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EXPLORING THE FUNCTIONAL AND RHEOLOGICAL PROPERTIES OF PSYLLIUM HUSK ARABINOXYLANS (PHAXS) IN RELATION TO ITS END-USE PERSPECTIVES

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Abstract
Psyllium husk is a significant functional ingredient in food applications like gluten-free bread and breakfast cereals because it is a rich source of natural dietary fiber with remarkable water absorption and gelling capabilities. The complex, branching arabinoxylan (AX) is the main bioactive ingredient in psyllium husk. This study aimed to investigate the functional and rheological properties of arabinoxylans (PHAXs) extracted from Indian and Pakistani psyllium husk varieties to explore their potential industrial applications. PHAXs were extracted using enzymatic and alkaline methods and characterized for their monosaccharide composition and phenolic acid content. Indian psyllium husk showed higher AX content (37.02 ± 0.05 g/100 g) compared to the Pakistani variety (34.52 ± 0.06 g/100 g), while the Pakistani PHAXs exhibited higher levels of arabinose, xylose, galactose, and glucose. Total phenolic content and flavonoids ranged from 7.82 ± 0.17 to 8.12 ± 0.18 mg GAE/g and 1.95 ± 1.50 to 2.24 ± 0.02 mg CE/g, respectively. Incorporation of 10% PHAXs into wheat flour significantly enhanced dough rheology, improving water absorption (69.98 ± 1.85%), dough stability (4.92 ± 0.7 min), peak height (67.72 ± 0.11 BU), and mixing tolerance index (65.61 ± 0.02%). Dough development time was highest in the control (8.25 ± 0.66 min), while the shortest mixing time (5.72 ± 0.01 min) and lowest dough softness (139 ± 0.02%) were observed in PHAX-enriched samples. Bread prepared with PHAXs (0–10%) showed increased moisture retention and loaf volume, with significantly reduced hardness after six days of storage. Notably, supplementation with 5–10% PHAXs had no adverse effect on overall sensory acceptability. These findings highlight the functional potential of PHAXs as natural additives in bakery and other fiber-enriched food products, supporting their broader use in edible films and pharmaceutical delivery systems.
Keywords: Psyllium husk, arabinoxylans, Phenolic content, Product development, rheological properties

INTRODUCTION

Phytochemicals have been utilized since ancient times across different cultures to enhance the quality and health-promoting characteristics of bake goods. Individuals who consume a diet abundant in functional or bioactive components face a reduced risk of chronic diseases, thereby lowering their mortality risk (Saeed et al., 2014). Consequently, it is crucial for nutritionists and health professionals to engage with plants and their derivatives due to their diverse functionalities. While plants are essential for humans to meet their vital nutritional needs, the presence of bioactive compounds renders them a significant element of a healthy diet. (El-Ramady et al., 2022). Vegetables, cereal grains (rice, barley, wheat, maize, and oats), and fruits and psyllium husk are among the plant species that contain significant amounts of both nutritional and non-nutritive components (Tanaji et al., 2021). Accordingly, in

order to have an effective and attentive awareness for customers, the extraction of bioactive compounds and their influence on development of products necessitate methodical scientific studies (Herzyk et al., 2024).
Plantago ovata, or Psyllium, is one of the 200 Plantago species that are grown worldwide, particularly in Iran and India (Assi et al., 2024). Psyllium husk (PH) has been utilized in nutritional supplements and animal feeds because it contains 17.3% soluble fiber and 59.1% insoluble fiber (TUV, 2013) (Kausar et al., 2024). The most common polysaccharide in PH is a highly branched heteroxylan with a backbone of 1, 4--D-xylopyranose, which includes xylose (24.1 wt percent, dry basis) and arabinose (46.8 wt percent, dry basis) (Waleed et al., 2022). Psyllium husk gum (PHG) is an acidic polymer that is derived from PH and contains significant levels of uronic acid (15 wt percent on a dry basis) (Agrawal, 2021). The gel-forming fraction (neutral arabinoxylan) is the physiologically active part of the PH, which accounts for 55–60% of the total (Qaisrani et al., 2016).

