Kwaghe International
Journal of Sciences and Technology

ISSN: 1595-7977
Index: Harvard, Boston, Sydney University, Dimensions, Lens, ResearchGet Scilit, Semantic, Google Scholar, Base etc

https://doi.org/10.58578/KIJST.v3i1.9397

Quality Characteristics of Wheat Flour and Fermented Watermelon Seed Flour Blends

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Article Info:

Submitted:	Revised:	Accepted:	Published:
Feb 14, 2025	Mar 14, 2026	Mar 26, 2026	Mar 31, 2026

Abstract

Bread quality can be enhanced through the incorporation of nutrient-dense alternative flours, yet evidence on the use of fermented watermelon seed flour remains limited. This study evaluated the quality characteristics of bread produced from wheat flour partially substituted with fermented watermelon seed flour (FWSF). Watermelon seeds were fermented with *Saccharomyces cerevisiae* for 72 hours, oven-dried at 40°C, milled, and sieved to 0.25 mm, after which the resulting flour was blended with wheat flour at substitution levels of 5%, 10%, 15%, 20%, and 25%. The flour blends were analyzed for proximate composition, phytochemical content, functional properties, and pasting characteristics, while the breads were evaluated for chemical composition, antioxidant activity, protein and starch digestibility, color, physical properties, and sensory attributes. The results showed that FWSF incorporation improved the proximate composition, phytochemical content, functional properties, and pasting characteristics of the flour blends. Antioxidant activity also increased significantly, with FRAP values rising from 0.13 mol/100 g in the control bread to 0.24–0.33 mol/100 g in composite breads, and DPPH values increasing from 21.74 to 36.71 mg AAE/100 g at 25% substitution. Baking loss decreased from 25% in the control to 16.65% in breads containing FWSF, while physical properties remained largely unaffected. Although sensory scores declined progressively with higher substitution levels, the 5% substitution sample recorded the highest taste rating among the composite breads and did not differ significantly (P > 0.05) from the control in overall sensory attributes. General acceptability ranged from 5.45 to 7.25 for composite breads compared with 7.50 for the control. In addition, L*, a*, and b* color values increased with FWSF inclusion, while the browning index decreased slightly. Overall, partial substitution of wheat flour with fermented watermelon seed flour enhanced the nutritional, functional, and antioxidant quality of bread without adversely affecting its physical characteristics, with 5% substitution identified as the most appropriate level based on improved quality attributes and consumer acceptability.

Keywords: Bread Quality; Fermented Watermelon Seed Flour; *Saccharomyces cerevisiae*; Antioxidant Activity; Sensory Acceptability

INTRODUCTION

Watermelon (*Citrullus lanatus*) is one of the most widely cultivated fruits globally, belonging to the Cucurbitaceae family (Arpa *et al*., 2020). With an estimated annual production of approximately 118 million metric tons (FAO, 2019), the fruit is primarily consumed fresh or processed into juice. However, significant quantities of seeds and rind are generated as by-products and are often discarded as waste. Among these, watermelon seeds are particularly underutilized despite their remarkable nutritional potential, which compares favorably with soybean, sunflower, and groundnut (Gabriel *et al*., 2018). Scientific studies have demonstrated that watermelon seeds are rich in macronutrients and bioactive compounds (Arpa *et al*., 2020; Janish and Mishra, 2023; Ana *et al*., 2021). The seeds reportedly contain approximately 35% protein, 48% fat, 15% carbohydrates, and substantial dietary fiber, along with B-vitamins and essential minerals such as magnesium, potassium, phosphorus, sodium, iron, zinc, manganese, and copper (Gabriel *et al*., 2017). In addition, phytochemicals including saponins, alkaloids, phenols, flavonoids, and tannins contribute to their documented antimicrobial, antimalarial, anti-inflammatory, anticancer, anti-infective (Adesanya *et al*., 2011), and antioxidant properties (Tabana *et al*., 2011). Beyond nutritional benefits, watermelon seeds have economic value; they are processed into flour, snacks, sauces (Asfaw, 2022), edible oils, and cosmetic products (Jensen *et al*., 2011), with recognized industrial and ethnomedicinal applications (Nzikou *et al.*, 2010). Nevertheless, effective processing methods are necessary to enhance shelf life, improve quality, and develop value-added products. Fermentation is one such innovative processing technique capable of improving the nutritional, functional, and sensory attributes of food materials. As one of the oldest food biotechnologies, fermentation enhances microbial stability, safety, digestibility, and palatability while preserving nutritional value (Shahida *et al.*, 2023; Mariod and Fatima, 2022; Şanlier *et al.*, 2019). Growing interest in natural fermentation processes has encouraged exploration of microbial diversity and its relationship with product quality (Şanlier *et al.*, 2019).

