Evaluation of Nutritional Quality of Wheat Flatbread Enriched with "Aidan" Fruit (*Tetrapleura tetraptera*) and Soybeans (*Glycine max*)

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ABSTRACT

Background: *Flatbreads are the most conventional bread product utilized everywhere in the world. The nutritional quality popularized by consumers calls for enhancement as functional food.*

Objective: *This study evaluated the nutritional profile of wheat flatbread enhanced with Aidan fruit pulp and 10% soybeans flour.*

Methodology: *Functional, pasting, proximate, microbial and sensory properties of wheat flatbread enhanced with soybeans and Aidan fruit pulp flours were evaluated using experimental methods.*

Results: *From the study, Aidan fruit pulp increased with 10% soybeans flour inclusion; bulk density, water holding capacity, and oil absorption capability increased from 0.75 g/cm^3 to 0.79 g/cm^3, 239.45% to 258.57%, and 129.36% to 152.45%, respectively. Peak viscosity, trough viscosity, breakdown viscosity, setback viscosity and final viscosity decreased from 1368 cP to 1190 cP, 721 cP to 635 cP, 647 cP to 553 cP, 838 cP to 743 cP and, 1559 cP to 1378 cP, respectively. There was a significant increase in the proximate content of wheat flatbread, which includes total ash (3.54% to 6.61%), crude fat (8.36% to 12.85%), crude fiber (1.40% to 2.30%), and crude protein (21.87% to 28.84%). At ambient, refrigeration and frozen temperature, the microbial growth increased from 2.0 CFU/g to 64.5 CFU/g, 1.0 CFU/g to 13.5 CFU/g and 0.5 CFU/g to 7.5 CFU/g respectively. The highest rating for color, taste, aroma, appearance, mouthfeel and overall acceptability is 7.56, 7.68, 7.56, 7.60, 7.62 and 7.52 respectively.*

Conclusion: *Enrichment of wheat flour with Aidan fruit pulp and 10% soybean flour improved the nutritional and functional quality of flatbread.*

Keywords: Aidan fruit, enhancement, soybeans, wheat, flatbread, nutrition

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INTRODUCTION

Increasing consumer awareness of health and nutrition has significantly contributed to the growing demand for nutrient-dense foods. According to [1], flatbreads are a rich source of calories and nutrients. To enhance the nutritional content of flatbreads into functional foods that meet consumers' dietary needs, several plant-based ingredients are added as fortifying agents. A well-known culinary herb, Aidan fruit (*Tetrapleura tetraptera*), commonly known as *Aridan*, *Uhio*, and *Daddawa-baki* in Yoruba, Igbo, and Hausa, respectively, is rich in phytochemicals like flavonoids, saponins, and tannins, as well as vitamins and antioxidants [2]. Historically, it is used in African herbal medicine for treating various conditions like inflammation and diabetes [2]. Soybeans (*Glycine max*), one of the most widely produced food crops globally, have a high seed content, containing abundant protein, fiber, essential vitamins, lipids, and healthy promoting antioxidants. They also contain dose-dependent, significant analgesic effects against thermally and chemically induced pain during childbearing [3].

Flatbreads are the most common type of bread product, used worldwide [4]. They are made from ingredients such as wheat flour, salt, water, and yeast. However, wheat flour, a key ingredient in flatbread, loses many nutrients during processing. Additionally, gluten, the main component of wheat required for baking, can cause adverse effects in individuals with celiac disease or gluten intolerance [5]. Therefore, incorporating functional ingredients like Aidan fruit and soybeans is necessary to reduce disease risk and boost nutrient content, making flatbread healthier to eat.

The use of soybeans as an ingredient has increased over the years in many food preparations, aiding in enhancing the nutritional value of products. Soybean flour helps improve the texture and sensory qualities of bread products [6]. Soybeans support weight control, optimize digestion [7], and have anti-inflammatory properties that fight oxidative stress and prevent the development of diseases, including neurological disorders and arthritis [8]. The anti-inflammatory and antioxidant properties of Aidan fruit give it the ability to inhibit certain infections [2].

The objective of this study was to evaluate the functional, pasting, proximate, microbial, and sensory composition of flatbread enriched with Aidan fruit pulp and soybean flour, with the goal of developing a healthier functional food product that can be eaten across age groups.

MATERIALS AND METHODS

Aidan fruits, whole wheat flour, soybeans, salt, sugar, yeast, and vegetable oil were purchased from a local market in Sango Ota, Ogun State, Nigeria. All chemical reagents used for this study were of analytical grade.

