Nutritional, Antioxidant and Sensory Properties of Wheat–Oat Composite Sourdough Breads

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Article History

Submitted: December 22, 2025 Accepted: Published:

Abstract

Sourdough breads produced from wheat and oat flours were evaluated for proximate compositions, mineral profiles, estimated mineral bioavailability, antioxidant activities, and sensory quality, with yeast-leavened breads used as controls. Five bread samples were prepared: 100% wheat yeast dough bread (WYD), 100% oat yeast dough bread (OYD), 100% wheat sourdough bread (WSD), 100% oat sourdough bread (OSD), and a 50:50 wheat–oat sourdough bread (WOSD). The bread samples exhibited moisture (23.54±0.36–32.38±0.09%), ash (0.80±0.01–1.32±0.12%), fat (8.55±0.50–18.11±0.67%) contents, crude protein (7.34±0.10–11.66±0.12%), crude fibre (0.18±0.00–1.04±0.04%), and carbohydrate by difference (40.21±0.70–55.27±0.97%). Sodium (31.19±0.01–41.21±0.00 ppm) and potassium (38.09±0.01–44.21±0.00 ppm) were the predominant minerals, with sourdough breads maintaining comparable mineral levels to yeast-leavened breads ($p < 0.05$). Phytate contents ranged from 8.15 to 12.10 mg/g, with WOSD exhibiting the lowest phytate level and more favourable phytate-to-mineral molar ratios, indicating improved relative mineral bioavailability. Antioxidant assays demonstrated significantly higher DPPH radical scavenging activity, ABTS activity, and FRAP in sourdough breads than yeast controls, with WOSD showing the peak antioxidant activity. Sensory evaluation indicated that wheat yeast bread was most preferred in terms of colour and appearance, while sourdough breads were rated higher for flavour and aroma, with overall acceptability scores ranging from 7.60±0.52 to 8.90±0.32 on a nine-point hedonic scale. These data indicated that the combination of improved antioxidant activity and acceptable sensory quality of WOSD unveiled its potential as a nutritionally enriched bakery food product.

Keywords

Antioxidants; Bioavailability; DPPH radical scavenging activity; fermentation; phytate content; sourdough bread; wheat–oat composite

Introduction

Renewed interest in traditional food processing technologies has stimulated extensive research into sourdough fermentation as a natural means of improving the nutritional and functional quality of cereal-based foods. Sourdough bread is produced through the metabolic activity of lactic acid bacteria (LAB) and yeasts, which collectively influence dough structure, flavour development, shelf stability, and nutrient bioavailability [1,2]. Compared with conventional yeast-leavened bread, sourdough bread is often associated with a lower glycemic response, improved mineral bioavailability, and improved sensory quality [3].

Sourdough fermentation improves mineral bioavailability primarily through acidification and microbial phytase activity, which hydrolyze phytic acid (inositol hexaphosphate) and reduce its capacity to chelate divalent minerals, such as Fe^{2+}, Zn^{2+}, Ca^{2+} [4,5]. *In-vitro* and animal studies show that sourdough fermentation significantly reduces phytate levels and enhances mineral solubility compared with yeast controls [4,5]. Mechanistic reviews emphasize that optimal phytate breakdown results from maintaining fermentation conditions in terms of pH, time, and microbial composition, which activate endogenous cereal phytases and microbial phytases expressed by lactic acid bacteria [1,6-8].

Microbial fermentation liberates cell-wall bound phenolics and can generate new antioxidant metabolites, in-

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creasing total phenolic content and in vitro antioxidant activity measured by DPPH, ABTS and FRAP assays [9,10]. Multiple cereal- and legume-based sourdough studies show consistent increases in radical scavenging capacity and reducing power after fermentation. The magnitude depends on substrate composition and starter microbiota [1,11].

Wheat flour remains the dominant raw material for bread production worldwide due to its gluten-forming proteins and favorable baking properties. However, oats (*Avena sativa* L.) have attracted growing attention because of their high dietary fiber content, balanced amino acid profile, and abundance of bioactive compounds such as phenolic acids and avenanthramides [12,13]. Oats are a rich source of soluble dietary fiber (notably β-glucan), lipid-soluble antioxidants, and unique phenolics, such asavenanthramides, which possess strong antioxidant and anti-inflammatory properties [14-17]. This is primarily due to the relative abundance of phenolics in the outer kernel, milling fraction and particle size influence the phenolic load and its release during processing [14,18-19].