Yeasts, particularly *Saccharomyces cerevisiae*, play a crucial role in food fermentation due to their metabolic activities, including ethanol and carbon dioxide production, enzyme secretion, and nutritional enrichment (Fleet, 2007; Maicas, 2020). Seed fermentation involves the biochemical transformation of proteins, carbohydrates, and lipids by microorganisms such as bacteria, yeasts, and molds, leading to improved nutritional, sensory, and functional characteristics (Achi, 2005; Nout and Sarkar, 1999). Submerged fermentation methods are commonly employed in seed processing (Achi, 2005; Fleet, 2007), offering advantages such as preservation, flavor enhancement, improved digestibility, and nutritional upgrading (Fleet, 2007; Sawant *et al.*, 2025). Despite the recognized benefits of fermentation, limited information exists on the fermentation of watermelon seeds using *Saccharomyces cerevisiae* and its application in food systems (Maqbool *et al.*, 2023). *S. cerevisiae*, widely known as baker's yeast, has been extensively studied for its ability to produce enzymes that degrade antinutritional factors such as phytates and tannins, thereby enhancing mineral bioavailability and flour quality (Mukherjee *et al.*, 2016). Fermenting watermelon seed flour with *S. cerevisiae* could therefore unlock its nutritional and functional potential for bakery applications. The problem addressed in this study arises from the environmental burden caused by discarded watermelon seeds and their limited integration into value addition chains. Although nutrient-dense, watermelon seed flour remains insufficiently characterized for bread production. Wheat bread, a global staple, is relatively low in phytochemicals and certain essential minerals; incorporation of fermented watermelon seed flour may enhance its nutritional and functional quality. However, information on the bread-making performance and qualitative attributes of fermented watermelon seed flour remains scarce.

The broad objective of this study was to produce and evaluate the quality of bread incorporated with fermented watermelon seed flour. Specifically, the study aimed to: (i) produce fermented watermelon seed flour and develop bread supplemented with the flour; (ii) evaluate the chemical composition, functional, and pasting properties of fermented watermelon seed flour, wheat flour, and their blends; (iii) assess the physical, sensory, color, and morphological properties of breads incorporated with fermented watermelon seed flour; and (iv) determine the starch digestibility of the developed bread samples. Through these objectives, the study seeks to promote waste valorization, enhance food quality, and support sustainable food innovation.

MATERIALS AND METHODS

This study employed an experimental design to evaluate the quality of bread produced from wheat flour partially substituted with fermented watermelon seed flour (FWSF). Watermelon (*Citrullus lanatus*) fruits, wheat flour, yeast, sugar, butter, and salt were procured from Wukari, Taraba State, Nigeria. All chemicals used were of analytical grade.

Preparation of Flours and Blends

Commercial wheat flour was sieved (0.25 mm) and packaged prior to use. Fermented watermelon seed flour was prepared following Adegunloye *et al.* (2020) with slight modification. Watermelon seeds were manually extracted, washed, and soaked (1:2 w/v). Fermentation was initiated by inoculating with 1 g *Saccharomyces cerevisiae* and allowed to proceed for 72 h at 30°C. The fermented seeds were oven-dried at 40°C to constant weight, milled, sieved (0.25 mm), packaged, and stored at 4°C. Unfermented seed flour served as control. Flour blends were formulated by substituting wheat flour with FWSF at 5%, 10%, 15%, 20%, and 25% levels, with 100% wheat flour as the control.

Bread Production

Bread was produced using the straight dough method (Nwosu *et al.*, 2014). Each formulation contained 100 g flour blend, 10 g sugar, 3 g yeast, 1.5 g salt, 2 g margarine, and 55 mL water. The dough was mixed, proofed (30 min), kneaded, molded, proofed again (45 min at 30°C), and baked at 250°C. After cooling (10 min), loaves were packaged in polyethylene bags. Bread from 100% wheat flour served as the control.

Analytical Determinations

Proximate Composition: Moisture, ash, crude protein (Kjeldahl), fat (Soxhlet), fiber, and carbohydrate (by difference) were determined using standard AOAC (2006; 2020) methods for flours and breads.

Mineral Analysis: Calcium, magnesium, iron, zinc (atomic absorption spectrophotometry), sodium and potassium (flame photometry), and phosphorus (colorimetry) were quantified after acid digestion.

Functional Properties of Flours: Bulk density, water and oil absorption capacities, swelling capacity, foaming capacity and stability, emulsification capacity, dispersibility, and least gelation concentration were evaluated using established methods.

Pasting Properties: Determined using a Rapid Visco Analyzer to obtain peak, trough, breakdown, final, and setback viscosities, as well as pasting temperature and time.