Preparation and Production of Fortified Wheat Flatbread

The flour samples were prepared using the method described by [9]. Flour (from Aidan fruit pulp, whole wheat, and soybean), salt, sugar, yeast, and vegetables were precisely weighed using a weighing balance, and the oven was preheated at 220°C. The dry ingredients were transferred to a bowl and mixed evenly with the wet ingredients to create a dough, which was left for 90 minutes to allow gluten relaxation. Afterward, the relaxed dough was cut into equal pieces and rested for 10 minutes. Each piece was rolled out with a rolling pin to form a flat shape, then placed on an oven tray to relax for 20 minutes. Subsequently, it was baked in the preheated oven for 5-8 minutes. The finished wheat flatbread was stored in a plastic bag and labeled. Five flatbread samples were prepared with 10 g of soybean flour in each portion and varying amounts of Aidan fruit pulp flour (1.0 g, 2.0 g, 3.0 g, 4.0 g, and 5.0 g per 100 g of flatbread). A plain flatbread (without soybean and Aidan fruit pulp flour) was used as the control.

Determination of Functional Properties

Bulk Density

The bulk density of the composite flour sample was determined as described. About 5 g of the sample was weighed into a graduated cylinder, then gently tapped the bottom 15 times on a laboratory bench until no further diminution of the sample [10]

$$\text{Bulk density (g/cm}^3) = \frac{\text{weight of sample}}{\text{volume of sample after tapping}} \quad (1)$$

Water Absorption Capacity (WAC)

One gram of the composite flour sample was weighed into a centrifuge tube and suspended in 10 mL of water. It was shaken on a stirrer (Stuart, UK) for 1 minute at room temperature, allowed to stand for 30 minutes, and centrifuged at 1200 × g for 30 minutes [9].

$$\text{Water absorption capacity (\%)} = \frac{\text{weight of wet sediment (g) - weight of dry sample (g)}}{\text{weight of dry sample (g)}} \times 100 \quad (2)$$

Oil Absorption Capacity (OAC)

The method of [9] was used to determine oil absorption capacity. 1 g of the flour was thoroughly mixed with 10 mL of refined corn oil in a centrifuge tube and allowed to stand at room temperature for 1 hour. It was centrifuged at 1600 x g for 20 minutes.

$$\text{Oil absorption capacity (\%)} = \frac{\text{weight of oiled sediment (g) - weight of dry sample (g)}}{\text{weight of dry sample (g)}} \times 100 \quad (3)$$

Swelling Capacity (SC)

Swelling capacity was determined using the method of [11] by dispersing 1 g of the composite flour sample in a graduated cylinder with 30 mL of distilled water and letting it stand for 1 hour. The final volume was then recorded.

$$\text{Swelling capacity (\%)} = \frac{\text{final volume of swollen sample (mL) - initial volume of dry sample (mL)}}{\text{initial volume of dry sample (mL)}} \times 100 \quad (4)$$

Determination of Pasting Properties

This was analyzed using a Rapid Visco Analyzer (RVA Model 4500) following the RVA protocol [12]. A 3% (w/w) sample was prepared in 25 mL of distilled water and transferred into an RVA canister. The standard pasting profile was applied: initial holding at 50°C for 2 minutes, heating at a rate of 11.25°C/min, holding at 95°C for 5 minutes, cooling back to 50°C, and holding again for 2 minutes. The RVA provided data including peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, and peak time, measured in centipoise (cP).

Determination of Proximate Composition

Moisture Content

This method was performed using the dry-base method [13]. A 5 g sample was weighed into a crucible and placed in an oven (FISHER Isotemp oven, SENIOR MODEL) at 105 °C for 3 hours. The dried sample was placed in a desiccator to cool and weighed.

$$\text{Moisture content (\%)} = \frac{\text{weight of wet sample (g) - weight of dry sample (g)}}{\text{weight of wet sample (g)}} \times 100 \qquad (5)$$

Ash Content

The method described by [14] was used to determine the ash content. A 2 g sample was weighed into a crucible, placed in a muffle furnace (THERMO SCIENTIFIC) at 600 °C for 2 hours, cooled in a desiccator, and weighed.

$$\text{Ash content (\%)} = \frac{\text{weight of crucible with ash (g) - weight of empty crucible (g)}}{\text{initial weight of sample (g)}} \times 100 \qquad (6)$$