Addition of oat flour to wheat doughs typically reduces loaf volume and alters crumb structure due to dilution of gluten. However, targeted use of sourdough fermentation or enzyme treatments can mitigate technological defects and improve sensory acceptance [20,21]. Sensory studies indicate that while wheat-dominant breads remain preferred for appearance and texture, composite sourdoughs often receive higher scores for flavour acceptability and perceived healthfulness [22,23].

Although numerous studies describe the benefits of sourdough on single-grain matrices, limited data on wheat–oat composite sourdough bread have been reported. This study, therefore investigates and unveils an integrated dataset that links compositional changes to estimated mineral bioavailability, antioxidant capacity (DPPH, ABTS, FRAP), and organoleptic acceptance for commercially relevant wheat–oat breads.

Materials and methods

Materials

Commercial wheat flour, sugar, salt, fat, and baking yeast were obtained from Uchi Market in Etsako-West Local Government Area, Edo State, Nigeria. Rolled oats were purchased from Jattu Market, Etsako West Local Government Area. All analytical reagents used were of analytical grade and sourced from certified laboratory suppliers (Pascal Scientific, Akure, Ondo State, and Promise Medical Equipment and Supply, Ekpoma, Edo State).

Methods

Sourdough Preparation and Bread Production

Sourdough fermentation was carried out following the method described by by Demirkesen-Bicak *et al.* [1] with minor modifications. Wheat and oat flours were separately dispersed in distilled water at a flour-to-distilled water ratio of 187.5 g to 112.5 mL to obtain 300 g of dough. Spontaneous fermentation was carried out at ambient temperature (24-27 ºC), with back-slopping every 24 h for 72 h. Fermentation was terminated when dough pH reached approximately 4.0. Five (5) bread samples were produced and coded as WYD = 100% wheat yeast dough bread; OYD = 100% oat yeast dough bread; WSD = 100% wheat sourdough bread; OSD = 100% oat sourdough bread; WOSD = 50% wheat and 50% oat sourdough bread. Corresponding yeast-leavened breads served as controls. Doughs were proofed at 30 °C and 75% relative humidity for 45 min and baked under standardized conditions. The dough was baked in an electric oven for 45 min at a bottom temperature of 190 °C and a top temperature of 215 °C.

Proximate and Mineral Analysis

Proximate composition was determined using standard AOAC methods [24 Accordingly, each bread sample was milled into flour, and 1.0 g of it was weighed into a crucible, transferred to a muffle furnace, ashed at 550 ºC and transferred into a desiccator to cool. Then, 0.1M HCl solution (10 mL) was used to digest the ash content, which was later washed three times with 0.1M HCl and made up to 100 mL with deionized water. The calcium, magnesium, zinc, and iron contents of the sample were evaluated using Atomic Absorption Spectrophotometer (AAS). Standard stock solution was prepared for each metal using suitable metal salts of each metal to prepare a standard curve. A flame photometer was used to determine the concentrations of sodium and potassium in the flour sample. The values obtained were plotted in the respective standard value to read the original values of the concentration of the element. The phosphorus concentration was determined using the Vanodo-molybdate method. To series of 100 mL volumetric flasks 0.0, 2.5, 5.0, 7.5, 11.0, 15.0, 20.0, 30.0, 40.0, 50.0 mL of the standard phosphate solution was made acidic by the addition of 2 mL nitric acid (2:1). After which 25 mL of the Vanodo-molybdate reagent was added. The solution was diluted to the mark, mixed thoroughly and allowed to stand for 10 min, while the optical density was measured at 47 mu. Mineral ratio, Na:K relevant to dietary quality, was also calculated.

Estimation of Mineral Bioavailability

Relative mineral bioavailability was estimated using phytate-to-mineral molar ratios (phytate:Fe, phytate:Zn, and phytate:Ca), following established criteria for predicting mineral absorption [25].

Antioxidant Activity Assays

An aqueous extract of the milled bread sample (500 g of flour to 2.5 L of distilled water) was prepared by maceration, filtration, concentration, and freeze-drying. Antioxidant activities were evaluated using DPPH radical scavenging, ABTS radical cation decolorization, and FRAP assays according to standardized protocols [26-28].