Phytochemical Analysis: Alkaloids, total phenolics (Folin Ciocalteu; expressed as GAE), flavonoids (quercetin equivalents), phytate, oxalate, and tannin contents were quantified using standard spectrophotometric and titrimetric methods.

Antioxidant Activity: DPPH radical scavenging activity and ferric reducing antioxidant power (FRAP) assays were conducted to evaluate in vitro antioxidant capacity.

Starch Digestibility: In vitro starch hydrolysis was assessed using enzymatic digestion (pepsin, α-amylase, amyloglucosidase), and hydrolysis kinetics were modeled to determine digestion rate constants and equilibrium hydrolysis.

Morphological and Color Analysis: Bread crumb microstructure was examined using scanning electron microscopy (SEM). Color parameters (L*, a*, b*), browning index, and whiteness index were measured using a Minolta Chroma Meter.

Physical Properties: Loaf weight, loaf volume (seed displacement method), specific volume, baking expansion, and baking loss were determined using standard procedures.

Sensory Evaluation: Twenty trained panelists evaluated taste, aroma, texture, color, and overall acceptability using a nine-point hedonic scale under controlled laboratory conditions.

Statistical Analysis

All experiments were conducted in triplicate using a completely randomized design. Data were analyzed by one-way ANOVA using GraphPad Instat (version 3.06), and means were separated using Duncan's New Multiple Range Test at $p < 0.05$. The methodology comprehensively assessed the chemical, functional, nutritional, physical, antioxidant, and sensory properties of breads produced from wheat fermented watermelon seed flour blends.

RESULTS AND DISCUSSION

Proximal Composition of Flour blends

The proximate composition of the flour mixes is presented in Table 1. The protein, crude fat, fiber, ash, moisture, and carbohydrate contents of wheat flour was 10.13%, 1.36%, 0.62%, 2.66%, 5.02%, and 80.23%, respectively, while the corresponding values for fermented watermelon seed flour (FWSF) were 19.0%, 16.0%, 3.5%, 3.0%, 8.2%, and 50.30%. The crude protein levels of the flour blends rose from 10.13% to 15.88% as a result of the elevated protein content in the FWSF. Research indicates that watermelon seed (Peter-Ikechukwu *et al.,* 2020) possesses a high protein level, rendering it an effective substitute for wheat flour.

The crude fat content of the flour samples ranged from 1.36% to 16%, with the FWSF displaying the highest fat concentration at 16%. The fat content of the blends increased with the incorporation of FWSF because of its high fat concentration. Fats function as flavor enhancers and improve the sensory qualities of baked products. Fat-rich diets predispose individuals to numerous health issues, including obesity and coronary heart disease (Ojinnaka and Nnorom, 2015). Therefore, these formulated flour blends would be advantageous in the production of baked goods for those with such medical conditions. The low-fat level is beneficial as it prolongs the shelf life of items, such as breads, by reducing the risk of rancidity (Onoja *et al.*, 2014).

The crude fiber content of the flour blends varied from 0.62% to 0.98%, with the FWSF contributing to the rise. Crude fiber aids in reducing blood sugar levels and decreases glucose absorption (Hamza et al., 2014). Crude fiber enhances satiety and hence aids in weight management (Hamza et al., 2014). The ash content of food quantifies the entire mineral composition included in the diet (Ibeabuchi et al., 2017). The ash level of the flour blends rose from 2.66% to 3.89% as a result of the elevated ash content in the FWSF. Certain elements constituting the ash content of diet contribute to the metabolism of other organic compounds such as fat and carbohydrate (Ojinnaka and Nnorom, 2015).

The moisture level of the flour blends varied between 5.02% and 5.49%. The moisture levels were diminished owing to the low moisture content of both wheat flour and FWSF. Elevated moisture levels promote the proliferation of contaminating bacteria, whose growth and activities lead to food spoiling (Okafor and Ugwu, 2014). The carbohydrate content of the flour blends diminished from 80.23% to 71.59% owing to the reduced moisture content of the FWSF compared to wheat flour. The blends would be beneficial for formulations aimed at reducing carbohydrate intake (Adebayo *et al.,* 2024).