Crude Fat

Crude fat content was determined using the Goldfish extraction method [13]. A 2 g sample was placed in an extraction thimble and extracted with petroleum ether for 6 hours. The solvent was removed by gentle evaporation, and the residue was dried in an oven (FISHER Isotemp oven, SENIOR MODEL) at 100 °C for 30 minutes until constant weight, then cooled in a desiccator and weighed.

$$\text{Crude fat (\%)} = \frac{\text{weight of dried fat residue (g)}}{\text{weight of initial sample (g)}} \times 100 \qquad (7)$$

Crude Fiber

The determination of crude fiber was performed using a FISHER Isotemp Oven (SENIOR MODEL) [14]. The defatted sample was digested with dilute sulfuric acid and sodium hydroxide, then dried in an electric oven at 100 °C for 1 hour, followed by ashing and gravimetric estimation of the residue.

$$\text{Crude fiber (\%)} = \frac{\text{weight of dried residue (g) - weight of ashed residue (g)}}{\text{weight of initials sample (g)}} \times 100 \qquad (8)$$

Protein Content

Protein content was determined using the Kjeldahl method as described by [13]. 2 g of the sample was boiled in 10 mL of concentrated H_2SO4 in the presence of a selenium catalyst inside a fume cupboard. The digest was transferred into a volumetric flask containing 100 mL of distilled water, and 10 mL was then transferred into a Kjeldahl distillate apparatus. The distillate was collected in 100 mL of 4% boric acid solution containing 3 drops of a mixed indicator (methyl red and bromocresol green). The distillate was titrated against 0.02N H_2SO4 solution.

$$\text{Nitrogen (\%)} = \frac{\text{VS-VB} \times \text{NQ} \times 0.01401}{\text{W}} \times 100 \qquad (9)$$

Where: VS is the Volume (mL) of acid required to titrate the sample, VB is the Volume (mL) of acid required to titrate the blank, NA is the Normality of acid, W is the Weight of Samples in grams, % Crude Protein is the N_2 x conversion factor.

Carbohydrate Content

The nitrogen-free method described by [13] was used. The carbohydrate was calculated as weight by difference between 100 and the summation of other proximate parameters as Nitrogen-free extract (NFE) percentage carbohydrate.

Carbohydrate (%) = 100-[Moisture (%) + Ash (%) + Crude Fat (%) + Crude Fibre (%) + Crude Protein (%)] (10)

Microbial Analysis

Microbial analysis was performed following the method of [15], using the serial dilution method.

Sensory Evaluation

Sensory Evaluation was carried out in an individual sensory booth within the Food Science Laboratory at Bells University of Technology, Ota, Nigeria. The samples were labeled as WSA1, WSA2, WSA3, WSA4, WSA5, and WC and presented randomly to 50 semi-trained panelists chosen among staff and students. Attributes evaluated included crust color, appearance, aroma, taste, mouthfeel, and overall acceptability on a 9-point hedonic scale, with water served to cleanse the palate between sample treatments.

Statistical Analysis

Data analyses were performed using one-way Analysis of Variance (ANOVA) followed by Duncan's New Multiple Range Test for significant means, with an accepted significance level of ($P < 0.05$) using SPSS (Statistical Package for the Social Sciences) version 21.

RESULTS

Functional Properties

The increase in Aidan fruit pulp and soybean flour inclusion significantly raised the bulk density, water-holding capacity, and oil absorption capacity of composite flour from 0.75 g/cm^3 to 0.79 g/cm^3, 239.45% to 258.57%, and 129.36% to 152.45%, respectively, as shown in Table 1. However, the swelling capacity decreased from 4.80% to 4.39%. This suggests an increase in the physical strength of the treated samples.

Table 1: Functional Properties of Composite Flour Samples

Sample	Bulk Density (g/cm^3)	Water Absorption Capacity (%)	Oil Absorption Capacity (%)	Swelling Capacity (%)
WSA1	0.75±0.00^{b}	239.45±0.01^{b}	129.36±0.03^{b}	4.80±0.02^{b}
WSA2	0.77±0.00^{c}	245.20±0.04^{c}	134.25±0.05^{c}	4.66±0.01^{c}
WSA3	0.77±0.00^{cd}	250.86±0.04^{d}	140.05±0.05^{d}	4.51±0.03^{d}
WSA4	0.78±0.00^{de}	254.94±0.04^{e}	146.36±0.04^{e}	4.45±0.02^{de}
WSA5	0.79±0.00^{e}	258.57±0.03^{f}	152.45±0.05^{f}	4.39±0.02^{e}
WC	0.73±0.00^{a}	228.60±0.02^{a}	121.87±0.02^{a}	4.90±0.03^{a}

