for fermentation to occur. At the end of fermentation periods, the steep water was drained, fermented grains were re-washed in distilled water, wet milled, and sieved to obtain the pomace (crushed bran) and starchy slurry. The slurry was left to sour for 24 h; thereafter, it was dewatered to obtain the decanted excess water and a solid-like paste called ogi (gruel). Market samples (red and white sorghum) were used as controls.

Proximate analysis

The standard method of (6) was used to determine the proximate composition of the samples. The hot air oven method was used to determine the moisture content; Protein was determined using the Kjeldahl method of protein analysis. Fat was determined by the Soxhlet method of fat extraction, while ash was obtained by weighing 5g of the sample into a tarred porcelain crucible. The crucible and its content were then transferred into a muffle furnace set at 550 °C for 6 hours until the ash content was obtained. The crude fibre was determined using the weighed samples resulting from fat extraction, while total carbohydrate content was obtained by difference.

Determination of mineral composition

Mineral's determination was carried out in a dilute solution of the ashed samples according to the method outlined in (6). Zinc (Zn), magnesium (Mg), phosphorus (P), calcium (Ca), and iron (Fe) were determined by using an Atomic Absorption Spectrophotometer (AAS 220GF, Buck). The standard curve for each mineral was prepared from known concentrations of mineral, and the mineral content of the samples was estimated from the standard curve, while sodium (Na) and potassium (K) content was determined using a Jenway flame photometer PFP7 (Cole-Palmer, UK).

Determination of anti-nutritional factors

The total tannin content was determined using the method described by (7). The sample absorbance was measured at 725 nm, and the concentration of tannin was extrapolated from a prepared standard graph of tannic acid (R^2= 0.9714). Phytic acid was determined calorimetrically by absorbance at 500 nm on a spectrophotometer according to the method of (8) modified by (9). Oxalate content was assayed according to the method of (10) by titrating the sample filtrate after addition of H_2SO_4 against hot 0.1 mol/L KMnO4 solution until a faint pink colour appeared, and the oxalate content was subsequently calculated. The spectrophotometric method described by (11) was used to determine saponin content.

Determination of antioxidant activity

α, diphenyl-β-picrylhydrazyl (DPPH) antioxidant and Ferric reducing antioxidant power assay (FRAP) of the gruel were carried out according to the methods reported by (12), (13), and (14), respectively. Absorbance of the samples was measured at 517 nm using a UV-VIS spectrophotometer (Model SP9, PyeUnican UK) to record the changes, and free radical scavenging ability was expressed as 50% maximal radical inhibition concentration (DPPH IC50), while FRAP antioxidant activity was quantified by trolox standard curve and expressed as mg/100g Trolox equivalents (TE).

Statistical analysis

The results were expressed as mean ± standard deviation, and the test for statistical significance was carried out using a one-way analysis of variance (ANOVA). The Statistical Package for Social Sciences (SPSS, Version 20) software determined significant differences. Significant means were separated using Duncan's New Multiple Range Test (DNMRT), and differences were considered significant at $p<0.05$.

RESULTS

Proximate composition of raw and fermented sorghum samples

Proximate composition varied significantly ($p<0.05$) based on the type of sorghum and fermentation duration (Table 1). Moisture content remained stable across fermentation durations, with minor variations between fermented red sorghum (RS) and fermented white sorghum (WS). RS24 recorded 48.00 ± 0.87%, while WS24 had slightly higher moisture at 48.33 ± 0.29%. Fat content showed a slight increase during fermentation, i.e., RS was increased from RS24 (1.33 ± 0.28%) to RS96 (2.17 ± 0.28%). Similarly, WS saw a rise, peaking at WS72 (2.83 ± 0.27%). Ash concentration, an indicator of mineral content, remained low across samples, with minimal differences between RS and WS, i.e., with values ranging from 2.00 ± 0.00% and 2.17 ± 0.29% for RS24 and WS24, respectively. Protein content increased significantly in both varieties, with RS96 (10.30 ± 0.27%) having the lowest values, while WS24 (10.50 ± 0.31%) had the highest value.