Arabinoxylans (AXs) significantly influence the rheological characteristics of wheat gluten. Potential reasons for the impact of AX in bread production include its exceptionally high-water retention ability, which contributes to viscosity and a robust capacity for gel formation. (Cappelli et al., 2020). The incorporation of AXs improves the previously mentioned characteristics through a distinct mechanism, such as loaf volume (Pietiäinen, 2024). The concentration of these non-starch polysaccharides in the dough system controls the beneficial effects; concentrations higher than ideal would cause the amount of baked goods to decrease. The type of flour used and the molecular weight of arabinoxylans determine the AX concentration that maximizes loaf capacity (Bender et al., 2018). AX-containing bread compositions experienced less retrogradation. These assets depended on the quality and scope of AXs (Henriksson, 2020). Non-starch polysaccharide (NSP) reduces retrogradation by interfering with starch intermolecular interactions. These functional elements' qualities are crucial for enhancing the rheological characteristics of flour, which in turn improves the quality of bread (Xu et al., 2025).
Functional foods have received a great deal of interest in the area of nutrition. These non-starch polysaccharides (NSP) have useful properties that are essential to the cereal business because they increase the dough's ability to absorb water, which promotes dough development and lengthens dough stability. Additionally, during the bread-making process, these ingredients improve the bread's shelf life and storage stability, increase loaf volume, firm the crumb, and reduce retrogradation. The idea that functional additives should increase bread's volume and texture is the main foundation for the improvement in baked goods quality. In terms of product quality, these functional additives enhance the rheological characteristics and gluten quality of different spring wheat varieties.
The objective of the present study was to analyze the varieties of Pakistani psyllium husk (PPH) in terms of their arabinoxylan content and to clarify their influence on the rheological, textural, and sensory properties of bread. This information will benefit both growers and bakers. Furthermore, the characterization of arabinoxylans will assist industrialists in enhancing their future product development initiatives.

MATERIALS AND METHODS

Materials
Wheat Research Institute, Ayub Agriculture Research Institute (AARI), Faisalabad, provided two psyllium husk kinds (Indian and Pakistani).

Chemical analysis
The varieties of psyllium husk (Pakistani and Indian) were assessed for their proximate composition, which includes moisture, ash, crude protein, crude fiber, and, following the methods outlined in AACC 2000. The nitrogen-free extract was determined based on the difference using the specified formulae.

$NFE\% = 100 - (Moisture + ash + crude\ fat + Crude\ fiber + Protein)$

Total, soluble, and insoluble dietary fiber compositions
Psyllium husk varieties (Pakistani & Indian) were analyzed for total dietary fiber (methods No. 32-05), soluble dietary fiber (methods No. 32-07), and insoluble dietary fiber (methods No. 32-20) using AACC (2000).

Mineral content
Psyllium husk variants (Indian and Pakistani) were assessed for mineral contents such as Ca, P, K, Mg, and Na using the procedure outlined in AOAC (2000).

Characterization of arabinoxylans

Extraction
Various techniques, including the enzymatic method (Cleemput et al., 1995) and the alkali extraction method (Hunninghake et al., 2005), were used to extract arabinoxylans from various psyllium husk kinds. These techniques were assessed in order to obtain the highest possible extraction yield.

Derivatization
Derivatization was a step in the preparation of the gas chromatogram flame ionization detector (GC-FID) sample. 0.6 mg of extracted AX, 0.5 mg of phenyl β-d-glucopyranoside, 0.5 ml of 99% pure pyridine, and 12.5 mg of

hydroxylamine hydrochloride were added to a 16 x 75 mm test tube. Caps lined with Teflon were sealed and kept in a water bath at 70ºC for five minutes. After cooling the tubes to 22ºC, each tube was filled with 0.4 ml of undiluted trifluoro-acetic acid and 0.5 ml of hexamethyldisilazane. Each tube was filled with 0.5 ml of undiluted isooctane and 4 ml of deionized water to dissolve any leftover salts. For analysis, the isooctane layer was pipetted into gas chromatography vials.

Determination of sugars through GC-FID

Using a gas chromatograph and a flame ionization detector, the amount of monosaccharides was determined. The DB-5 fused silica capillary column was 30 meters long. Using a multi-ramp column oven temperature algorithm, the monosaccharides were separated. 180 degrees Celsius was the initial temperature, and it was raised to 200, 260, and 290 degrees Celsius. The temperature of the detector was 300ºC, and the injection port was 280ºC. Injecting a 2.0µl split-less sample allowed for the quantification of individual sugars using nitrogen as the carrier gas. The flow rate of the carrier gas was approximately 1.5 milliliters per minute.

Determination of phenolic compounds

The Irmak et al. (2007) method was used to determine the major phenolic acids of AXs.

Addition of Arabinoxylans in flour

Using a farinograph and mixograph, the rheology of the dough was assessed both with and without the incorporation of AXs to the flour as shown in Table 1, in accordance with the guidelines provided in AACC (2000).

Farinographic studies

The physical properties of dough derived from various wheat flour blends that include AXs at varying concentrations were assessed utilizing a Farinograph (Brabender D-4100 SEW; Germany), following the methodology outlined in AACC (2000). The farinograph results were analyzed for several characteristics, including water absorption, dough stability, dough development time, dough softening, and mixing tolerance index as detailed below.

Mixographic studies

The AACC (2000) method was used to run the wheat flour containing AXs through a mixograph (National NSI-33R) to evaluate the dough's mixing qualities, such as peak height % and mixing time.