Values are the means of the SD of duplicate readings. Values with different superscripts within the same column are statistically different. ($p<0.05$). WSA1: 89% Wheat flour + 10% Soybean flour + 1% Aidan fruit pulp flour; WSA2: 88% Wheat flour + 10% Soybean flour + 2% Aidan fruit pulp flour; WSA3: 87% Wheat flour + 10% Soybean flour + 3% Aidan fruit pulp flour; WSA4: 86% Wheat flour + 10% Soybean flour + 4% Aidan fruit pulp flour; WSA5: 85% Wheat flour + 10% Soybean flour + 5% Aidan fruit pulp flour; WC: 100% Wheat flour

Pasting Properties

The pasting properties of composite flour (Figure 1) showed that peak viscosity, trough viscosity, breakdown viscosity, setback viscosity, final viscosity, and peak time decreased at the inclusion of soybeans and Aidan fruit pulp from 1368 cP to 1190 cP, 721 cP to 635 cP, 647 cP to 553 cP, 838 cP to 743 cP, 1559 cP to 1378 cP, and 5.67 minutes to 5.33 minutes, respectively while pasting time increased from 87.95°C to 88.10°C.

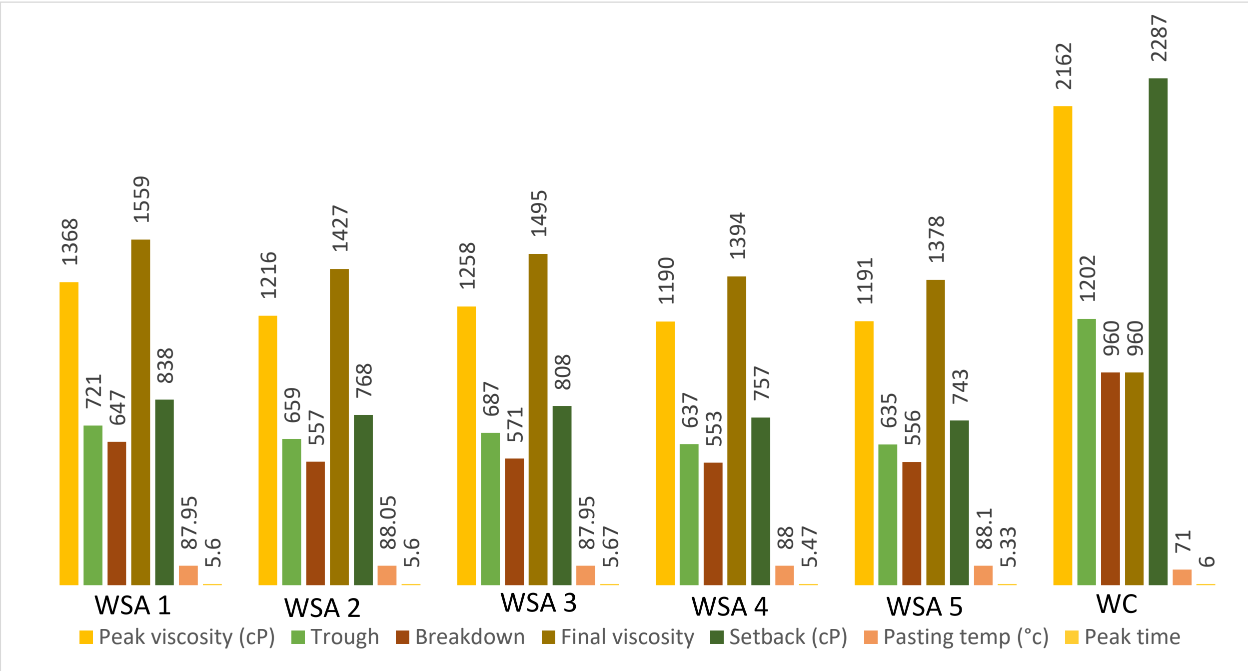

Figure 1: Pasting Properties of Composite Flour Blend

WSA1: 89% Wheat flour + 10% Soybean flour + 1% Aidan fruit pulp flour; WSA2: 88% Wheat flour + 10% Soybean flour + 2% Aidan fruit pulp flour; WSA3: 87% Wheat flour + 10% Soybean flour + 3% Aidan fruit pulp flour; WSA4: 86% Wheat flour + 10% Soybean flour + 4% Aidan fruit pulp flour; WSA5: 85% Wheat flour + 10% Soybean flour + 5% Aidan fruit pulp flour; WC: 100% Wheat flour

Proximate Analysis

The proximate composition of fortified flatbread, as shown in Figure 2, experienced a significant increase in total ash (3.54% to 6.61%), crude fiber (1.40% to 2.30%), and crude protein (21.87% to 28.84%), enhancing the nutritional value of the fortified flatbread. Moisture content decreased from 22.85% to 26.30%, and carbohydrate content also decreased from 38.55% to 27.00% with the inclusion of Aidan fruit.