Table 1. Proximate Composition of Flour Blends (%) of Wheat Flour and fermented water melon seed flour Blends

Blends (WF:FWSF)	Crude Protein	Crude Fat	Crude Fibre	Ash	Moisture	Carbohydrates
100:0	10.13^{f}±0.01	1.36^{f}±0.03	0.62^{e}±0.01	2.66^{f}±0.02	5.02^{f}±0.02	80.23^{a}±0.09
0:100	19.0±0.08	16.0±0.02	1.52±0.08	4.82±0.07	8.20±0.03	54.30±0.05
95:5	12.34^{e}±0.01	1.78^{e}±0.02	0.85^{d}±0.02	3.37^{e}±0.02	5.96^{a}±0.01	75.52^{b}±0.09
90:10	13.08^{d}±o.o2	1.82^{d}±0.01	0.89^{c}±0.01	3.57^{d}±0.01	5.66^{b}±0.01	74.91^{c}±0.06
85:15	13.80^{c}±0.02	1.86^{c}±0.00	0.93^{b}±0.00	3.78^{c}±0.01	5.35^{e}±0.01	74.29^{d}±0.04
80:20	14.80^{b}±0.09	2.03^{b}±0.01	0.96^{ab}±0.01	3.84^{b}±0.01	5.42^{d}±0.01	72.95^{e}±0.04
75:25	15.88^{a}±0.01	2.19^{a}±0.01	0.98^{a}±0.01	3.89^{a}±0.00	5.49^{c}±0.01	71.59^{f}±0.03

Values are the mean ± standard deviation of three replicates. Means within a column that lack a common superscript are significantly different ($p<0.05$). WF signifies wheat flour, and FWSF denotes fermented watermelon seed flour.

Phytochemicals Constitution of Flour Blends

The phytochemical composition of wheat flour and fermented watermelon seed flour (FWSF) blends is shown in Table 2. The total phenols, flavonoids, alkaloids, oxalates, phytates and tannains contents of wheat flour were 28.15, 2.85, 1.29, 4.04, 6.73 and 7.43 mg/100g, respectively. The total phenols, flavonoids, alkaloids, oxalates, phytates and tannains contents of fermented watermelon seed flour were 67.35, 18.55, 14.26, 17.23, 12.33 and 16.41mg/100g, respectively.

All the phytochemicals assessed increased with the FWSF probably due to additive effect for the FWSF had higher amounts of them than wheat flour. Total phenolic samples varied from 28.15 to 56.37 mg/100 g with the 100% wheat flour (control) having the lowest value (28.15 mg/100 g) and the blends containing 25% FWSF have the highest value (56.37 mg/100 g). The phenol contents increased with the amount of FWSF in the blend. Probably due to additive effect since FWSF contained higher level of phenol than wheat flour (Vu et al., 2017).

The flavonoids contents of the wheat flour bread were 2.85mg/100g and significantly increased from 4.63-8.47 for the blends due the higher content of FWSF. Flavonoids are group of natural substances with variable phenolic structures, which have i-carcinogenic properties (Vu et al., 2017) They also displayed antioxidant activities, free radical scavenging properties, heart disease prevention and exhibit potentials for anti-immunodeficiency virus (Vu et al., 2017). The findings in this study were lower than 42.94 - 83.11 mg CE/100 g documented for breads from wheat-plantain composite flours enriched with velvet beans flours by Adebayo and Ibrahim (2024). However, it has been reported that low flavonoids contents as in this study could offer anti-inflammatory, anti-cancer and anti- hypertensive potentials (Arukwe et al., 2012).

The alkaloids contents of the breads increased from 1.29 to 6.56 mg/100 g with the 100% wheat having the lowest value (1.29mg/100 g) while the highest value (6.56mg/100 g) was obtained in the bread containing 30 % FWSF. Alkaloids have antibiotics, anti-cancer, anti- arrhythmic, and sedative properties (Akubor and Nwawi, 2019). However, alkaloids at high levels in foods cause cellular weakening, inhibits enzymes and also affect the r-RNA formation (Akubor and Nwawi, 2019).

The oxalates content of the wheat flour was 4.04 mg/100 g. The inclusion of the fermented watermelon seed flour increased the oxalates content from 7.46 mg/100 g to 12.38 mg/100 g. Oxalates when present in large quantity in foods (above 50 mg/100 g) chelate some metal ions and render them insoluble and hence, the metal ions cannot be absorbed in the intestine (Akubor and Nwawi, 2019).

The phytate contents of the flour blends increased from 8.23 mg/100 g in to 14.56 mg/100 g . Akubor and Nwawi (2019) had earlier reported that the interest in phytases is in their use for reducing phytic acid in animal feeds. Low levels of phytates in foods are of significance because they are considered to have antioxidant property due to their capacity to chelate iron and prevent both iron reactivity and absorption (Coulibay et al., 2011). However, at levels above 1.4%, phytates can bind minerals in the digestive tract and make them less available to the body (Akubor and Nwawi, 2019). Phytate is an inhibitor of mineral absorption because the negative charges of the phosphate groups form insoluble salts on interaction with di- and tri-valent cations such as Ca, Fe, Mg, and Zn (Akubor and Nwawi, 2019).