Bread characteristics

The extracted AXs were incorporated during the dough preparation process, and the bread was produced using the straight dough method as outlined in AACC (2000).

Texture analysis

Using Texture Analyzer, the texture analysis of bread was carried out with various adjustments in accordance with Piga et al. (2005). For each formulation, three separate measurements were made, and mean values were computed.

Moisture content of bread

In accordance with AACC (2000) technique No. 44-15A, a hot air oven set at 105 ± 5ºC was used to measure the moisture content of each wheat variety's bread.

Bread loaf volume

After the loaves cooled for 15 minutes, their volumes were measured using the rapeseed displacement method. Every loaf was put in a container and encircled entirely by rapeseed to make sure the container was full. After that, the loaf was removed, and the amount of rapeseed was recorded using the method described in AACC (2000).

Sensory evaluation of bread

The methodology developed by Lawless and Heymann (1998) was followed in the sensory evaluation of the bread.

Statistical analysis

Every analysis was carried out three times, and the results were presented as the mean and standard deviation. Furthermore, the significance level ($p \leq .05$) was assessed through the analysis of variance (ANOVA).

RESULT AND DISCUSSION

Table 1: Treatment plan for addition of Arabinoxylans

Treatments (PH_{F-AX})	Flour (%)	Incorporation of AX (%)
PH $_{(100-0)}$	100	-
PH $_{(97.5-2.5)}$	97.5	2.5
PH $_{(95-5)}$	95	05
PH $_{(92.5-7.5)}$	92.5	7.5
PH $_{(90-10)}$	90	10

PH= Psyllium husk**, F=** Flour**, AX=** Arabinoxylan, **PH $_{(100-0)}$** = 0% control Bread, **PH $_{(97.5-2.5)}$** = 97.5% flour with 2.5% addition of AXs, **PH $_{(95-5)}$** = 95% flour with 5% addition of AXs, **PH $_{(92.5-7.5)}$** = 92.5% flour with 7.5% addition of AXs, **PH $_{(90-10)}$** = 90% flour with 10% addition of AXs

Table 2: Mean value for Biochemical composition of Psyllium Husk varieties (Pakistani & Indian)

Varieties	Pakistani Psyllium Husk (PPH)	Indian Psyllium Husk (IPH)
Moisture Content	6.9±0.01[a]	5.49±0.01[b]
Ash	3.75±0.03[b]	4.9±0.01[a]
Crude Protein	3.48±0.04[b]	4.45±0.05[a]
Crude Fiber	7.2 ±0.34[b]	7.95 ±0.21[a]
NFE	74.4±0.9[b]	77.2±1.2[a]

NFE= Nitrogen Free Extract, means with different letter (a-b) within columns are significantly different ($p<0.05$)

Table 3. Mean value of total, soluble and insoluble dietary fiber of psyllium husk varieties

Varieties	TDF	SDF	IDF
PPH	48.76±0.34[b]	3.44±0.04[b]	46.32±0.42[b]
IPH	51.46±0.14[a]	3.98±0.02[a]	49.62±0.12[a]

Means with different letter (a-b) within rows are significantly different ($p<0.05$)

TDF= Total dietary fiber, **SDF=** Soluble dietary fiber, **IDF=** Insoluble dietary fiber, PPH= Pakistan psyllium husk, **IPH=** Indian psyllium husk

Table 4: Mineral analysis of psyllium husk varieties

Varieties	PPH	IPH
Calcium (µg/g)	1475	1513
Phosphorus(µg/g)	135	138
Potassium(µg/g)	8340	8504
Magnesium(µg/g)	148	151
Sodium(µg/g)	638	642

Table 5: Arabinoxylans content of Psyllium Husk Varieties

Varieties	AXs Content
PPH	33.52±0.06 g/100g
IPH	37.02±0.05g/100g

PPH= Pakistan Psyllium Husk, **IPH=** Indian Psyllium Husk

Table 6: Monosaccharide composition of Psyllium Husk Varieties

Varieties	PPH	IPH
Arabinose	22.07±0.1[a]	21.19±0.1[b]
Xylose	54.75±0.4[a]	53.29±0.4[b]
Galactose	4.48±0.1[a]	3.15±0.1[b]
Glucose	2.2 ±0.1[a]	1.95 ±0.1[b]
Mannose	1.54±0.1[a]	2.2±0.1[b]
Rhamnose	1.12±0.1[a]	1.91±0.1[b]

PPH= Pakistan Psyllium Husk, **IPH=** Indian Psyllium Husk, means with different letter (a-b) within columns are significantly different ($p<0.05$)

Table 7: Phenolic compounds in psyllium husk varieties

Varieties	TPC (mg GAE/g)	TFC (mg CE/g)
PPH	7.82±0.17[b]	1.95±1.50[b]
IPH	8.12±0.18[a]	2.24±0.02[a]