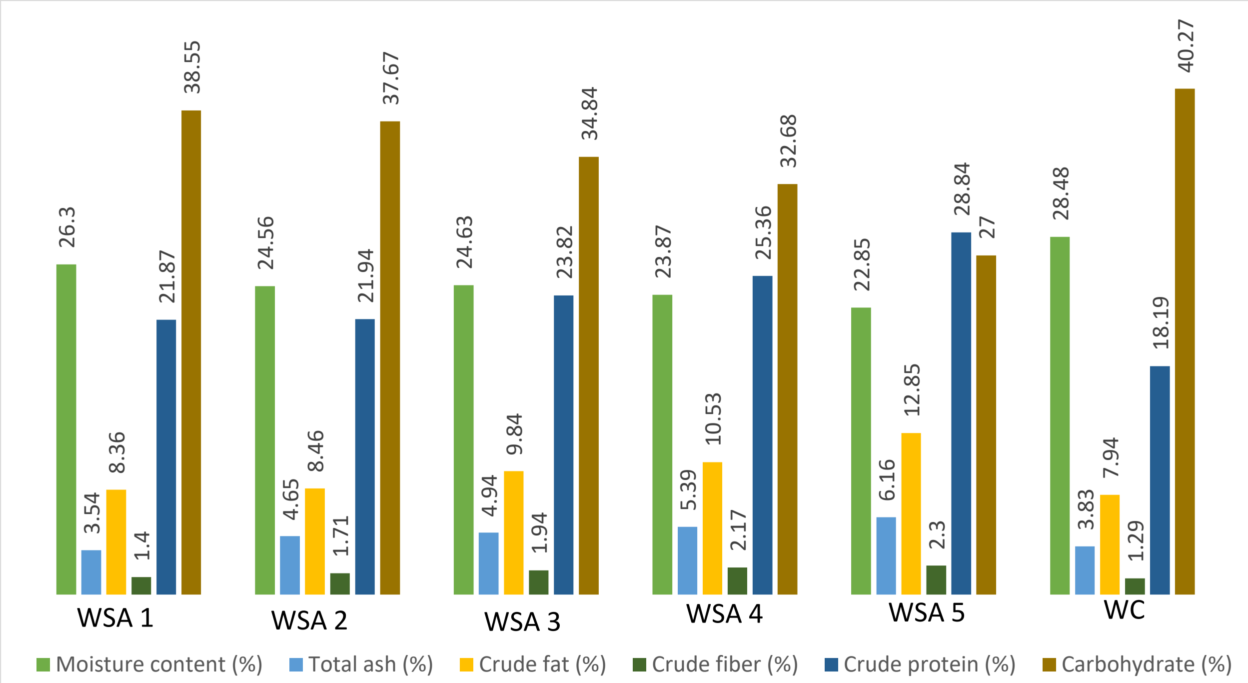

Figure 2: Proximate Composition of Fortified Flatbread

WSA1: 89% Wheat flour + 10% Soybean flour + 1% Aidan fruit pulp flour; WSA2: 88% Wheat flour + 10% Soybean flour + 2% Aidan fruit pulp flour; WSA3: 87% Wheat flour + 10% Soybean flour + 3% Aidan fruit pulp flour; WSA4: 86% Wheat flour + 10% Soybean flour + 4% Aidan fruit pulp flour; WSA5: 85% Wheat flour + 10% Soybean flour + 5% Aidan fruit pulp flour; WC: 100% Wheat flour

Microbial Analysis of Fortified Flatbread Samples

Table 2 presents the microbial quality of flatbread stored under different conditions. At ambient temperature, total viable bacterial count (TVBC) and total yeast and mold count (TYMC) increased significantly from 2.0 CFU/g to 64.5 CFU/g ($p < 0.05$) across storage weeks, with the control showing the highest counts (107.5 CFU/g) in Week 4. Sample WSA5 (5% Aidan fruit pulp flour) recorded the lowest values. Storage under refrigeration slowed microbial growth, with all samples remaining within acceptable limits up to Week 4 (1.0 CFU/g to 13.5 CFU/g). Frozen storage maintained stable counts throughout, with no significant changes ($p > 0.05$).