Sensory Evaluation

Sensory evaluation was conducted using 30 untrained panelists, aged 18–50 years. Bread samples were assessed for colour, appearance, texture, aroma, taste, and overall acceptability, using a nine-point hedonic scale of dislike extremely = 1, dislike very much = 2, dislike moderately = 3, dislike slightly = 4, neither like nor dislike = 5, like slightly = 6, like moderately = 7, like very much = 8 and like extremely = 9. Water was provided for palate cleansing between samples. The bread samples were coded as WYD = 100% wheat yeast dough bread; OYD = 100% oat yeast dough bread; WSD = 100% wheat sourdough bread; OSD = 100% oat sourdough bread; WOSD = 50% wheat and 50% oat sourdough bread.

Statistical Analysis

All analyses were performed in triplicate, using SPSS (version 26) and GraphPad Prism (version 5). Data were expressed as mean±standard deviation of the mean. Statistical significance was determined using one-way analysis of variance (ANOVA), and mean separation was carried out using Duncan's multiple range test at $p < 0.05$.

Results and Discussion

Proximate Compositions

Moisture content varies markedly among the samples, ranging from 23.54% in 100% wheat yeast dough (WYD) to 32.38% in 100% oat sourdough (OSD) (Table 1). High moisture observed in 100% oat yeast dough (OYD), 100% oat sourdough (OSD) and 50% wheat and 50% oat sourdough (WOSD) samples can be attributed to the presence of soluble fibres, particularly β-glucans in oats, which exhibit high water-binding capacity [29]. Fermentation promotes the formation of organic acid and exopolysaccharides, which tend to enhance water retention in the crumb matrix of sourdough [30]. Doughs with high moisture content have been report to possess reduced caloric density, improved crumb softness, enhanced digestibility and consumer comfort during mastication, especially for elderly populations and individuals with chewing difficulties [31]. These observations do not rule out the observation that doughs with high moisture content have low shelf-life, due to significantly high susceptibility to microbial spoilage [32], and increased water retention due to fibre-starch interactions [33]. Ash content increases with oat inclusion, with values rising from 0.80±0.01% in WYD to 1.32±0.12% in OYD (Table 1). Ash reflects total mineral matter [34], indicating that oat flour contributed significantly to micronutrient density. Similar trends have been reported for oat-composite breads in recent cereal nutrition studies [13,17].Crude protein content is highest in WYD (11.66±0.12%) and lowest in OSD (Table 1). This implies that fermentation facilitates a general decline in the crude protein of the doughs. Comparatively, the wheat-based doughs are richer in protein than the oat-based sourdoughs. This reduction is expected, as oats contain lower gluten-forming proteins and sourdough fermentation induces proteolysis through lactic acid bacteria activity [4], improving protein digestibility by releasing bioactive peptides and free amino acids, hence amino acid bioavailability. Recent studies have confirmed that fermentation improves protein quality in sourdoughs [35]. Crude fibre increases substantially with oat inclusion, reaching 1.04±0.04% in oat yeast bread and remaining high in oat sourdough. Wheat-based samples show very low fibre content. Oat fibre, especially β-glucan, has approved cholesterol-lowering health claims. High-fibre claims significantly increase market value and consumer appeal, particularly in functional and health-oriented food markets. These findings align with recent evidence on fibre enrichment in oat-based bakery products [14,36]. Fat content increases notably in oat-based breads, with peak value of 18.11±0.67% obtained in OSD. It has been reported that oats naturally contain higher lipid levels, which gives oat lipids a material advantage in baked goods [17]. Carbohydrate content decreases with oat inclusion and sourdough fermentation, with the lowest value observed in OSD (40.21±0.70%). Sourdough fermentation has been shown to reduce starch digestibility and glycemic impact in recent clinical and *in-vitro* studies [37].