Antioxidant activity of fermented sorghum gruel

The Ferric Reducing Assay Power (Table 2) for red and white sorghum (ogi) ranged from (73.08 to 81.18 mg TE/100g) and (77.00 to 81.18 mg TE/100g), respectively. The values decreased steadily with fermentation time, from RS24 (81.18 ± 0.31) to RS96 (73.08 ± 0.14) at 500 mg/mL. WS exhibited higher FRAP activity than RS, with values for WS96 (81.18 ± 0.31) comparable to WS24.

Table 1: Proximate composition (%) of raw and fermented sorghum samples

Samples	Moisture	Ash	Fat	Fibre	Protein	Carbohydrate
RS	47.00 ± 0.00^{ab}	2.50 ± 0.00^{a}	1.17 ± 0.29^{a}	0.10 ± 0.00^{a}	8.05 ± 0.00^{bc}	40.25 ± 0.39^{b}
RS24	48.00 ± 0.87^{ab}	2.00 ± 0.00^{a}	1.33 ± 0.28^{ab}	0.08 ± 0.02^{a}	7.23 ± 0.10^{a}	40.87 ± 1.00^{b}
RS48	46.83 ± 0.29^{ab}	2.00 ± 0.58^{a}	1.83 ± 0.28^{abcd}	0.05 ± 0.05^{a}	8.23 ± 0.00^{c}	39.07 ± 0.37^{ab}
RS72	46.77 ± 1.44^{ab}	2.50 ± 0.50^{a}	2.17 ± 0.28^{cde}	0.10 ± 0.00^{a}	8.05 ± 0.00^{bc}	39.66 ± 1.78^{ab}
RS96	46.00 ± 0.00^{ab}	2.00 ± 0.87^{a}	2.17 ± 0.28^{cde}	0.08 ± 0.03^{a}	10.3 ± 0.27^{de}	38.88 ± 1.04^{ab}
WS	48.33 ± 0.29^{b}	2.17 ± 0.29^{a}	1.83 ± 0.29^{abcd}	0.05 ± 0.05^{a}	10.50 ± 0.31^{e}	36.90 ± 0.29^{a}
WS24	46.00 ± 0.00^{ab}	2.50 ± 0.50^{a}	1.50 ± 0.00^{abc}	0.10 ± 0.00^{a}	9.92 ± 0.20^{d}	39.32 ± 0.28^{ab}
WS48	45.67 ± 0.29^{a}	2.67 ± 0.29^{a}	2.33 ± 0.29^{de}	0.08 ± 0.03^{a}	7.88 ± 0.00^{bc}	40.78 ± 0.19^{b}
WS72	47.17 ± 2.00^{ab}	2.33 ± 0.29^{a}	2.83 ± 0.27^{e}	0.03 ± 0.03^{a}	7.50 ± 0.10^{ab}	39.51 ± 1.51^{ab}
WS96	46.30 ± 0.82^{ab}	2.67 ± 0.29^{a}	2.00 ± 0.00^{bcd}	0.05 ± 0.00^{a}	7.58 ± 0.20^{ab}	40.71 ± 1.14^{b}

Values represent the mean ± standard deviation (SD) based on three separate determinations. Means with different superscripts within the same column indicate significant differences ($p < 0.05$). RS: Red sorghum control, RS24: Red sorghum 24h steeping time, RS48: Red sorghum 48h steeping time, RS72: Red sorghum 72h steeping time, RS96: Red sorghum 96h steeping time, WS: White sorghum control, WS24: White sorghum 24h steeping time, WS48: White sorghum 48h steeping time, WS72: White sorghum 72h steeping time, WS96: White sorghum 96h steeping time.

The DPPH radical scavenging ability (Table 3) for red and white sorghum (ogi) ranged from (51.72 to 65.44 mg/mL) and (60.10 to 74.10 mg/mL), respectively. DPPH showed a peak activity at RS48 (65.44 ± 0.29) for RS but subsequently declined by RS96 (61.19± 0.23). WS had the highest scavenging ability throughout the fermentation period, with WS48 (74.10 ± 0.23) being the highest.