Table 2. Phytochemical content (mg/100g) wheat flour and watermelon seed flour blends

Blends WF:FWSF	Total phenols	Flavonoids	Alkaloids	Oxalates	Phytates	Tannins
100:0	$28.15^{f}\pm0.02$	$2.85^{f}\pm0.02$	$1.29^{f}\pm0.01$	$4.04^{f}\pm0.02$	$6.73^{f}\pm0.15$	$7.43^{f}\pm0.02$
0:100	67.35 ± 0.06	18.55 ± 0.03	14.26 ± 0.09	17.23 ± 0.04	12.33 ± 0.09	16.41 ± 0.07
95:5	$35.24^{e}\pm0.02$	$4.63^{e}\pm0.01$	$2.32^{e}\pm0.01$	$7.46^{e}\pm0.03$	$8.23^{e}\pm0.01$	$9.23^{e}\pm0.02$
90:10	$38.29^{d}\pm0.03$	$5.50^{d}\pm0.01$	$3.51^{d}\pm0.02$	$8.37^{d}\pm0.03$	$9.98^{d}\pm0.01$	$10.69^{d}\pm0.03$
85:15	$41.34^{c}\pm0.03$	$6.36^{c}\pm0.01$	$4.69^{c}\pm0.01$	$9.29^{c}\pm0.02$	$11.74^{c}\pm0.01$	$12.15^{c}\pm0.03$
80:20	$48.86^{b}\pm0.02$	$7.42^{b}\pm0.01$	$5.56^{b}\pm0.02$	$10.84^{b}\pm0.02$	$13.15^{b}\pm0.01$	$14.57^{b}\pm0.02$
75:25	$56.37^{a}\pm0.01$	$8.47^{a}\pm0.01$	$6.56^{a}\pm0.02$	$12.38^{a}\pm0.02$	$14.56^{a}\pm0.02$	$16.92^{a}\pm0.02$

Values are mean ± standard deviation of three replicates. Values inside a column that do not share the same superscript are significantly different ($p<0.05$). WF denotes wheat flour, while FWSF = fermented watermelon seed flour.

Functional Properties of Flour Blends

The functional properties of the wheat and fermented watermelon seed flour (FWSF) blends are shown in Table 3. In comparison to the FWSF, wheat flour performed better in terms of dispensability, foaming capacity, and emulsifying capacity, but it was worse in terms of bulk density, water absorption capacity, oil absorption capacity, and swelling capacity. Between 40 and 44.50 g/cm3 were the bulk densities. Findings demonstrated that flour mixes with a higher percentage of water melon seed flour had higher bulk density. The bulk density of the blends was raised by the addition of FWSF.

Bulk density is important in determining the packaging requirement, material handling, and application in processing in food industry (Chukwu et al., 2018). Low bulk density is a desirable factor in food formulation especially food with less retrogradation tendency (Peter-Ikechukwu et al., 2020). However, high bulk density is a good physical attribute when determining the mixing quality of particular flour (Chukwu et al., 2018). Peter-Ikechukwu et al. (2020) reported low bulk density of 0 .72 g/ml to 0.85 g/ml for composite flour produced with date fruit pulp, toasted watermelon seed and wheat.

Inclusion of watermelon seed flour decreased the dispensability from 72.00% for the wheat flour to 66.00%. Dispensability represents the ease of reconstitution of starch samples and high dispensability value indicates better reconstitution in water with less ability of lump formation during preparation (Banti et al., 2020). The flours would reconstitute easily in water and would not form lump during food preparation. The WAC of wheat flour was 150% while that of FWSF was 170% and increased to 231% for the blend containing 30% FWSF. The crude protein and fiber contents were responsible for the higher WAC of the FWSF. The high WAC of flours has been be ascribed to the high amounts of hydrophilic constituents particularly, proteins, carbohydrates and fiber it contains (Onoja et al., 2014). Onoja et al. (2014) also reported that WAC mainly depends on the amount and nature of the hydrophilic constituents present in the samples. The low-fat contents of the blends may have enhanced their WAC. Fat has been shown to decrease the hydration capacity of flour used in the formulation of the blends and the control (Onoja et al., 2014). It has been reported that WAC is critical in bulking and consistency of products as well as in baking processes (Akubor et al., 2013). Many researchers have reported that water also plays a significant role in the major changes that take place during the baking process, which include starch gelatinization, protein denaturation, yeast and enzyme inactivation, as well as flavor and color (Onoja et al., 2014).

