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Enhancing rheological properties of dough and quality of potato fibre-enriched bread

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Abstract: This study investigates the effect of varying concentrations of potato fibre (PF) (1, 2, and 3%) on wheat flour (WF) dough rheological properties and the resultant pan bread quality. Chemical analysis, physical characteristics (weight, loaf volume, and specific volume), and colour attributes were estimated to assess bread quality. The impact of PF on bread sensory evaluation was estimated. The addition of PF significantly affected the properties of the dough. Moreover, the data indicated a substantial increase in water absorption ($P \leq 0.05$) from 57.2% for the control to 65.5, 73.3, and 77.6% with the addition of 1, 2, and 3% PF to WF, respectively. Protein, crude fibre, and ash levels significantly increased ($P \leq 0.05$) with higher PF ratios. Moisture and carbohydrate contents were markedly reduced ($P \leq 0.05$). The specific volume considerably decreased from 3.15 $cm^3 \cdot g^{-1}$ in the control to 2.9, 2.74, and 2.53 $cm^3 \cdot g^{-1}$ with the addition of 1, 2, and 3% PF to WF, respectively. All replacement samples exhibited no significant alterations ($P \leq 0.05$) in L^* values and substantially ($P \leq 0.05$) increased values of yellowness (b^*) in all fortified samples relative to the control. Sensory assessments revealed that PF can be incorporated into WF at concentrations of 1% and 2% without compromising the overall acceptability of bread compared to the control.

Keywords: wheat flour; farinograph; bread quality; water absorption; specific volume

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Bread is among the most widely consumed foods globally (Elkatry et al. 2023). Owing to its widespread consumption and popularity, bread is one of the most affordable and essential food items in the world. It is regarded as one of the most basic foods produced, and its characteristics can vary from nation to nation (Barnes 2023). Dietary fibre (DF) is a prevalent and essential component of a new generation of healthy food products that consumers want daily. DF enhances the nutritional content of bread but typically modifies rheological qualities of dough, ultimately affecting bread quality and sensorial evaluation (Gómez et al. 2003; El-Beltagi et al. 2017, 2022). Fibre source, along with the kind and level of processing, determines its functional characteristics (Elleuch et al. 2011). Today, bakeries have access to a wide variety of DF sources, some of which have a comparatively high soluble dietary fibre (SDF) level (Guillon et al. 2011; El-Beltagi et al. 2017). In addition to the functional effects of insoluble dietary fibre (IDF) fraction, the presence of an SDF fraction in DF can improve physiological functions (Guillon and Champ 2000). Consequently, the production of fibre-enriched bread is an effective means to enhance fibre consumption (Gómez and Oliete 2016). Numerous authors examined the incorporation of substantial proportions of various types of DF in baking, however, they typically faced significant challenges in dough manipulation and bread quality unless certain food additives were used. The primary issue with including DF in baking is the considerable decrease in loaf volume and the altered texture of the resulting bread (Kurek and Wyrwisz 2015).

Potatoes and their derivatives have long been incorporated into bread formulations to improve texture and retain moisture. Additionally, they have historically served to enhance flavour and prolong freshness. Mashed potatoes, cooked flour, and yeast were combined to create a ferment used as a leavening agent, as potatoes are recognised as an excellent nutrient for yeast (Ezekiel and Singh 2011). Numerous historical studies exist regarding the use of potatoes and other dehydrated potato derivatives (Camire et al. 2009). DF, functioning as a bulking agent in the digestive tract, holds significant importance in health and nutrition (Gill et al. 2021). Moreover, previous studies indicated that potato peel may serve as a viable source of DF. Ali et al. (2020) evaluated chemical and physical characteristics of potato peel and performed baking tests to assess the mixing and baking attributes of flours with varying concentrations of potato peel components. Potato peel is evidently superior to wheat bran in mineral content, total DF, water retention capacity, lower carbohydrate content, and absence of phytate. These nutritional benefits were seen in baking quality assessments. This research primarily aimed to provide breads with enhanced nutritional value while ensuring high consumer acceptance, considering the need to increase DF intake and the demand for healthier yet sensory-pleasing foods. This research investigates the impact of varying concentrations of potato fibre (PF) (1, 2, and 3%) on rheological characteristics of wheat flour (WF) dough and resultant pan bread quality.