Table 2: Ferric Reducing Assay Power (FRAP) mg TE/100g of fermented sorghum gruel at different concentrations

	Concentration (mg TE/100g)			
Samples	500	250	125	62.5
RS	77.96±0.12^{c}	40.01±0.07^{bc}	20.96±0.21^{b}	10.79±0.40^{a}
RS24	81.18±0.31^{f}	42.96±0.33^{d}	23.80±0.45^{d}	13.69±0.54^{c}
RS48	79.96±0.07^{d}	41.50±1.97^{cd}	22.07±0.24^{c}	12.74±0.62^{bc}
RS72	74.33±0.50^{b}	39.04±0.21^{ab}	20.05±0.10^{a}	10.77±0.41^{a}
RS96	73.08±0.14^{a}	37.89±1.27^{a}	19.77±0.33^{a}	10.59±0.59^{a}
WS	77.00±0.30^{c}	39.98±0.03^{bc}	20.96±0.25^{ab}	11.72±0.52^{a}
WS24	80.25±1.06^{ef}	42.88±0.17^{d}	23.81±0.44^{d}	13.69±0.55^{c}
WS48	79.05±0.33^{d}	41.18±1.16^{cd}	21.65±0.63^{bc}	12.54±0.65^{bc}
WS72	80.96±0.45^{ef}	42.99±0.25^{d}	23.80±0.28^{d}	13.60±0.57^{c}
WS96	81.18±0.31^{f}	42.97±0.33^{d}	23.80±0.45^{d}	13.69±0.54^{c}

Values represent the mean ± standard deviation (SD) based on three separate determinations. Means with different superscripts within the same column indicate significant differences ($p < 0.05$). RS: Red sorghum control, RS24: Red sorghum 24h steeping time, RS48: Red sorghum 48h steeping time, RS72: Red sorghum 72h steeping time, RS96: Red sorghum 96h steeping time, WS: White sorghum control, WS24: White sorghum 24h steeping time, WS48: White sorghum 48h steeping time, WS72: White sorghum 72h steeping time, WS96: White sorghum 96h steeping time.

Table 3: DPPH (2,2-diphenyl-1-picrylhydrazyl (mg/mL)) assay of fermented sorghum gruel at different concentrations

	Concentration (mg/mL)			
Samples	500	250	125	62.5
RS	63.42±0.18^{e}	53.44±0.01^{e}	39.03±0.30^{f}	20.37±0.24^{f}
RS24	51.72±0.22^{a}	41.15±0.23^{a}	24.18±0.23^{a}	9.97±0.34^{a}
RS48	65.44±0.29^{fg}	57.51±0.21^{g}	41.85±0.18^{g}	23.58±0.28^{g}
RS72	57.38±0.37^{b}	47.99±0.23^{b}	30.57±0.12^{b}	12.95±0.11^{b}
RS96	61.19±0.23^{d}	52.38±0.27^{d}	36.70±0.21^{e}	18.12±0.27^{e}
WS	64.62±0.34^{f}	55.59±0.22^{f}	39.28±0.21^{f}	20.74±0.34^{f}
WS24	65.82±0.26^{g}	58.73±0.31^{h}	44.00±0.18^{h}	25.83±0.12^{h}
WS48	74.10±0.23^{h}	65.72±0.25^{i}	47.11±0.30^{i}	28.41±0.17^{i}
WS72	60.10±0.23^{c}	50.65±0.30^{c}	31.85±0.18^{c}	13.59±0.23^{c}
WS96	62.56±0.21^{e}	52.16±0.25^{d}	34.23±0.25^{d}	17.55±0.15^{d}

Values represent the mean ± standard deviation (SD) based on three separate determinations. Means with different superscripts within the same column indicate significant differences ($p < 0.05$). RS: Red sorghum control, RS24: Red sorghum 24h steeping time, RS48: Red sorghum 48h steeping time, RS72: Red sorghum 72h steeping time, RS96: Red sorghum 96h steeping time, WS: White sorghum control, WS24: White sorghum 24h steeping time, WS48: White sorghum 48h steeping time, WS72: White sorghum 72h steeping time, WS96: White sorghum 96h steeping time.