Mineral Compositions

Table 2 shows the mineral compositions of yeast-based doughs and sourdoughs. Mineral analysis reveals that mineral bioavailability improves upon fermentation and through composite formulation. Sodium content ranges from 31.19±0.01 to 41.21±0.00 ppm, with lower values observed in OSD. Reduced sodium intake has been reported to be associated with lower hypertension risk [38,39]. Potassium content is relatively high across all samples, with values up to 44.21±0.00 ppm in WYD. High potassium intake has been reported to facilitate osmoregulation and support nerve and muscle function [40]. WHO [41] emphasizes maintaining a low Na:K ratio for cardiovascular health, which is strategic at simultaneous increase in potassium intake and decrease in sodium intake. Calcium and magnesium are high in WYD and WSD, but remain nutritionally relevant in WOSD. Calcium supports bone health, while magnesium plays roles in glucose metabolism and enzymatic activity. Iron and zinc contents are low across the samples, which is a typical limitation of cereal products [42,43], majorly adduced to the formation of phytate complex with them.. Recent evidence confirms improved iron and zinc bioavailability in sourdough products [5]. The difference in the phosphorus contents in yeast-based doughs and the sourdoughs adjudges the bioavailability of phosphorus to the body [5]. High phosphorus content in wheat yeast-based bread is an indication of large amount of indigestible phytate bound phosphorus while low phosphorus content in sourdough indicates large amount of unbound, available and digestible phosphorus [4].

Phytate Content and Relative Mineral Bioavailability

Phytate contents and relative mineral bioavailability of the bread samples are presented in Table 3. OSD has the highest phytate content (12.10±0.06 mg/g), WYD and WSD moderate while WOSD has the lowest phytate content (8.15±0.08 mg/g). This observation is an indication that sourdough fermentation has a greater overall effect when applied to the wheat–oat composite than in oats grains alone, likely because mixed substrates offer a broader array of endogenous and microbial phytases. Phytase in wheat sourdough has been shown to be more active near the pH levels achieved in sourdough fermentation (3.8–4.2), whereas phytase in oat sourdough is less effective under the same conditions [4]. The Phy:Fe ratio is an indication of iron bioavailability, with values less than 1 generally considered acceptable for improved bioavailability [44,45]. OSD exhibits the highest Phy:Fe ratio (12.10±0.06), likely inhibiting iron absorption despite fermentation. WOSD has the lowest Phy:Fe ratio (8.15±0.08), indicating relatively high iron bioavailability among all the bread samples whereas WYD and WSD reflect moderate phytate impact. Zinc bioavailability is particularly sensitive to phytate, with values greater 15 widely recognized as inhibitory [46]. In the same trend, OSD has the highest Phy:Zn ratio (4.99±0.09) predicting poor zinc bioavailability while WOSD has the lowest ratio (2.23±0.08), indicating the most favourable zinc bioavailability. These observations show that zinc is highly reactive with phytate such that a modest reduction in phytate can significantly improve Zn availability. This is evident in WOSD studied, and this seems to be a response to an observation that a sourdough fermentation in composite flours markedly reduces the Phy:Zn ratio below the inhibitory threshold, supporting enhanced zinc access [4], which appears less pronounced in single-grain oat sourdough bread sample. Calcium bioavailability is less sensitive to phytate than Fe or Zn, but high ratios still negatively impact absorption. WOSD has the lowest Phy:Ca ratio (0.06±0.00), suggesting better calcium potential. OSD has the highest ratio (0.11±0.00) whereas WSD and WYD have intermediate impact. The improved Phy:Ca ratio in WOSD is a reflection of balanced phytate degradation and moderate calcium levels, leading to enhanced solubility. Conversely, oat sourdough's elevated phytate impairs calcium interactions, potentially reducing calcium uptake [47]. Generally, sourdough fermentation improves relative mineral availability compared with yeast leavening due to phytate breakdown and acidic conditions [5]. Blending wheat with oats before sourdough fermentation yields the most nutritionally advantageous profile, balancing enhanced cereal diversity with optimized enzyme activity.