TPC= Total Phenolic content, **TFC=** Total Flavonoids Content, **PPH=** Pakistan Psyllium Husk, **IPH=** Indian Psyllium Husk, means with different letter (a-b) within columns are significantly different ($p<0.05$)

Table 8. Effect of arabinoxylans on farinographic characteristics of wheat flour

Treatment (PH_{F-AX})	WA (%)	DDT (min)	DS (min)	MTI (%)	SD (%)
$PH_{(100-0)}$	61.98±01.76[e]	8.25±0.66[a]	3.98±0.13[e]	63.83±0.02[e]	139±0.02[a]
$PH_{(97.5-2.5)}$	66.32±1.9[d]	7.99±0.16[b]	4.17±0.11[d]	64.07±0.03[d]	138.5±0.02[b]
$PH_{(95-5)}$	68.39±2.35[c]	7.78±0.38[c]	4.32±0.12[c]	64.67±0.01[c]	137.7±0.03[c]

PH **(92.5-7.5)**	69.69±2.35[b]	7.66±0.38[d]	4.54±0.6[b]	65.32±0.02[b]	137.63±0.03[d]
PH **(90-10)**	69.98±1.85[a]	6.75±0.25[e]	4.92±0.7[a]	65.61±0.02[a]	132.3±0.06[e]

WA=Water Absorption, **DDT**=Dough development time**, DS=** Dough Stability, **MTI=** Mixing tolerance index, **SD=** Softness of Dough, **PH=** Psyllium husk**; F=** Flour**; AX=** Arabinoxylan, **PH** **(100-0)** = 0% control Bread, **PH** **(97.5-2.5)** = 97.5% flour with 2.5% addition of AXs, **PH** **(95-5)** = 95% flour with 5% addition of AXs, **PH** **(92.5-7.5)** = 92.5% flour with 7.5% addition of AXs, **PH** **(90-10)** = 90% flour with 10% addition of AXs, means with different letter (a-e) within rows are significantly different ($p<0.05$)

Table 9. Effect of arabinoxylans on mixographic characteristics of wheat flour

Treatments (PH_{F-AX})	**Peak height (BU)**	**Mixing time (min)**
PH **(100-0)**	53.23±0.21[e]	6.23±0.04[a]
PH **(97.5-2.5)**	60.11±0.13[d]	6.08± 0.03[b]
PH **(95-5)**	63.19±0.17[c]	5.88± 0.13[c]
PH **(92.5-7.5)**	65.69±0.18[b]	5.82± 0.13[d]
PH **(90-10)**	67.72±0.11[a]	5.72± 0.01[e]

BU= Brabender Units, **PH=** Psyllium husk**; F=** Flour**; AX=** Arabinoxylan, **PH** **(100-0)** = 0% control Bread, **PH** **(97.5-2.5)** = 97.5% flour with 2.5% addition of AXs, **PH** **(95-5)** = 95% flour with 5% addition of AXs, **PH** **(92.5-7.5)** = 92.5% flour with 7.5% addition of AXs, **PH** **(90-10)** = 90% flour with 10% addition of AXs, means with different letter (a-e) within rows are significantly different ($p<0.05$)

Table 10: Effect of Arabinoxylans on bread hardness

Parameter	**Storage days**	**Bread with AXs addition**				
		PH (100-0)	**PH (97.5-2.5)**	**PH (95-5)**	**PH (92.5-7.5)**	**PH (90-10)**
PPH	0	32.02±0.12[a]	29.71±0.14[b]	28.28±0.11[c]	27.86±0.07[d]	26.61±0.05[e]
	6	36.54±0.17[a]	31.33±0.13[b]	30.02±0.05[c]	29.28±0.03[d]	28.14±0.02[e]
IPH	0	35.82±1.02[a]	34.52±0.18[b]	33.05±0.12[c]	30.87±0.12[d]	28.86±0.04[e]
	6	37.18±1.11[a]	36.85±0.21[b]	35.73±0.15[c]	32.48±0.13[d]	30.16±0.07[e]

*** PH=** Psyllium husk**; F=** Flour**; AX=** Arabinoxylan, **PH** **(100-0)** = 0% control Bread, **PH** **(97.5-2.5)** = 97.5% flour with 2.5% addition of AXs, **PH** **(95-5)** = 95% flour with 5% addition of AXs, **PH** **(92.5-7.5)** = 92.5% flour with 7.5% addition of AXs, **PH** **(90-10)** = 90% flour with 10% addition of AXs, means with different letter (a-e) within columns are significantly different ($p<0.05$)