Mineral content of fermented sorghum gruel

Mineral content (Table 4) such as zinc, magnesium, potassium, calcium, iron, sodium and phosphorous ranged from (1.50 to 4.98 mg/100g), (18.52 to 26.56 mg/100g), (55.72 to 68.43 mg/100), (12.84 to 22.67 mg/100g), (2.79 to 9.55 mg/100g), (3.18to 5.56 mg/100g) and (34.75 to 56.36 mg/100g) respectively. Zinc was slightly higher in WS than in RS, peaking at WS48 (2.04± 0.05 mg/100g) compared to RS48 (1.90 ± 0.06 mg/100g). Magnesium was highest in RS24 (26.56

± 0.22 mg/100g), while WS48 recorded the highest calcium level (68.43 ± 0.36 mg/100g). Iron levels varied, peaking at WS96 (7.49 ± 0.26 mg/100g) and RS48 (3.25 ± 0.05 mg/100g). Sodium content was higher in RS samples, with RS24 recording 6.54 ± 0.32 mg/100g.

Table 4: Mineral Content (mg/100g) of fermented sorghum gruel samples

Samples	Zinc	Magnesium	Potassium	Calcium	Iron	Sodium	Phosphorous
RS	4.98±0.05^{g}	20.69±0.0^{c}	58.92±0.03^{b}	15.97±0.06^{d}	3.97±0.03^{e}	5.56±0.06^{g}	52.52±0.42^{i}
RS24	1.50±0.06^{ab}	26.56±0.22^{f}	55.72±0.08^{a}	20.47±0.15^{g}	3.56±0.11^{c}	6.54±0.32^{h}	39.27±0.64^{b}
RS48	1.71±0.08^{abc}	18.52±0.07^{a}	62.29±0.04^{d}	20.35±0.05^{g}	3.25±0.05^{b}	5.38±0.02^{f}	46.47±0.00^{e}
RS72	1.90±0.06^{c}	18.61±0.07^{a}	60.38±0.04^{c}	12.84±0.26^{a}	9.55±0.04^{i}	4.85±0.04^{e}	46.90±0.10^{f}
RS96	2.51±0.10^{e}	22.87±0.07^{d}	62.86±0.05^{d}	15.28±0.02^{c}	7.19±0.09^{h}	3.39±0.01^{b}	50.25±0.05^{h}
WS	3.56±0.01^{f}	20.47±0.12^{c}	65.08±0.02^{e}	22.67±0.15^{h}	2.79±0.03^{a}	3.57±0.03^{c}	48.29±0.01^{g}
WS24	1.44±0.08^{a}	22.20±0.5^{d}	59.03±0.10^{b}	13.52±0.07^{b}	6.28±0.25^{g}	3.98±0.29^{d}	50.36±0.05^{i}
WS48	1.60±0.10^{ab}	20.31±0.29^{c}	66.48±0.00^{ef}	18.72±0.07^{f}	4.50±0.25^{f}	6.93±0.11^{i}	46.22±0.06^{d}
WS72	2.04±0.05^{d}	19.27±0.29^{b}	68.43±0.36^{f}	18.53±0.04^{f}	7.49±0.26^{h}	3.18±0.02^{a}	40.28±0.06^{c}
WS96	5.48±0.02^{h}	23.15±0.29^{e}	65.70±0.10^{e}	16.92±0.07^{e}	3.86±0.46^{d}	3.98±0.03^{c}	34.75±0.05^{a}

Values represent the mean ± standard deviation (SD) based on three separate determinations. Means with different superscripts within the same column indicate significant differences ($p < 0.05$). RS: Red sorghum control, RS24: Red sorghum 24h steeping time, RS48: Red sorghum 48h steeping time, RS72: Red sorghum 72h steeping time, RS96: Red sorghum 96h steeping time, WS: White sorghum control, WS24: White sorghum 24h steeping time, WS48: White sorghum 48h steeping time, WS72: White sorghum 72h steeping time, WS96: White sorghum 96h steeping time.