The oil absorption capacity (OAC) of wheat flour was 120%, but that of the FWSF was 129%, increasing to 150% for the blend containing 30% FWSF. Akubor *et al.* (2013) ascribed OAC mostly to the physical trapping of oils, illustrating the rate at which proteins interact with fat in food compositions. OAC is deemed significant in baked goods. This investigation demonstrated that the mixes possess potential applicability in baking items. Fat serves as a flavor enhancer and enhances the mouthfeel of foods (Akubor *et al.,* 2013). It has been demonstrated to enhance the leavening capacity of baking powder in the dough and to improve the texture of baked goods, especially bread (Onoja *et al.,* 2014).

The foam capacity of the flour mixes varied from 3.0% to 4.0%. The reduction in the foaming power of the flour blends resulted from the increased proportion of fermented watermelon seed flour, which diminished the gluten content of the wheat flour. Gluten contributes to the excellent foaming characteristics of wheat flour. Optimal foam stability is a sought-after characteristic for flours used in the manufacture of various baked products, including cookies and muffins. It also serves as functional agents in certain food compositions (Chukwu *et al.,* 2018). Akubor *et al.* (2013) indicated that foaming capacity is influenced by protein content, protein solubility, swelling power, and additional parameters. Foams enhance the texture, consistency, and appearance of food products (Onoja *et al.*, 2014). Peter-Ikechukwu *et al.* (2020) documented that the foaming capacity of several blends of wheat flour, date palm fruit pulp, and toasted watermelon seed varied from 9.48% to 11.95%. The discrepancies in the results may stem from various factors, including protein structure and solubility (Onoja *et al.,* 2014).

The incorporation of FWSF increased the swelling capacity (SC) from140% in wheat flour to a range of 150 -200% in the blends. The high swelling capacity for the blends could be due to higher starch content than the other samples (Ubor et al., 2022). Onoja et al. (2014) reported a lower swelling power of 0.036 ml for bread produced from blends of Orarudi (Vigna sp) and wheat flour. Swelling capacity shows the cumulative effects of starch quality, specifically amylose/amylopectin ratio as reflected by the volume of gel produced when flour is heated with an excess of water (Ubor et al., 2022).

The emulsion capacity of the flour blends ranged from 10.0 % to 21.0. The high emulsion capacities of the blend were due to their protein contents over that of wheat flour. High emulsification is an indication that the flour sample could be a good emulsifier in various foods (Peter-Ikechukwu et al., 2020). The significant increase in the emulsifying capacity of the blends could be attributed to protein being surface-active agents and can form and stabilize the emulsion by creating electrostatic interaction on oil droplets surface (Peter-Ikechukwu et al., 2020). In accordance with Peter-Ikechukwu et al. (2020), the values showed that blends possess good emulsifying property that could serve as a vital source for emulsification (Oloyede et al., 2015; Chukwu et al., 2018).

Table 3. Functional properties of flour blends from wheat flour and fermented watermelon seed flour

WF:FWSF 100:0	Bulk density (g/ml)	Dispersibility (%)	WAC (%)	OAC (%)	Foaming capacity (%)	Swelling capacity (%)	Emulsifying capacity (%)
100:0	$0.41^{b}\pm0.10$	$70.00^{a}\pm0.50$	$1.70^{a}\pm0.08$	$1.29^{ab}\pm0.43$	$3.00^{a}\pm0.67$	$1.70^{a}\pm0.20$	$1.00^{b}\pm0.07$
95:5	$0.41^{ab}\pm0.71$	$71.00^{ab}\pm1.41$	$1.00^{a}\pm0.04$	$1.00^{b}\pm0.00$	$4.00^{a}\pm0.00$	$2.00^{a}\pm0.00$	$2.10^{a}\pm0.00$
90:10	$0.40^{b}\pm0.71$	$67.00^{c}\pm1.41$	$1.50^{a}\pm0.14$	$1.00^{b}\pm0.00$	$3.50^{a}\pm0.00$	$2.00^{a}\pm0.00$	$2.00^{a}\pm0.00$
85:15	$0.41^{b}\pm0.71$	$68.00^{bc}\pm1.41$	$2.00^{a}\pm1.41$	$1.40^{a}\pm1.41$	$3.00^{a}\pm0.00$	$1.50^{a}\pm0.00$	$1.50^{c}\pm0.00$
80:20	$0.41^{ab}\pm0.71$	$69.00^{abc}\pm1.41$	$2.10^{a}\pm1.41$	$1.45^{ab}\pm1.41$	$3.00^{a}\pm0.00$	$1.50^{a}\pm0.00$	$1.00^{b}\pm0.00$
75:25	$0.44^{a}\pm0.71$	$66.00^{c}\pm1.41$	$2.31^{a}\pm7.07$	$1.50^{ab}\pm0.14$	$3.00^{a}\pm0.00$	$1.50^{a}\pm0.00$	$1.50^{b}\pm0.00$

WF= Wheat flour, FWSF= fermented watermelon seed flour, WAC= water absorption capacity, OAC= oil absorption capacity.