Table 11: Effect of Arabinoxylans on moisture

Parameter	**Storage days**	**Bread with AXs addition**				
		PH (100-0)	**PH (97.5-2.5)**	**PH (95-5)**	**PH (92.5-7.5)**	**PH (90-10)**
Pakistani Psyllium Husk	0	43.28±1.86[e]	44.74±1.83[d]	45.35±2.24[c]	45.92±2.38[b]	46.51±2.91[a]
	6	39.22±1.22[e]	40.31±1.87[d]	41.02±1.92[c]	42.13±2.02[b]	42.21±1.02[a]
Indian Psyllium Husk	0	42.72±1.64[e]	43.31±0.96[d]	44.98±1.03[c]	44.72±1.92[b]	45.86±1.84[a]
	6	38.18±0.75[e]	39.85±0.82[d]	40.98±1.05[c]	40.48±1.63[b]	41.67±0.87[a]

PH= Psyllium husk**; F=** Normal flour**; AX=** Arabinoxylan, **PH** **(100-0)** = 0% control Bread, **PH** **(97.5-2.5)** = 97.5% flour with 2.5% addition of AXs, **PH** **(95-5)** = 95% flour with 5% addition of AXs, **PH** **(92.5-7.5)** = 92.5% flour with 7.5% addition of AXs, **PH** **(90-10)** = 90% flour with 10% addition of AXs

Table 12: Effect of Arabinoxylans on bread loaf volume

Parameter	**Storage days**	**Bread with AXs addition (cm^3)**				
		PH (100-0)	**PH (97.5-2.5)**	**PH (95-5)**	**PH (92.5-7.5)**	**PH (90-10)**
PPH	0	427.89±25.67[e]	433.33±26.00[d]	445.67±27.13[c]	451.67±27.12[b]	463.33±26.18[a]
	6	424.33±24.27[e]	429.83±27.21[d]	444.02±18.92[c]	449.13±28.23[b]	462.14±18.02[a]
IPH	0	434.72±19.64[e]	445.31±21.96[d]	447.98±21.03[c]	448.74±20.92[b]	451.86±19.84[a]
	6	431.18±18.75[e]	443.85±19.82[d]	445.98±20.05[c]	446.48±21.63[b]	450.67±20.87[a]

* **PH=** Psyllium husk**; F=** Flour**; AX=** Arabinoxylan, **PH $_{(100-0)}$** = 0% control Bread, **PH $_{(97.5-2.5)}$** = 97.5% flour with 2.5% addition of AXs, **PH $_{(95-5)}$** = 95% flour with 5% addition of AXs, **PH $_{(92.5-7.5)}$** = 92.5% flour with 7.5% addition of AXs, **PH $_{(90-10)}$** = 90% flour with 10% addition of AXs

Parameter	**PH $_{(100-0)}$**		**Bread with AXs addition**		
		PH $_{(97.5-2.5)}$	**PH $_{(95-5)}$**	**PH $_{(92.5-7.5)}$**	**PH $_{(90-10)}$**
Appearance	8.41^{a}	8.36^{b}	8.26^{d}	8.35^{c}	8.02^{e}
Colour	7.98^{a}	7.58^{c}	7.72^{b}	7.58^{d}	7.11^{e}
Taste	7.63^{b}	7.69^{a}	7.58^{d}	7.61^{c}	7.47^{e}
Flavour	7.71^{b}	7.75^{a}	7.62^{c}	7.75^{a}	7.03^{d}
Texture	7.11^{a}	6.83^{c}	6.87^{b}	6.83^{c}	6.15^{d}
Overall acceptability	7.71 ^{a}	7.58^{b}	7.56 ^{c}	7.58^{b}	7.10^{d}

Table 13: Sensory Evaluation of bread

PH= Psyllium husk**; F=** Flour**; AX=** Arabinoxylan, **PH $_{(100-0)}$** = 0% control Bread, **PH $_{(97.5-2.5)}$** = 97.5% flour with 2.5% addition of AXs, **PH $_{(95-5)}$** = 95% flour with 5% addition of AXs, **PH $_{(92.5-7.5)}$** = 92.5% flour with 7.5% addition of AXs, **PH $_{(90-10)}$** = 90% flour with 10% addition of AXs

Biochemical composition of Psyllium husk

Moisture content is a crucial factor in food quality, affecting taste, shelf life, safety, texture, and overall quality. It determines density, viscosity, appearance, and composition, controlling microbial load and preventing spoilage. It is a fundamental parameter for food product classification. The biochemical composition of nutrients in Psyllium Husk varieties (Pakistani & Indian) are presented in Table 2. The current findings indicate that Pakistani Psyllium Husk (PPH) had a slightly higher moisture content (6.9±0.01) as compared to Indian Psyllium Husk (IPH) (5.49±0.01). While, Other nutrients including ash, crude fiber, protein, and NFE of PPH had slightly lower than IPH. According to Waleed et al. (2022), the PH sample exhibited moisture, ash, crude protein, crude fiber, crude fat, and NFE in quantities of 4.9 ± 0.01, 4.1 ± 0.01, 3.9 ± 0.05, 20.23 ± 0.40, 1.2 ± 0.01, and 78.2 ± 4.01 g/100 g, respectively. These outcomes are strongly corroborated by the present findings.