MATERIAL AND METHODS

Materials

Wheat flour with 72% extraction rate (medium granulation, particle size 150–250 μm) was obtained from the East Delta Milling Company, Zagazig City, Egypt. PF (dietary fibre content ≥ 70%, moisture ≤ 8%) was provided by Ceamsa (O Porriño, Spain). Fresh compressed baker's yeast (dry matter 30–32%) was purchased from the local market in Zagazig, Egypt, along with analytical-grade sodium chloride (NaCl), granulated white sugar, and spray-dried skimmed milk powder (fat content < 1.5%). Refined maize oil (food grade, peroxide value < 10 meq $O_2 \cdot kg^{-1}$ oil) was also obtained locally. All chemicals and reagents used were of analytical grade and met standard food research specifications.

Chemical composition and mineral analysis of wheat flour

The standard AACC method 44-15A (Rasper and Walker 2000) was used to determine the proximate composition of WF used in this investigation. Calcium, magnesium, iron, zinc, sodium, and potassium contents of the flour were determined by atomic absorption spectrophotometry as outlined in Rasper and Walker (2000).

Wheat flour, potato fibre blends, and pan bread preparation

Flour blends were created by substituting WF with PF at levels of 0, 1, 2, and 3%, and the impact of PF substitution on the rheological properties of WF dough was analysed using a Brabender FarinoGraph (Brabender, Germany). Subsequently, pan bread was prepared using these blends, and proximate composition, physical properties, and sensory attributes of the PF-enriched bread were evaluated.

Pan bread was produced using the straight dough method outlined in AACC method 10-10B (2022), as previously detailed (Zafar et al. 2015). In a dough mixing bowl, 1 kg flour, 15 g dry yeast, 10 g salt, 10 g bread improver

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(commercial blend containing ascorbic acid, α-amylase, and emulsifiers), 60 g sugar, 20 g milk powder, and 60 g maize oil were combined with 500 mL of water until the dough developed optimally, as indicated by dough clumped around mixing hook, and mixing bowl was completely cleaned. Components were combined at 30 rpm for 4 min, followed by 60 rpm for 6 min. The dough was allowed to rest at 28 °C for 20 min, and it was then divided, rolled, and automatically moulded in a moulding machine (Sinmag SM-380, Taiwan). Each item was placed in a metal pan and left to ferment for 60 min at 30 ± 2 °C and 85 ± 2% RH in a fermentation cabinet (Salva, Spain) and was subsequently baked in an electrically heated oven (Tagliavini, Italy) for 15–20 min at 210–220 °C.

Rheological properties

Rheological properties of WF with 1, 2, and 3% PF were evaluated using the Brabender FarinoGraph (Brabender, Germany) as outlined by Rasper and Walker (2000).

Pan bread evaluation

PF-enriched bread was prepared and evaluated for its chemical composition, physical properties, colour characteristics, and sensory attributes.

Chemical composition. The standard AACC method 44-15A was used to determine the proximate composition of PF-enriched bread according to Rasper and Walker (2000).

Physical characteristics. Loaf weight, volume, and specific volume were estimated as described by Shittu et al. (2007). The loaf weight of pan bread samples was recorded using a digital scale, while loaf volumes were assessed using the rapeseed displacement method. Specific volume was calculated from the following equation:

$$\text{Specific volume}\left(\text{cm}^3\cdot\text{g}^{-1}\right)=\frac{\text{loaf volume}}{\text{loaf weight}} \quad (1)$$

Colour characteristics. Hunter Lab colour analyser (Hunter Lab ColorFlex Ez, USA) was employed to determine colour attributes of the PF-enriched bread (L^*, a^*, and b^*). L^* value (lightness) spans from 0 (black) to 100 (white), whereas the a^* value denotes redness ($+a^*$) or greenness ($–a^*$) and the b^* value signifies yellowness ($+b^*$) or blueness ($–b$).