Pasting Properties of Composite Flours

Peak viscosity increased from 175.65 RVU (100% WF) to 288.67 RVU at 15% FWSF before declining slightly at higher substitution levels. Final viscosity rose steadily (212.72–274.38 RVU), indicating improved gel-forming capacity. Setback values increased with FWSF inclusion, suggesting greater retrogradation tendency at higher levels. Breakdown viscosity decreased, implying improved paste stability under heat and shear. Peak time and pasting temperature reduced with increasing FWSF, indicating faster cooking and lower gelatinization temperatures in composite flour.

Table 4. Pasting Properties of Wheat Flour and fermented watermelon seed flour blends

Blends (WF:FWS)	Peak Viscosity (RVU)	Final viscosity (RVU)	Setback (RVU)	Breakdown (RVU)	Pasting time (min)	Pasting temperature (^{o}C)	Trough (RVU)
100:0	$175.65^{f}\pm0.02$	$212.72^{f}\pm0.01$	$16.35^{f}\pm0.02$	$23.70^{a}\pm0.02$	$9.17^{a}\pm0.01$	$83.36^{a}\pm0.01$	$159.32^{f}\pm0.02$
95:5	$216.42^{e}\pm0.02$	$251.41^{e}\pm0.01$	$26.12^{e}\pm0.01$	$22.76^{b}\pm0.01$	$6.55^{b}\pm0.00$	$78.75^{b}\pm0.00$	$190.31^{e}\pm0.02$
90:10	$227.55^{d}\pm0.02$	$260.04^{d}\pm0.01$	$29.65^{d}\pm0.01$	$22.20^{c}\pm0.01$	$6.23^{c}\pm0.00$	$77.46^{c}\pm0.01$	$197.92^{d}\pm0.02$
85:15	$288.67^{a}\pm0.01$	$268.66^{c}\pm0.00$	$33.17^{c}\pm0.01$	$21.63^{d}\pm0.01$	$6.00^{d}\pm0.00$	$76.16^{d}\pm0.01$	$205.52^{c}\pm0.02$
80:20	$241.42^{c}\pm0.01$	$271.41^{b}\pm0.00$	$35.57^{b}\pm0.01$	$21.21^{e}\pm0.01$	$5.18^{f}\pm0.00$	$75.16^{e}\pm0.01$	$205.86^{b}\pm0.02$
75:25	$244.16^{b}\pm0.02$	$274.38^{a}\pm0.32$	$37.98^{a}\pm0.01$	$20.76^{f}\pm0.01$	$5.62^{e}\pm0.00$	$74.15^{f}\pm0.00$	$206.21^{a}\pm0.01$

Values are mean ± SD of three replicates. Means within a column not followed by the same superscript are significantly different ($P \leq 0.05$).WF= wheat flour, FWSF = fermented watermelon seed flour, RVU= rapid viscos unit

Scanning Electron Microscopy of bread

The scanning electron microscopy images of the bread produced from wheat and fermented watermelon flour are shown in Plate 1. The SEM was utilized to examine the detailed microstructure of the baked breads and reveals differences in lipid properties that influence the bread's microstructure. It is probable that variations in the fine structure are significantly associated with the textural character of the bread. Fewer cavities were observed in all the bread samples. However, alterations in the bread's microstructure were observed depending on the amount of watermelon seed incorporated. Regarding the fine structure surface, a smoother surface was observed in comparison to bread with butter or watermelon seed bread. This may be because bread without watermelon seeds possesses a favorable texture. Moreover, the microstructure result consists with the results of bread properties.