Total Dietary Fiber (soluble and insoluble dietary fiber)

The total dietary fiber (soluble and insoluble) of Pakistani psyllium husk and Indian psyllium husk is depicted in Table 3. The total dietary fiber content in IPH (51.46±0.14) is slightly higher than PPH (48.76±0.34), respectively. Soluble content results were 3.44±0.04 and 3.98±0.02, while insoluble content was 46.32±0.42 and 49.62±0.12 in psyllium husk varieties. Dietary fiber values in a study varied from those in Guo et al. (2008), which may have been caused by variations in assessment techniques and varieties. The husks of ripe seeds are the source of psyllium, a water-soluble fiber. Commonly utilized as pharmaceutical supplements and food additives in processed foods, psyllium dietary fibers assist people manage their weight, reduce glucose levels in diabetics, and lower serum cholesterol levels in hyperlipidemics. The polysaccharide found in psyllium has pharmacological significance and therapeutic value in treating constipation, irritable bowel syndrome, diarrhea, diabetes, ulcerative colitis, colon cancer, and hypercholesterolemia. Additionally, psyllium can be used to develop drug delivery systems (Elhassaneen et al., 2021).

Mineral analysis

Minerals are crucial chemical elements for life, essential for maintaining good health, and are required in varying amounts depending on physiological function, making them essential for organism's function. The mean values of Psyllium Husk Varieties, including phosphorus, potassium, calcium, phosphorus, magnesium and sodium are shown in Table 4. In Psyllium Husk Varieties, the greatest value was observed in potassium and the smallest value in phosphorus, while other elements such as potassium, magnesium, and sodium are slightly higher in IPH, respectively. The current results are closely corroborated with Guo et al., (2008) carried out research on fractionation and physicochemical characterization of psyllium gum. It was concluded that mineral content of psyllium husk varieties which was calcium (1500), phosphorus (140), magnesium (150), potassium (8500), sodium (640) and sulphur (23), respectively.

Arabinoxylans content of Psyllium Husk Varieties

Table 5. explicated mean values regarding arabinoxylans contents of Psyllium Husk Varieties. The maximum arabinoxylan content were revealed by in IPH variety 37.02±0.05 g/100g. The PPH showed a minimum arabinoxylan content of 34.52±0.06 g/100 g. In the previous study, Qaisrani et al. (2014) carried out research on characterization and utilization of psyllium husk. It was determined that 46.71±2.14% of arabinoxylans made up the arabinoxylan content. A number of variables, including time, temperature, pH, and medium concentration, influence the extraction yield of arabinoxylan.

Monosaccharide composition

The monosaccharide composition of arabinoxylan extracted from psyllium husk varieties was shown in table 6. The monosaccharide moieties that were most prevalent were xylose and arabinose, while galactose, glucose, mannose, and rhamnose were the other minor ones, which are slightly higher in PPH than IPH. A similar study conducted by Van Craeyveld et al. (2008) studied the fractional form of arabinoxylan found in psyllium husk, which was 1.50% rhamnose, 21.96% arabinose, 3.76% galactose, 0.64% glucose, 56.72% xylose, and 0.40% mannose. Another study by Patel et al. (2019) also showed nearly similar results.

Phenolic compounds

Plant-based substances with phenolic properties are called polyphenols. They are known to have prebiotic effects on gut bacteria, alter macronutrients digestion, and affect oxidative and inflammatory stress. They have a phenyl-ring structure and hydroxyl substituents, ranging from simple aromatic-ring structures to complex tannins (Bertelli et al., 2021). According to the results of the current study, which calculated the amount of phenolic compounds in AXs, the total phenolic and flavonoid contents in AXs of psyllium husk varieties were 7.82±0.17 and 8.12±0.18 mg GAE/g and 1.95±1.50 and 2.24±0.02 mg CE/g, respectively. It is shown in table 7. Sagar et al. (2020) found that Plantago ovata seeds had total phenolic and flavonoid levels of 8.72±0.17 mg GAE/g and 2.11±1.50 mg CE/g, respectively.