Table 2: Microbial Counts (TVBC and TYMC) of Fortified Flatbread Samples during Four Weeks of Storage under Different Temperature Conditions

Storage condition	Samples	Weeks							
		1		2		3		4	
		TVBC	TYMC	TVBC	TYMC	TVBC	TYMC	TVBC	TYMC
Ambience	WC	10.5 ± 0.71^a	3.5 ± 0.71^a	25.0 ± 2.83^a	8.0 ± 0.00^b	52.0 ± 4.24^a	19.0 ± 2.83^c	107.5 ± 7.78^a	43.5 ± 2.12^d
	WSA1	10.0 ± 1.41^a	3.0 ± 0.00^a	17.5 ± 2.12^b	5.5 ± 0.71^b	38.0 ± 1.41^b	13.0 ± 1.41^c	64.5 ± 3.54^b	31.5 ± 1.41^d
	WSA2	9.0 ± 4.24^a	2.5 ± 0.71^a	14.0 ± 1.41^c	5.0 ± 0.00^b	33.0 ± 1.41^c	12.5 ± 2.12^c	45.5 ± 3.54^c	20.5 ± 0.71^d
	WSA3	8.0 ± 2.83^a	$2.5\pm0.71a$	12.0 ± 1.41^c	4.0 ± 1.41^b	24.0 ± 1.41^d	10.0 ± 1.41^c	38.0 ± 1.41^d	18.0 ± 1.41^d
	WSA4	8.0 ± 1.41^a	2.0 ± 0.00^a	10.5 ± 0.71^c	3.0 ± 0.00^b	$23.0^a\pm4.24^d$	9.0 ± 1.41^c	34.0 ± 1.41^d	18.0 ± 2.83^d
	WSA5	7.0 ± 2.83^a	2.0 ± 0.00^a	9.5 ± 3.54^c	2.5 ± 0.71^b	16.5 ± 0.71^e	8.0 ± 0.00^c	26.5 ± 0.71^e	15.5 ± 2.12^d
Refrigerated	WC	11.0 ± 2.83^a	1.5 ± 0.71^a	14.0 ± 4.24^a	2.0 ± 1.41^b	15.0 ± 5.66^a	3.0 ± 0.00^b	17.5 ± 4.95^a	4.0 ± 1.41^c
	WSA1	8.5 ± 2.12^b	2.0 ± 0.00^a	9.5 ± 3.54^b	2.5 ± 0.71^b	10.5 ± 2.12^b	2.5 ± 0.71^b	13.5 ± 2.12^b	4.0 ± 0.71^c
	WSA2	8.0 ± 0.00^b	1.5 ± 0.71^a	9.0 ± 1.41^b	2.0 ± 0.00^b	10.0 ± 1.41^b	2.0 ± 0.00^b	11.5 ± 2.12^c	3.0 ± 0.00^c
	WSA3	6.5 ± 2.12^c	1.5 ± 0.71^a	7.0 ± 1.41^c	2.0 ± 1.41^b	8.5 ± 0.71^c	2.0 ± 0.00^b	10.0 ± 1.41^c	2.5 ± 0.71^c
	WSA4	6.0 ± 0.00^c	1.5 ± 0.71^a	6.5 ± 0.71^c	2.0 ± 0.71^b	7.0 ± 1.41^c	2.0 ± 1.41^b	8.0 ± 1.41^d	2.5 ± 0.71^c
	WSA5	5.5 ± 2.12^c	1.0 ± 0.00^a	5.5 ± 2.12^c	1.0 ± 0.00^b	5.5 ± 2.12^d	1.0 ± 0.00^b	6.0 ± 2.12^d	1.5 ± 0.71^c
Frozen	WC	6.5 ± 0.71^a	1.5 ± 0.71^a	6.5 ± 0.71^b	1.5 ± 0.71^a	6.5 ± 0.71^b	1.5 ± 0.71^a	7.5 ± 0.71^a	1.5 ± 0.71^a
	WSA1	6.0 ± 1.41^a	1.5 ± 0.71^a	6.0 ± 1.41^b	1.5 ± 0.71^a	6.0 ± 1.41^b	1.5 ± 0.71^a	6.5 ± 0.71^a	1.5 ± 0.71^a
	WSA2	5.5 ± 2.12^b	1.0 ± 1.41^a	5.5 ± 2.12^b	1.0 ± 1.41^a	5.5 ± 2.12^b	1.0 ± 1.41^a	5.5 ± 2.12^b	1.0 ± 1.41^a
	WSA3	6.0 ± 2.83^b	1.0 ± 0.00^a	6.0 ± 2.83^b	1.0 ± 0.00^a	6.0 ± 2.83^b	1.0 ± 0.00^a	6.0 ± 2.83^b	1.0 ± 0.00^a
	WSA4	5.5 ± 0.71^b	1.0 ± 1.41^a	5.5 ± 0.71^b	1.0 ± 1.41^a	5.5 ± 0.71^b	1.0 ± 1.41^a	5.5 ± 0.71^b	1.0 ± 1.41^a
	WSA5	5.0 ± 2.83^b	0.5 ± 0.71^a	5.0 ± 2.83^b	0.5 ± 0.71^a	5.0 ± 2.83^b	0.5 ± 0.71^a	5.0 ± 2.83^b	0.5 ± 0.71^a