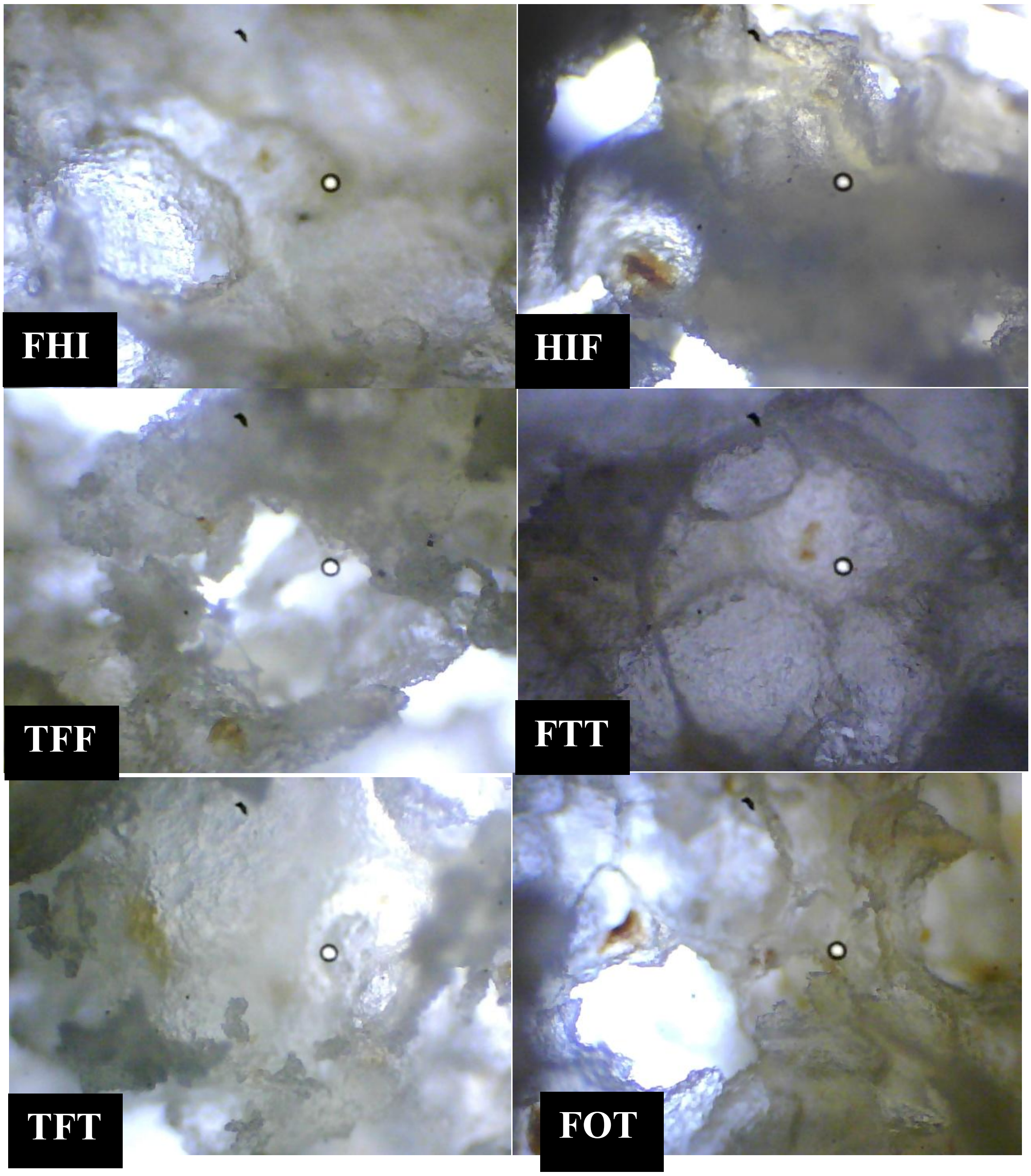

Plate 1: Scanning electron microscopy of breads, FHI = 100% wheat flour bread, HIF = 5% watermelon seed flour and 95% wheat flour bread. TTF = 10% watermelon seed flour and 90% wheat flour bread, FTT = 15% watermelon seed flour and 85% wheat flour bread, TFT = 20% watermelon seed flour and 80% wheat flour bread, FOT = 25% watermelon seed flour and 75% wheat flour bread.

CONCLUSION

i. It is concluded that incorporation of fermented watermelon seed flour into wheat flour improved the chemical composition, functional and pasting properties of the blends. Chemical composition, antioxidant activity, color, physical and sensory properties of the breads from the blends.

ii. It is also concluded that supplementing wheat flour with 5% fermented watermelon seed flour did not adversely affect the sensory properties of the bread from the blends.

iii. The improved antioxidant activities and phytochemical content suggest potential health benefits, including enhanced protection against oxidative stress and inflammation. With its enhanced properties and potential health benefits, fermented watermelon seed flour presents a promising ingredient for the development of nutritious and appealing food products.

iv. Overall, this study underscores the potential of fermentation as a valuable tool in enhancing the nutritional and functional qualities of food ingredients, paving the way for innovative applications in the food industry. By leveraging the benefits of fermentation, food manufacturers can create sustainable, nutritious, and appealing food products that cater to the growing demand for health-promoting foods.

Recommendations

Based on the study, the following are recommended that:

i. wheat flour supplemented with 5% fermented watermelon seed flour should be used for production of bread.

ii. further studies should investigate the effects of different fermentation methods and microorganism strains on the nutritional and techno-functional properties of watermelon seed flour and the quality of bread supplemented with the flours.

iii. value-added products such as snacks, baked goods, and beverages should be encouraged using fermented watermelon seed flour.

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