Antioxidant Activities

Figures 1–4 exhibit the quality of the bread samples using three antioxidant assays, FRAP, DPPH, and ABTS**,** and α-amylase inhibition, a key indicator of glycemic modulation. Each assay reflects a different antioxidant mechanism: FRAP measures reducing power, DPPH and ABTS assess radical scavenging capacity, while α-amylase inhibition reflects the ability of bioactive compounds to slow starch hydrolysis [5,48]. FRAP values are lowest in WYD and OYD, while sourdough breads, particularly WOSD exhibits significantly higher reducing power (Figure 1). This indicates that WOSD outperforms single-grain sourdoughs. This significant potential of WOSD may be linked with the possible release of bound phenolic acids, leading to the formation of low-molecular-weight phenolic metabolites through microbial biotransformation, and release of avenanthramides, specific antioxidants of oats, which possess strong reducing capacity [4,17]. Similarly, WOSD and OSD exhibit high DPPH scavenging activity, indicating high radical scavenging capacity, compared to other bread samples (Figure 2). The sourdoughs consistently outperform the yeast-based breads whereas the WOSD displays the peak DPPH activity. The data obtained unveils the the improvement in DPPH activity upon sourdough fermentation, , aligning with observation that linear increase in the antioxidant activity by 2-3 times upon sourdough fermentation [35]. ABTS values are generally higher than DPPH values across all samples (Figure 3), indicating a broader spectrum of antioxidant activity, particularly for both hydrophilic and lipophilic compounds. WOSD shows the highest ABTS scavenging ability, followed closely by OSD, whereas WYD and OYD exhibit limited activity. The elevated ABTS activity in WOSD may suggest a diverse antioxidant profile**,** enhanced by mixed-flour fermentation [48]. α-Amylase inhibition is lowest in WYD and highest in WOSD, with oat sourdoughs showing stronger inhibitory effects (Figure 4). This inhibition may be adduced to the presence of soluble dietary fibre (β-glucan) in oats, which physically limits enzyme–substrate contact. This observation aligns with reports that sourdough-induced formation of bioactive peptides interferes with enzyme activity [5,37]. Collectively, the antioxidant and α-amylase inhibition data indicate that WOSD may improve oxidative stress protection, increase metabolic regulation, reduce glycemic impact, and provide greater functional food value. This study has noted that the synergistic effect of the wheat-oat composite flours provides novel improvement in the antioxidant activities compared to the singular effects of the individual flours.

Sensory Evaluation

Sensory evaluation shows that WYD has the highest scores for colour, appearance, texture, and overall acceptability, reflecting consumer familiarity with conventional wheat bread (Table 4). However, sourdough breads, particularly WSD and WOSD, have peak values for aroma and flavour. Lower colour and appearance scores for OYD and OSD may be attributed to darker crumb colour and denser texture, commonly reported for oat-based products [21]. Despite this, overall acceptability scores for all samples range from 7.60±0.52 to 8.90±0.32, indicating good consumer acceptance. Sensory acceptance is essential for sustained consumption of nutritionally improved foods, providing possible alternative to wheat-based sourdough breads and wheat yeast-leavened breads.

Conclusions

This study has demonstrated that sourdough fermentation and inclusion of wheat-oat composite flours substantially improved the nutritional, antioxidant and sensory properties of breads for consumer acceptability. Compared with yeast-leavened controls, sourdough breads exhibited improved compositional attributes, including higher moisture retention, increased dietary fiber and lipid contents in oat-based formulations, and modified protein profiles consistent with enhanced digestibility. Mineral analysis showed that sodium and potassium were the predominant minerals across all samples, while sourdough fermentation retained overall mineral contents and improved nutritionally relevant Na:K ratio. Notably, the wheat–oat composite sourdough bread exhibited the lowest phytate content and the most favourable phytate-to-mineral molar ratios, indicating relative bioavailability of iron, zinc, and calcium among the samples. This improvement highlights the synergistic effect of wheat–oat composite flours in mitigating the inhibitory effects of phytate on mineral absorption. Antioxidant evaluation further revealed that sourdough breads, particularly the wheat–oat composite (WOSD), possessed significantly higher ferric reducing power, radical scavenging activity, and α-amylase inhibition capacity which could improve oxidative stress protection and potential glycemic modulation. Sensory evaluation showed that while conventional wheat bread remained most preferred for appearance and texture, sourdough breads were favourably rated for aroma and flavour, with all samples achieving good overall acceptability. Collectively, these findings indicate that wheat–oat composite sourdough bread offers a balanced combination of improved mineral bioavailability, enhanced antioxidant activities, and acceptable sensory quality. The study underscores the potential of wheat–oat sourdough bread as a nutritionally enriched bakery food product.