Rheological Properties of Dough

Farinographic analysis

Dough is created when wheat flour, Ispaghol husk arabinoxylans, and water are combined. Its development occurs during the mixing phase as a result of intricate interactions among the components of wheat. The absorption of water is essential for achieving the ideal consistency and for producing superior bread dough. Applying the appropriate amount of water prevents the mixture from becoming too sticky. It is shown in Table 8, with the increment of PHAXs levels, the water absorption of the dough gradually increased. PH addition to bread could enhance gluten network development and quality by improving water absorption via hydrophilic contacts and hydrogen bonding with molecules of carbohydrate and protein. The duration of dough development was high in PH $_{(100\text{-}0)}$ (8.25±0.66), followed by PH $_{(97.5\text{-}2.5)}$, PH $_{(95\text{-}5)}$, PH $_{(92.5\text{-}7.5)}$, and PH $_{(90\text{-}10)}$, which were 7.99±0.16, 7.78±0.38, 7.66±0.38, and 6.75±0.25, respectively. Development time for dough PH $_{(90\text{-}10)}$ (6.75±0.25 min) was lower than control treatment PH $_{(100\text{-}0)}$ (8.25±0.66). When psyllium husk arabinoxylan levels were high, farinograph characteristics indicated an increase in dough stability and mixing tolerance index. By adding arabinoxylans in different concentrations, the softness of wheat flour dough also showed a declining trend. In PH $_{(100\text{-}0)}$, PH $_{(97.5\text{-}2.5)}$, PH $_{(95\text{-}5)}$, PH $_{(92.5\text{-}7.5)}$, and PH $_{(90\text{-}10)}$, the dough's softness was found to be 139.4±0.02, 138.5±0.02, 137.7±0.03, and 132.3±0.06%, respectively. Sudha et al. (2007) found that when the amount of bran in the wheat flour-bran blends increased from 0% to 40%, the Farinograph properties of the blends increased from 60.3% to 76.3% in water absorption.

Mixographic analysis

The findings concerning the mean values of peak height variation in wheat flour due to the addition of arabinoxylans indicated a notable increase in peak height. In the PH (90-10) treatment, the highest peak height recorded was 67.72± 0.11 BU in flour containing 10% arabinoxylans. The results for peak height showed a significant enhancement with the incorporation of arabinoxylans (refer to Table 9). For the treatments PH $_{(100\text{-}0)}$, PH $_{(97.5\text{-}2.5)}$, PH $_{(95\text{-}5)}$, PH $_{(92.5\text{-}7.5)}$, and PH $_{(90\text{-}10)}$, the mixing times were measured at 6.23±0.04, 6.08± 0.03, 5.88± 0.13, and 5.72± 0.01 minutes, respectively. The analysis of mean values indicated that the longest mixing time (6.23 ± 0.04 min) was found in the control treatment PH $_{(100\text{-}0)}$, while the shortest mixing time (5.72± 0.01 min) was observed in the flour with PH $_{(90\text{-}10)}$ containing 10% arabinoxylans. This study aligns closely with the findings of Gomez et al. (2011), who reported that mixing time and peak height in wheat flour ranged from 4.57±0.03 to 6.80±0.06 and 43.3±1.3 to 47.4±0.9, respectively.

Product development

During a 5-day storage period, physical and chemical characteristics of the control and psyllium husk arabinoxylan-containing bread were assessed every two weeks. Similarly, during the entire investigation, estimates of textural characteristics and physicochemical changes were made at the appropriate intervals.

Texture Analysis

The study analyzed the hardness of bread prepared with different levels of PHAXs along with storage intervals. As shown in table 10, the results showed the hardness of the bread was notably influenced by these factors, with the interaction between psyllium husk arabinoxylans (PHAXs) levels and storage intervals also showing a significant effect. The hardness of the bread increased significantly as a result of storage intervals, but it dropped greatly as a result of elevated PHAX levels. The mean hardness values for the bread from PHAXs treatments were 34.02±0.12, 29.71±0.14, 28.28±0.11, 27.86±0.07, and 26.61±0.05 N at 0-day analysis. The highest hardness was found in PH $_{(100\text{-}0)}$, PH $_{(97.5\text{-}2.5)}$, PH $_{(95\text{-}5)}$, PH $_{(92.5\text{-}7.5)}$, and PH $_{(90\text{-}10)}$ treatments at 6-day intervals. The PHAXs values increased after 6-day storage intervals, reaching 37.18±1.11, 36.85±0.21, 35.73±0.15, 32.48±0.13, and 30.16±0.07 N in PH $_{(100\text{-}0)}$, PH $_{(97.5\text{-}2.5)}$, PH $_{(95\text{-}5)}$, PH $_{(92.5\text{-}7.5)}$, and PH $_{(90\text{-}10)}$ treatments, respectively. In a previous study, Biliaderis et al., (1995), similarly noted a decrease in the hardness of bread as the levels of arabinoxylans, the primary constituent of psyllium, were elevated.