Antinutritional factors of fermented sorghum gruel samples

Oxalate levels were significantly reduced in WS96 (0.32 mg/g) compared to RS96 (0.36 mg/g). Phytate levels showed a sharper decline in WS, with WS96 having the lowest value (0.36 mg/g). Tannin content ranged from 0.00 mg/100g to 2.47 mg/100g. Saponin content ranged from 2.63 mg/100g to 8.90 mg/100g for raw sorghum samples (Table 5).

Table 5: Antinutritional factors (mg/g) of fermented sorghum gruel samples

Samples	Oxalate	Phytate	Saponin	Tannin
RS	0.45±0.00^{b}	1.07±0.12^{c}	2.63±0.03^{a}	0.00±0.00^{a}
RS24	1.29±0.05^{f}	1.07±0.00^{c}	6.06±0.05^{g}	2.47±0.02^{d}
RS48	0.50±0.05^{b}	1.31±0.00^{d}	2.82±0.02^{b}	2.35±0.04^{c}
RS72	0.93±0.05^{e}	0.12±0.07^{f}	3.01±0.02^{c}	0.00±0.00^{a}
RS96	0.36±0.00^{a}	0.83±0.00^{a}	8.04±0.06^{h}	0.00±0.00^{a}
WS	0.66±0.05^{c}	1.19±0.00^{cd}	5.27±0.03^{f}	0.00±0.00^{a}
WS24	0.32±0.05^{a}	0.95±0.00^{b}	8.90±0.02^{i}	2.10±0.10^{b}
WS48	2.04±0.05b	0.51±0.05^{d}	7.99±0.01^{h}	0.00±0.00^{a}
WS72	2.51±0.10^{d}	0.78±0.05^{cd}	4.30±0.10^{e}	0.00±0.00^{a}
WS96	1.61±0.52^{a}	0.36±0.00^{e}	3.42±0.01^{d}	0.00±0.00^{a}

Values represent the mean ± standard deviation (SD) based on three separate determinations. Means with different superscripts within the same column indicate significant differences ($p < 0.05$). RS: Red sorghum control, RS24: Red sorghum 24h steeping time, RS48: Red sorghum 48h steeping time, RS72: Red sorghum 72h steeping time, RS96: Red sorghum 96h steeping time, WS: White sorghum control, WS24: White sorghum 24h steeping time, WS48: White sorghum 48h steeping time, WS72: White sorghum 72h steeping time, WS96: White sorghum 96h steeping time.

DISCUSSION

Sorghum gruel (ogi) is a Nigerian traditional fermented cereal that serves as a convenient meal for children and adults. Studies have suggested that fermentation of sorghum helps to reduce the activity of antinutritional factors, thereby improving nutrient bioavailability and mineral absorption in humans (3). The proximate composition of sorghum gruel samples shows significant variations based on the type (red sorghum [RS], white [WS]) and fermentation duration. The proximate analysis reveals the nutritional shifts in fat, fiber, protein, carbohydrates, and moisture content due to

fermentation. Moisture content remained stable across fermentation durations, with minor variations between RS and WS. Fermentation creates a hydrated environment favorable for microbial metabolism, leading to stable moisture retention. The slight increase in fat content during fermentation is due to microbial activity breaking down complex lipids into simpler forms, which enhances extractability. This also suggests that ogi (gruel) made from sorghum grain would be a good source of energy. This finding is in contrast to the report of (15), where a reduction in fat content of fermented sorghum was observed and may be attributed to the process of oxidation, which could occur during fermentation. Low-fat content is advantageous for consumers requiring reduced fat intake, such as those managing cardiovascular diseases (16). Fiber levels showed negligible variation in red sorghum across fermentation periods. White sorghum followed a similar trend, maintaining stable values. Fiber plays a critical role in gastrointestinal health and impacts the glycemic index of foods. Fibre content is reduced during fermentation, and the negligible variation observed in fiber level may be attributed to the secretion of extracellular enzymes by microorganisms that metabolize and hydrolyze polysaccharides during fermentation (17). Ash levels, an indicator of mineral content, may increase due to the enzymatic activities that occur during the steeping of grain in water, causing the constituents to dissolve in water, thereby leading to high mineral content in sorghum (18). Protein content is essential for nutritional quality; the increase observed in this study is attributed to microbial proteolysis, which breaks down complex proteins into free amino acids and peptides, hence, enhancing digestibility (18).