List of abbreviations

- WYD = Wheat-based yeast-dough bread (100%)
- OYD = Oat-based yeast-dough bread (100%)
- WSD = Wheat-based sourdough bread (100%)
- OSD = Oat-based sourdough bread (100%)
- WOSD = Wheat–oat (50:50) sourdough bread
- DPPH = 2,2-diphenyl-1-picrylhydrazyl
- ABTS = 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)
- FRAP = Ferric Reducing Antioxidant Power
- AOAC = Association of Official Analytical Chemists

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Authors' Contributions

Conceptualization, methodology: A.A.O; Investigation, resources, data analysis, writing of original draft preparation, visualization, supervision and editing: A.O.O. The authors have read and agreed to the published version of the manuscript

Availability of Data and Materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

Authors declare that there is no conflict of interest.

Ethics Committee Approval and Consent to Participate

Ethical approval was not required by the institution, Auchi Polytechnic, Auchi, Nigeria, where sensory evaluation of this study was carried out since it was a non-invasive sensory evaluation of food products and Informed consent to participate was obtained from the sensory evaluation panelists to participate in this study, and use the data obtained for publication.

Human Rights
The study adhered to ethical research practices and was conducted in accordance with the Declaration of Helsinki.

Funding

Authors did not receive external funding for this research.

Acknowledgments

Authors acknowledge the authorities of University of Medical Sciences, Ondo, Nigeria and Auchi Polytechnic, Auchi, Nigeria for permission to use the facilities in the Science Laboratory Technology Laboratory and Food Technology Laboratory respectively.

AI Declaration

The authors used ChatGPT for clarification of ideas during the writing of this manuscript. The contents obtained from the tool were thoroughly reviewed, verified and revised for accuracy and originality. The authors, therefore take full responsibility for the accuracy and integrity of the manuscript.

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Table 1: Proximate compositions of the samples

Samples	Moisture (%)	Ash Content (%)	Crude Protein (%)	Crude Fibre (%)	Fat Content (%)	Carbohydrate By Difference (%)
WYD	23.54^{a}±0.36	0.80^{a}±0.01	11.66^{e}±0.12	0.18^{a}±0.00	8.55^{a}±0.50	55.27^{d}±0.97
OYD	26.15^{b}±0.48	1.32^{d}±0.12	9.77^{c}±0.13	1.04^{d}±0.04	13.57^{c}±0.82	48.15^{b}±1.09
WSD	26.25^{b}±0.02	0.85^{ab}±0.01	10.34^{d}±0.26	0.20^{a}±0.01	9.42^{a}±0.19	52.94^{c}±0.46
OSD	32.38^{d}±0.09	1.11^{c}±0.01	7.34^{a}±0.10	0.85^{c}±0.05	18.11^{d}±0.67	40.21^{a}±0.70
WOSD	27.83^{c}±0.05	0.95^{b}±0.05	8.11^{b}±0.03	0.33^{b}±0.04	10.92^{b}±0.33	51.86^{c}±0.36

Mean±SD in the same column with different superscripts are significantly different at 5% level with a > ab > b > c > d > e. Mean separation done by Duncan Multiple Range Test. WYD = 100% wheat yeast dough bread; OYD = 100% oat yeast dough bread; WSD = 100% wheat sourdough bread; OSD = 100% oat sourdough bread; WOSD = 50% wheat and 50% oat sourdough bread

Table 2: Mineral compositions of the samples

Sample	Mineral (ppm)							Na:K
	Na	K	Ca	Mg	Fe	P	Zn	
WYD	41.21^{a}±0.00	44.21^{a}±0.00	8.32^{a}±0.00	14.06^{b}±0.02	0.03^{b}±0.01	8.95^{a}±0.00	0.21^{d}±0.01	0.96^{b}±0.00
OYD	33.10^{d}±0.01	39.50^{c}±0.00	5.96^{e}±0.00	15.50^{a}±0.01	0.04^{a}±0.00	7.54^{c}±0.00	0.45^{a}±0.00	0.84^{d}±0.00
WSD	36.00^{c}±0.00	41.30^{b}±0.00	7.17^{c}±0.00	10.06^{d}±0.01	0.02^{d}±0.01	7.81^{b}±0.00	0.19^{d}±0.00	0.87^{c}±0.00
OSD	31.19^{e}±0.01	38.09^{e}±0.01	6.00^{d}±0.00	7.79^{e}±0.00	0.02^{e}±0.00	6.80^{d}±0.00	0.26^{c}±0.01	0.82^{e}±0.00
WOSD	37.18^{b}±0.00	38.20^{d}±0.00	7.92^{b}±0.00	10.68^{c}±0.02	0.02^{c}±0.00	6.56^{e}±0.02	0.36^{b}±0.01	0.97^{a}±0.00