Organoleptic evaluation. A sensory evaluation of pan bread was performed using a nine-point hedonic scale (1 = dislike extremely, 9 = like extremely) to assess taste, colour, flavour, texture, appearance, and overall acceptability. The panel consisted of 15 trained staff members (eight females and seven males, aged 25–45 years) from the Faculty of Agriculture, Zagazig University. Evaluations were performed in a well-lit sensory laboratory under controlled environmental conditions (22 ± 2 °C, fluorescent white lighting). Panellists were provided with water to cleanse their palates between samples.

Statistical analysis

Data were analysed via SPSS for Windows, Version 23.0 (IBM Corp., Armonk, USA) by one-way ANOVA. The distinctions among examined factors were analysed using the protected Tukey's HSD test at a significance threshold of $P \leq 0.05$.

RESULTS AND DISCUSSION

Wheat flour proximate and mineral analysis

Proximate composition and mineral content of 72% extraction wheat flour are presented in Table 1. The moisture, protein, fat, crude fibre, ash, and total carbohydrate were measured, along with levels of Zn^{2+}, Fe^{2+}, Ca^{2+}, K^+, Mg^{2+}, and Na^+.

Rheological properties

The results (Table 2, Figure 1) demonstrate the impact of replacing WF with 1, 2, and 3% PF on farinograph parameters. Data revealed a substantial increase in water absorption ($P \leq 0.05$) from 57.2% for the control sample (100% WF) to 65.5, 73.3, and 77.6% with the addition of 1, 2, and 3% PF to WF, respectively. Dough properties were impacted by the addition of PF at levels of 1, 2, and 3% because it increased the absorption

Table 1. Proximate analysis of wheat flour

Constituents	Percentage (%)
Moisture	10.55 ± 0.095
Protein	13.10 ± 0.05
Fat	1.11 ± 0.02
Crude fibre	2.01 ± 0.01
Ash	0.75 ± 0.01
Carbohydrate	72.48 ± 0.14
Mineral content	[mg·(100 g^{-1})]
Zinc	0.61 ± 0.02
Iron	1.09 ± 0.03
Calcium	24.8 ± 0.72
Potassium	165.6 ± 2.08
Magnesium	15.5 ± 0.35
Sodium	15.5 ± 0.21

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Table 2. Impact of potato fibre (PF) incorporation to wheat flour (WF, 72% extraction) on farinograph parameters

Parameters	Mixture			
	100% WF	99% WF : 1% PF	98% WF : 2% PF	97% WF : 3% PF
Water absorption (%)	57.2 ± 0.2^{d}	65.5 ± 0.1^{c}	73.3 ± 0.3^{b}	77.6 ± 0.2^{a}
Arrival time (min)	1 ± 0.2^{b}	0.5 ± 0.1^{c}	1 ± 0.1^{b}	1.5 ± 0.1^{a}
Dough development (min)	1.5 ± 0.1^{b}	1 ± 0^{c}	1.5 ± 0.1^{b}	2 ± 0.1^{a}
Dough stability (min)	3 ± 0.1^{a}	1 ± 0.2^{b}	1 ± 0.3^{b}	0.5 ± 0.1^{c}
Degree of weakening (BU)	120 ± 8^{d}	240 ± 5^{c}	300 ± 6^{b}	330 ± 3^{a}

$^{a–d}$different letters in the same row indicate significantly different means (Tukey's HSD test, $P \leq 0.05$); 100% WF = control
BU – Brabender units