Moisture content of bread

The study examined the moisture content of bread prepared with psyllium husk arabinoxylans varieties. The results showed a gradual increase in moisture content with the addition of PHAXs varieties (Table 11). The moisture content decreased with storage intervals (0-6 days). In the analysis conducted on 0-day, the incorporation of 5% and 10% of PHAX types into the bread dough demonstrated a rising trend in moisture content. The maximum moisture content was recorded in the PH $_{(90-10)}$ treatment, while the highest moisture was observed at 10% levels. After 6 days, the moisture content decreased to 41.67±0.87%. The mean values for PHAXs showed maximum moisture in all five treatments at 0-day, while the minimum was observed in PHAXs treatments. After 6-day storage, the moisture content decreased, with the lowest values recorded in PH $_{(100-0)}$, PH $_{(97.5-2.5)}$, PH $_{(95-5)}$, PH $_{(92.5-7.5)}$, and PH $_{(90-10)}$ were 38.18±0.75, 39.85±0.82, 40.98±1.05, 40.48±1.63 and 41.67±0.87%, respectively.

Bread loaf volume

Table 12 presents the results according to mean squares for bread volume. Different PHAX levels and storage intervals clearly had a substantial impact on volume. There are also notable variations in the ways that treatments and days interact. Although a declining trend in bread volume was observed during the storage period, the mean values for this attribute indicated that there was a considerable gain in bread volume by the varied rates of PHAXs. In all treatments (PH $_{(100-0)}$, PH $_{(97.5-2.5)}$, PH $_{(95-5)}$, PH $_{(92.5-7.5)}$, and PH $_{(90-10)}$) of psyllium husk arabinoxylans got the highest volume 427.89±14.67, 433.33±13.00, 445.67±13.13, 451.67±12.12 and 463.33±14.18, respectively, at 0-day. After six days, the volume of bread reduced, and the values were 424.33±14.27, 429.83±14.21, 444.02±11.92, 449.13±12.23 and 462.14±11.02 in PH $_{(100-0)}$, PH $_{(97.5-2.5)}$, PH $_{(95-5)}$, PH $_{(92.5-7.5)}$, and PH $_{(90-10)}$ treatments respectively. Control treatment of Pearl-11 volume of bread was 434.72±11.64, after the addition of PHAXs, highest bread volume (451.86±12.84) was noted in 10% PHAXs treatments at 0-day. Other treatment of PHAXs PH $_{(97.5-2.5)}$, PH $_{(95-5)}$, PH $_{(92.5-7.5)}$ had 445.31±12.96, 447.98±10.03 and 448.74±10.92, respectively. The lowest values were observed in PHAXs treatments after 6-days storage interval 431.18±10.75, 443.85±12.82, 445.98±13.05, 446.48±11.63 and 450.67±13.87 in PH $_{(100-0)}$, PH $_{(97.5-2.5)}$, PH $_{(95-5)}$, PH $_{(92.5-7.5)}$, and PH $_{(90-10)}$ treatments, respectively. A significant increasing trend was evaluated in bread volume after the addition of psyllium husk arabinoxylans. In a study, Pejcz et al. (2018), also showed nearly similar results.

Sensory evaluation

Sensory evaluation of PH $_{(100-0)}$, PH $_{(97.5-2.5)}$, PH $_{(95-5)}$, PH $_{(92.5-7.5)}$, and PH $_{(90-10)}$ treatments are presented in Table 13. The panelists rated the four bread varieties from "like moderately" to "like very much" based on their appearance and color. There were no statistically significant differences in the panelists' ratings for appearance and color since they were told to evaluate each piece of bread separately rather than in relation to one another. Each of the four loaves received a texture and flavor grade between "like somewhat" and "like moderately." The taste scores were relatively lower due to the absence of any additional flavoring. The incorporation of psyllium husk arabinoxylans at levels of 5% and 10% in the bread did not have a significant impact on the overall acceptability ratings. According to the findings of this study, it is advisable to use up to 5% arabinoxylan in bread and similar products. The texture was rated as "like slightly" when arabinoxylan was included in the manufacturing process, thereby enhancing the overall approval of bread with a high fiber content that contains coarsely powdered arabinoxylans.

CONCLUSION

Psyllium husk arabinoxylans (PHAXs) positively influence the bread water activity, which in turn lower microbial proliferation and extends the bread shelf life. The amount of PHAXs present in the dough matrix determines the beneficial benefits. These useful components also play a crucial role in preserving the moisture content of the bread, thereby improving its freshness and softness. Additionally, PHAXs contribute to an increase in loaf volume during the bread-making process, mitigate retrogradation ae well as significantly increase both the bread storage stability and shelf life. The functional components of PHAXs have qualities that are essential to the cereal sector. Nevertheless, it is essential to monitor their compositions to ensure precision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Author's Contribution

Muhammad Waleed conducted research, analyzed data, and wrote manuscript. Farhan Saeed is the Corresponding Author. He helped in planning of experiment, supervised throughout the experiment, and reviewed the manuscript. Muhammad Afzaal helped in the conceptualization and planning of the experiment. Bushra Niaz reviewed and edited this manuscript.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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