Mean±SD in the same column with different superscripts are significantly different at 5% level with a > b > c > d > e. Mean separation done by Duncan Multiple Range Test. WYD = 100% wheat yeast dough bread; OYD = 100% oat yeast dough bread; WSD = 100% wheat sourdough bread; OSD = 100% oat sourdough bread; WOSD = 50% wheat and 50% oat sourdough bread

Table 3: Phytate contents and relative mineral bioavailability of the samples

Samples	Phytate (mg/g)	Phy/Zn	Phy/Fe	Phy/Ca
WYD	9.23^{d}±0.00	4.40^{c}±0.13	23.51^{d}±0.84	0.07^{d}±0.00
OYD	9.56^{c}±0.01	2.10^{d}±0.02	22.95^{d}±0.34	0.10^{b}±0.00
WSD	10.29^{b}±0.01	5.25^{a}±0.04	42.34^{b}±2.27	0.09^{c}±0.00
OSD	12.10^{a}±0.06	4.99^{b}±0.09	63.67^{a}±2.39	0.11^{a}±0.00
WOSD	8.15^{e}±0.08	2.23^{d}±0.08	28.43^{c}±0.49	0.06^{e}±0.00

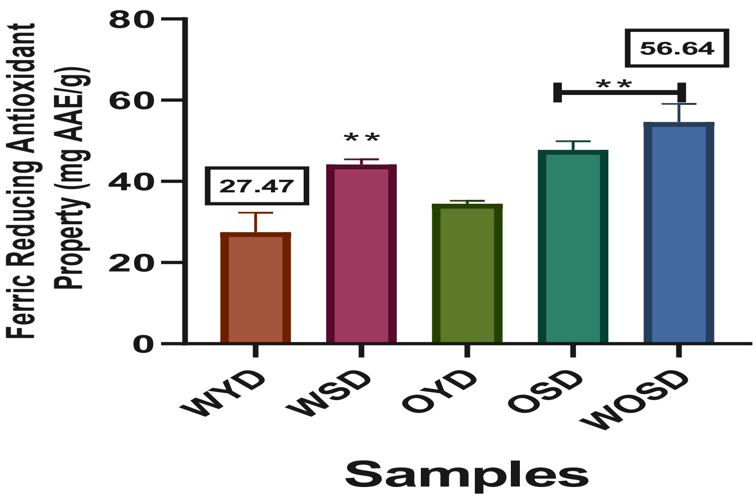
Mean±SD in the same column with different superscripts are significantly different at 5% level with a > b > c > d > e. Mean separation done by Duncan Multiple Range Test. WYD = 100% wheat yeast dough bread; OYD = 100% oat yeast dough bread; WSD = 100% wheat sourdough bread; OSD = 100% oat sourdough bread; WOSD = 50% wheat and 50% oat sourdough bread

Table 4: Sensory attributes of the samples

Samples	Colour	Appearance	Texture	Aroma	Taste	General Acceptability
WYD	8.80^{a}±0.42	8.60^{a}±0.70	8.32^{a}±1.03	8.40^{b}±0.70	8.30^{a}±0.67	8.90^{a}±0.32
OYD	6.80^{bc}±1.03	7.20^{ab}±1.14	7.40^{a}±1.35	7.30^{a}±0.95	8.50^{b}±0.53	8.50^{ab}±0.71
WSD	7.50^{ab}±1.35	7.10^{b}±1.52	7.50^{a}±1.27	7.50^{a}±1.43	7.60^{b}±0.52	8.00^{bc}±0.67
OSD	5.80^{cd}±1.93	6.40^{bc}±1.78	5.90^{b}±1.79	7.50^{a}±1.43	7.50^{b}±0.53	7.60^{c}±0.52
WOSD	5.20^{d}±2.35	5.40^{c}±2.22	5.50^{b}±2.01	6.00^{b}±1.41	8.20^{a}±0.42	8.10^{bc}±0.57

Mean±SD in the same column with different superscripts are significantly different at 5% level with a > ab > b > bc > c > cd > d. Mean separation done by Duncan Multiple Range Test