The antioxidant analyses in this study include the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity, and the FRAP (ferric reducing antioxidant power) assay. These parameters reflect the capacity of the fermented sorghum samples to neutralize free radicals with ability of providing potential health-promoting properties. The reduction observed in FRAP values is attributed to the degradation of antioxidant compounds, such as polyphenols and flavonoids, due to extended microbial activity during fermentation (19). WS retained higher FRAP activity than RS, the lighter pigmentation of WS may result in a more stable antioxidant profile, as observed in previous studies (19). The rise and subsequent decline in DPPH radical scavenging ability indicates a balance between antioxidant extraction and degradation during fermentation (19). WS samples exhibited superior scavenging ability throughout, with WS48 being the highest.

Mineral content revealed significant variation due to fermentation, with improvements in bioavailability for key minerals like zinc, magnesium, and calcium. zinc bioavailability may have been enhanced as a result of reduction in phytate content through fermentation. The reduction in phytate content through fermentation may have enhanced zinc bioavailability (20). Increase in magnesium and calcium level observed in this study align with previous research showing that fermentation activates phytase enzymes, which release bound minerals (18). Iron levels varied, peaking at WS96, sodium content was higher in RS samples, with RS24 recording the highest. These variations are influenced by the innate composition of sorghum varieties.

Fermentation reduced antinutritional compounds, such as oxalates, phytates, and tannins, which inhibit nutrient absorption. These reductions improve mineral bioavailability and align with findings by (15). The reduction of oxalate level during fermentation is expected to improve the bioavailability of essential minerals in fermented sorghum. This reduction shows that oxalate content in these samples can positively impact consumers' health and help to reduce any risk of kidney diseases among consumers. This corroborates the findings that fermentation reduces oxalate content in cereal grains, and the oxalate content of all samples is within the tolerance level, and consumers are not at risk of kidney stone formation (21, 22). The reduction of phytate content in all the samples may be attributed to the degradation of the inherent phytate enzymes in sorghum, which were activated by lactic acid bacteria during fermentation (23). A 76% reduction in tannin content was observed at 48 h fermentation for red sorghum, 63 % reduction was observed at 24 h fermentation for white sorghum, while a reduction/elimination of tannin content in all the samples was observed from 48 h to 96 h fermentation period. The soaking, dehulling, and lactic acid fermentation processes that the sorghum samples have undergone might have been responsible for the significant reduction/elimination of tannin content in all the samples. This is in agreement with the finding that tannin content regarding the level in cereals can be significantly reduced or eliminated through processes like soaking, dehulling, germination, and fermentation (24). Comparatively, saponin content is higher in red sorghum samples

compared to white sorghum samples. The saponin content observed in this study is lower than (53.82 – 177 mg/g) reported by (23) for ogi samples from different cereals such as maize, sorghum, millet, and popcorn maize.

CONCLUSION

The nutritional content of ogi was improved with increased protein, fat, and mineral content. The comparative evaluation reveals that white sorghum was superior to red sorghum in retaining nutritional and antioxidant properties. White sorghum exhibited better antioxidant stability, higher protein and mineral content, and lower levels of antinutrients. The study also reveals that fermentation significantly reduced the levels of antinutrients in ogi, leading to improved mineral bioavailability, enhanced protein digestibility, and increased nutritional value. Optimal fermentation duration (48–72 hours) balances nutrient retention and antinutritional factor reduction. White sorghum, due to its superior performance, is recommended for producing Ogi with enhanced health benefits.

Declaration of Conflict of Interest

The authors declared that there were no conflicts of interest for the study.