TVBC= Total viable bacterial count; TYMC= Total yeast and mold count; WSA1: 89% Wheat flour + 10%; Soybean flour + 1% Aidan fruit pulp flour; WSA2: 88% Wheat flour + 10% Soybean flour + 2% Aidan fruit pulp flour; WSA3: 87% Wheat flour + 10% Soybean flour + 3% Aidan fruit pulp flour; WSA4: 86% Wheat flour + 10% Soybean flour + 4% Aidan fruit pulp flour; WSA5: 85% Wheat flour + 10% Soybean flour + 5% Aidan fruit pulp flour; WC: 100% Wheat flour

Sensory Evaluation of Flatbread Samples

Sensory scores in Table 3 showed that the control bread (WC) received the highest ratings for crust color (7.56) and taste (7.68). WSA1 had the highest rating for aroma (7.56) and overall acceptability (7.54). Appearance (7.60) and mouthfeel (7.62) were significantly high in the WSA5 sample.

Table 3: Sensory Evaluation of Flatbread Samples

Sample	Crust color	Appearance	Aroma	Taste	Mouthfeel	Overall acceptability
WC	7.56±0.31^{a}	7.38±0.52^{a}	6.38±0.42^{a}	7.68±0.34^{a}	7.58±0.31^{a}	7.52±0.40^{a}
WSA 1	6.64±0.40^{bd}	6.52±0.48^{b}	7.56±0.37^{a}	7.58±0.43^{a}	6.42±0.48^{b}	7.54±0.45^{a}
WSA 2	6.62±0.46^{b}	5.54±0.42^{b}	6.72±0.46^{b}	6.64±0.42^{c}	6.5±0.44^{c}	6.74±0.38^{b}
WSA 3	5.92±0.52^{c}	5.36±0.33^{c}	7.46±0.41^{b}	6.36±0.32^{b}	6.36±0.39^{c}	6.32±0.47^{c}
WSA 4	5.6±0.46^{c}	5.46±0.38^{d}	6.36±0.46^{b}	6.58±0.50^{c}	6.26±0.44^{b}	6.8±0.41^{b}
WSA 5	6.66±0.54^{b}	7.6±0.56^{d}	4.54±0.42^{c}	5.6±0.38^{d}	7.62±0.41^{d}	5.58±0.35^{d}

Values are the means of the SD of duplicate readings. Values with different superscripts within the same column are statistically different. ($p<0.05$). WSA1: 89% Wheat flour + 10% Soybean flour + 1% Aidan fruit pulp flour; WSA2: 88% Wheat flour + 10% Soybean flour + 2% Aidan fruit pulp flour; WSA3: 87% Wheat flour + 10% Soybean flour + 3% Aidan fruit pulp flour; WSA4: 86% Wheat flour + 10% Soybean flour + 4% Aidan fruit pulp flour; WSA5: 85% Wheat flour + 10% Soybean flour + 5% Aidan fruit pulp flour; WC: 100% Wheat flour