Figure 1: Activity of FRAP of the samples
($^{**}p < 0.05$)



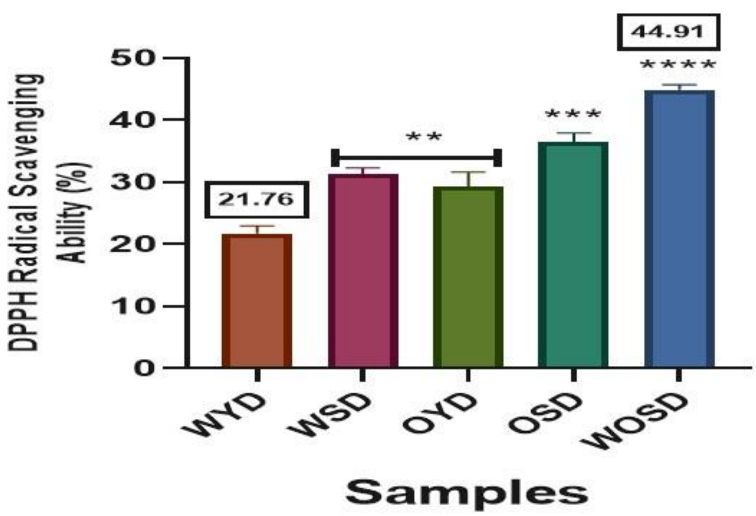


Figure 2: DPPH reduced scavenger ability of the samples
($^{**}p < 0.05$; $^{***}p < 0.01$); $^{****}p < 0.001$)

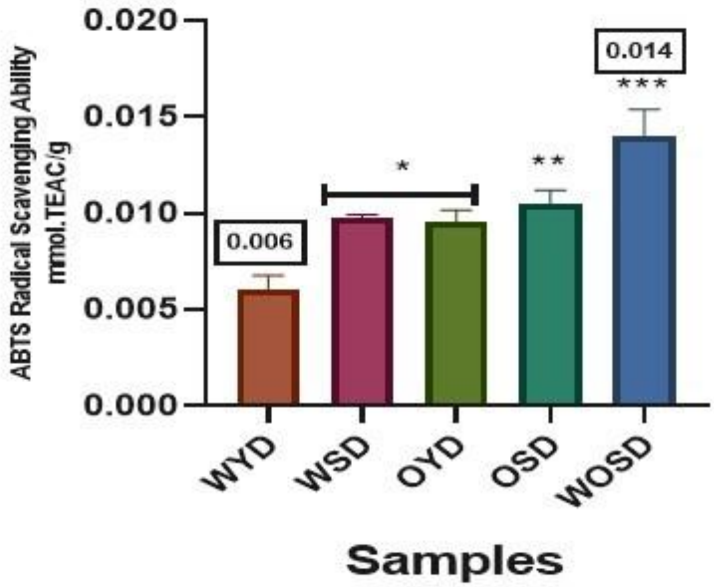


Figure 3: ABTS radical scavenging ability of the samples
($^{*}p > 0.05$; $^{**}p < 0.05$; $^{***}p < 0.01$)

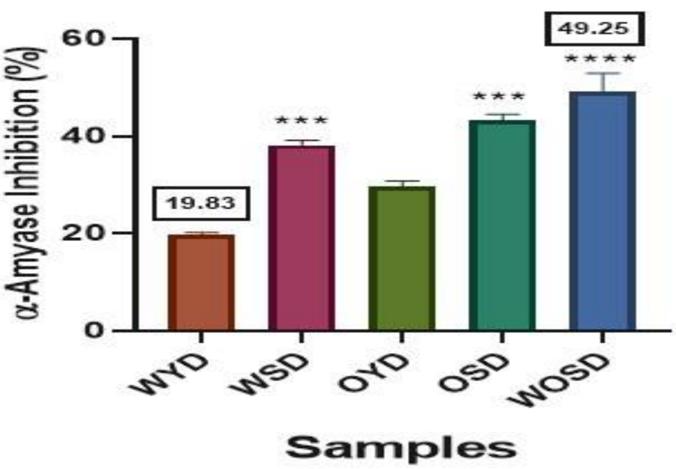


Figure 4: α-amylase inhibition of the samples
($^{***}p < 0.01$; $^{****}p < 0.05$)