Author's Contribution

Adebowale Oluwatoyin Motunrayo, Chinma Chiemela Enyinnaya, Makun Hussain Anthony, and Adebo Oluwafemi Ayodeji designed the research. Implementation of the research and data analyses was done by Adebowale Oluwatoyin Motunrayo, Chinma Chiemela Enyinnaya, Makun Hussain Anthony, and Adebo Oluwafemi Ayodeji. Manuscript preparations were done by Adebowale Oluwatoyin Motunrayo and Chinma Chiemela Enyinnaya.

REFERENCES

1. Ediage, E.N., Poucke, C. V., & Sarah De Saeger (2015). A multi-analyte LC–MS/MS method for the analysis of 23 mycotoxins in different sorghum varieties: The forgotten sample matrix. *Food Chemistry,* 177: 397–404. http://dx.doi.org/10.1016/j.foodchem.2015.01.060
2. Taylor, J.R.N. & Emmambux, M.N. (2018). Gluten-free cereal products and beverages. In Gluten-Free Foods and Beverages from Millets; Arendt, E.K., Bello, F.D., Eds.; Elsevier: Amsterdam, The Netherlands, (pp. 119–148).
3. Mohammed, N.A., Ahmed, I.A.M. & Babiker, E.E. (2011). Nutritional Evaluation of Sorghum Flour (*Sorghum bicolor* L. Moench) during Processing of *Injera*. *International Journal of Biological and Life Sciences*, *7, 35-39*. ISSN: 2415-6612
4. Adebo, O.A., Tumisi, M., Rhulani, M., Janet, A.A., Ajibola, B.O., Sefater, G., Martins, A.A, Opeoluwa, M.O., & Patrick, B.N. (2020). A review on novel non-thermal food processing techniques for mycotoxin reduction. *International Journal of Food Science and Technology*, doi: 10.1111/ijfs.14734
5. Okeke, C.A., Ezekiel, C.N., Sulyok, M., Ogunremi, O.R., Ezeamagu, C.O., Sarkanj, B., Warth, B. & Krska, R. (2018). Traditional processing impacts mycotoxin levels and nutritional value of *gruel* - A maize-based complementary food. *Food Control,* 86, 224–233. https://doi.org/10.1016/j.foodcont.2017.11.021
6. AOAC (2010). Official Methods of Analysis of Association of Official Analytical Chemists. (8th Edition), Washington, DC.
7. Olawole, T.D., Olalere, A.N. & Adeyemi, O.A. (2019). Tannin and antioxidant status of fermented and dried Sorghum bicolor. *Rasayan Journal of Chemistry,* 12(2): 523-530. *http://dx.doi.org/10.31788/RJC.2019.1224066*
8. Latta, M., & Eskin, M. (1980). A simple and rapid colorimetric method for phytate determination. *Journal of Agricultural and Food Chemistry,* 28(6), 1313–1315. https:// doi.org/10.1021/jf60232a049
9. Azeez, S.O., Chinma, C.E., Bassey, S.O., Eze, U.R., Makinde, A.F., Sakariyah, A.A., Okubanjo, S.S., Danbaba, N., & Adebo, O.A. (2022). Impact of germination alone or in combination with solid-state fermentation on the physicochemical, antioxidant, in vitro digestibility, functional and thermal properties of brown finger millet flours. *Lebensmittel-Wissenschaft und -Technologie – Food Science and Technology,* 154, 112734. https://doi.org/10.1016/j.lwt.2021.112734
10. Ijarotimi, O. S. (2008). Nutritional composition, microbial status, functional and sensory properties of infant diets formulated from cooking banana fruits (*Musa spp*, ABB genome) and fermented Bambara groundnut (*Vigna subterranea* L. Verdc) seeds. *Nutrition & Food Science,* 38, 325–340. https://doi.org/10.1108/00346650810891388