DISCUSSION

The primary objective of this study was to improve the nutritional value of wheat flatbread fortified with Aidan fruit pulp and soybean flour. There was a positive shift in the overall functional properties of composite flour with a difference in the swelling capacity. The increase in bulk density resulted in a higher flow property, therefore, reducing storage and transportation costs. This finding is in accordance with [16], who stated the advantage of high bulk density in food processing. Water absorption capacity influences dough handling and mouthfeel, with sample WSA5 having the highest mouthfeel scores. The increase in WAC (239.45% to 258.57%) increased the water retention in the samples. This could be due to the presence of hydroxyl groups in the treated samples. Similar increase (230% to 262%) in WAC of chemically modified starches was recorded during findings of [17]. The increase in OAC (129.36% to 152.45%) of treated samples enhanced surface hydrophobicity and disrupted the starch-protein structure, which improved oil absorption, thereby retaining the flavour, mouthfeel, and shelf life of the products. A similar observation was found in [18], who reported the modification of starch that increased the OAC (135% to 159%) in plant-based flour. The negative trend in the swelling capacity of the treated products showed that the starch granules were bound, limiting their free expansion in water. This could be useful in products that require low viscosity breakdown under shear or extended heat. This behaviour supports earlier findings of [19], who reported that modified starches where a low swelling index was correlated to molecular rigidity.

The pasting properties of the composite flour were significantly affected by 10% soybean and Aidan fruit pulp flour with a decrease in the peak, trough, breakdown, final, and setback viscosities. This decrease indicates moderate stability and lower vulnerability of starch granules to rupture under heat and shear. The drop in final viscosity and setback also suggests reduced retrogradation, which is beneficial for improving texture stability and extending storage life. Notably, while the pasting temperatures of the treated samples stayed consistent at around ~88 °C, the control sample (WC) had a much lower pasting temperature (71 °C), reflecting earlier gelatinization due to higher starch content. Peak time increased slightly with concentration, ranging from 5.33 minutes to 5.67 minutes for the treated samples compared to 6.00 minutes for the control. These results align with the results of [20, 21], confirming that higher starch concentration boosts viscosity and gel strength, while flour substitution moderates pasting properties. This can improve processing stability, reduce retrogradation, and potentially extend shelf life of final product.

Ash, fiber, fat, and protein contents of treated samples were significantly increased compared to the control sample. The increase in ash content enhanced the presence of essential macronutrients and micronutrients. This result was in support of [22], who reported an increase in ash content of cereal fortified with legume flour. Fiber is an important contributor to human digestion as it enhances gut motility, lowers cholesterol, and glycemic levels [23]. Fat facilitates absorption of fat-soluble vitamins (A, D, E, K). High presence of fat in the treated samples added to their palatability, energy density, food texture, and flavour. Similar effects were reported by [24], who found that composite flour with oilseed meals had a high fat level. The increase in protein content showed its important role in the synthesis of muscle, enzyme activity, immune response, and tissue healing. A report also showed a significant increase in protein content in cereal produced from soybean and groundnuts [25]. However, moisture and carbohydrate contents of the treated samples were reduced. The moisture reduction extends product shelf-life, as lower water activity impedes microbial growth and enzymatic reactions, extending the stability of food systems [26]. Although carbohydrates are a major source of energy, a decrease in the amount is effective for consumers with metabolic complications like diabetes [27].

Microbial analysis carried out on the samples showed that ambient storage promotes rapid microbial proliferation, rendering bread unsafe within 2–3 weeks; this is consistent with [28, 29] as reported. The lower counts in fortified samples suggest that 10% soybean and Aidan fruit pulp flours contribute antimicrobial effects. Refrigeration extends shelf-life but did not prevent microbial growth. This report aligned with [30], which highlighted the extension of shelf-life using a refrigeration method, but it does not entirely prevent microbial spoilage. Freezing was most effective as microbial counts remained stable throughout. These findings were in corroboration with [31], which emphasized freezing to effectively maintain microbial stability in bakery products for extended periods.

Consumer expectations are related to the appearance of bread, such as loaf shape, the integrity of the crust and crumb. WSA5 had the highest score for colour, appearance, and mouthfeel. This indicates that the structural modification made with Aidan fruit pulp flour inclusion in wheat flour has a positive effect as far as visual appearance is concerned. The control sample showed optimum browning, and the rate of crust colour was, however, noted to gradually decrease from WSA1 to WSA5. This may be explained by the dilution effect of Aidan fruit pulp flour on wheat flour and its effect on the sugar and protein contents of the product, which creates less intense browning. Apparently, flatbread made from WSA5 was more colour-appealing to the consumers, and this may be explained by the difference in the reaction of phenolic compounds in Aidan fruit pulp at high concentration to produce a darker crust.

CONCLUSION

This study revealed that fortifying wheat flour with Aidan fruit pulp and 10% soybean flour significantly improved the nutritional composition of flatbread. Flatbread samples stored under refrigeration and freezing conditions showed significantly lower microbial counts. The sensory evaluation showed that the sample WSA1 was the most acceptable to consumers.

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