11. Aiwonegbe, A.E., Iyasele, J.U., & Izevbuwa, N.O. (2018). Proximate composition phytochemical and antimicrobial screening of methanol and acetone extracts of Vitex doniana fruit Pulp. *Ife Journal of Science,* 20(2): 207-212. https://dx.doi.org/10.4314/ijs.v20i2.12
12. Pownall, T.L., Udenigwe, C.C., & Aluko, R.E. (2010). Amino acid composition and antioxidant properties of pea seed (*Pisum sativum* L.) enzymatic protein hydrolysate fractions. *Journal of Agricultural Food Chemistry,* 58(8): 4712–4718. doi: 10.1021/jf904456r
13. Benzie, I. F. F., & Strain, J. J. (1999). Ferric reducing/antioxidant power assay: Direct measure of total antioxidant activity of biological fluids and modified version for simultaneous measurement of total antioxidant power and ascorbic acid concentration. *Methods in Enzymology,* 15–27. doi:10.1016/s0076-6879(99)99005-5.
14. Punia, H., Tokas, J., Malik, A., Satpal, & Sangwan, S. (2021). Characterization of phenolic compounds and antioxidant activity in sorghum [Sorghum bicolor (L.) Moench] grains. *Cereal Research Communications,* 49(3): 343–353. doi:10.1007/s42976-020-00118-w
15. Sobowale, S.S., Bamidele, O.P., Adebo, J.A. (2024). Physicochemical, functional, and antinutritional properties of fermented Bambara groundnut and sorghum flours at different times. *Food Chemistry Advances* 4, 100729. https://doi.org/10.1016/j.focha.2024.100729
16. Ihekoronye, R.I., and Ngoddy, P.O. (1985). Integrated food science and technology for the tropics. Macmillan Publishers, London, pp 259-262. ISBN: 0333388836.
17. Terefe, Z. K., Omwamba, M. N., & Nduko, J. M. (2021). Effect of solid-state fermentation on proximate composition, antinutritional factors, and in vitro protein digestibility of maize flour. *Food Science and Nutrition*, 9, 6343–6352. DOI: 10.1002/fsn3.2599.
18. Makinwa T. T., Fabusiwa M. M., Bolarin, J. A. & Onugwu, E. O. (2019). Comparative effect of steeping and sieving on the nutritional content of sorghum. *Salem University Journal of Life Sciences*, 1(1), 47-60. ISBN: 9789785877585
19. Collins, A., Santhakumar, A., Latif, S., Chinkwo, K., Francis, N. & Blanchard, C. (2024). Impact of Processing on the Phenolic Content and Antioxidant Activity of Sorghum bicolor L. Moench. *Molecules*, 29, 3626. https://doi.org/10.3390/molecules291536226
20. Nsabimana, S., Ismail, T. & Lazarte, C.E. (2024). Enhancing iron and zinc bioavailability in maize (Zea mays) through phytate reduction: the impact of fermentation alone and in combination with soaking and germination. *Frontiers in Nutrition.* 2:11:1478155. doi: 10.3389/fnut.2024.1478155.
21. Ufere, E. A., Onuoha, O. N. & Ezeja, P. (2021). Effect of Fermentation and Drying on the Nutrient and Antinutrient Composition of Yellow and White Maize Flours. *Journal of Dietitians Association of Nigeria*. Vol. 12, 92-99. DOI: https://dx.doi.org/10.4314/jdan.v12i1.12
22. Ijarotimi, O.S., Oluwajuyitan, T.D., Olugbuyi, A.O. & Makanjuola, S.B. (2022). Comparative study on nutrient composition, functional property, and glycaemic index of "Ogi" in healthy rats prepared from selected cereal grains. *Journal of Future Foods*, 2(4):380-387. DOI:10.1016/j.jfutfo.2022.08.010
23. Ojha, P., Adhikari, R., Karki, R., Mishra, A., Subedi, U. & Karki, B. T. (2018). Malting and fermentation effects on antinutritional components and functional characteristics of sorghum flour. *Food Science and Nutrition*. 6: 47-53. https://doi.org/10.1002/fsn3.525
24. Ijarotimi, O.S., Adesanya, I.H. & Oluwajuyitan, T.D. (2021). Nutritional, antioxidant, angiotensin-converting-enzyme, and carbohydrate-hydrolyzing-enzyme inhibitory activities of underutilized leafy vegetable: African wild lettuce (Lactuca taraxacifolia Wild), *Clinical Phytoscience*. 7(47) 1-15. https://doi.org/10.1186/s40816-021-00282-4.