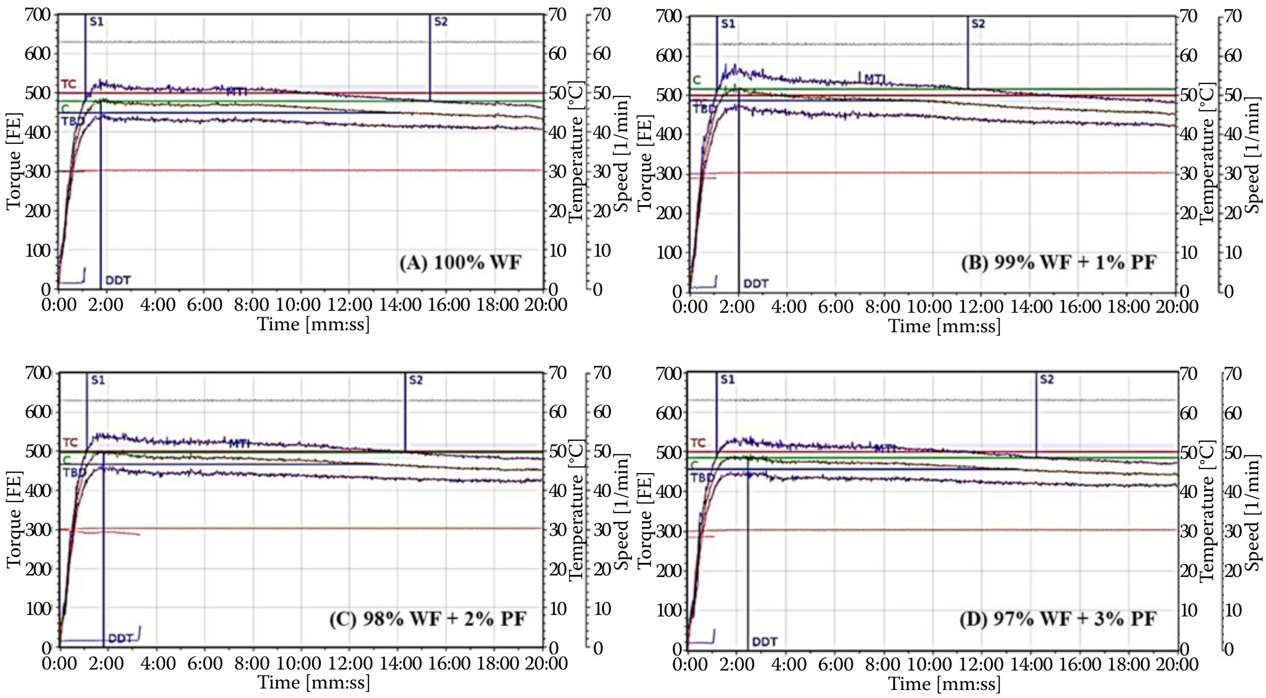

Figure 1. Impact of potato fibre (PF) incorporation into wheat flour (WF, 72% extraction) on farinograph parameters (A) Control (100% wheat flour), (B) 99% WF + 1% PF, (C) 98% WF + 2% PF, and (D) 97% WF + 3% PF

of water. According to the farinograph measurements, the dough was strengthened by the addition of a PF ingredient, allowing for higher water content. This resulted in a dough that was manageable during the baking process. Previous studies reported that dough containing fibre additives can retain higher water content (Gómez et al. 2003; Purhagen et al. 2012; Bhise et al. 2013). The fibre primarily interacts with water through hydrogen bonds formed by OH on the fibre's structure (Xu et al. 2021). Moreover, the outcomes demonstrated that, compared to control, all pan bread dough formulated with 99% WF and 1% PF exhibited reduced arrival time (min) and dough development time (DDT; min). DDT refers to the duration necessary to produce dough achieving a maximum consistency of 500 Brabender Units (BU), signifying that dough is adequately mixed and prepared for bread production (Xu et al. 2021).

Chareonthaikij et al. (2016) observed that incorporation of pineapple pomace fibre prolonged DDT of wheat dough due to the fibre's capacity to diminish the rate of hydration and gluten formation. The extended DDT has been attributed to water hydration and the formation of a gluten network. Dough stability refers to the dough's capacity to withstand mixing while maintaining optimal consistency, serving as an effective indicator of dough strength (Amjid et al. 2013). The dough stability time (ST) is a critical parameter for assessing dough strength, influenced by gluten quality and quantity. Notably, the ST of WF dough significantly ($P \leq 0.05$) decreased from 3 min in the control

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sample to 0.5 min upon substituting WF (72% extraction) with 3% of PF. The reduction in ST signifies a deficiency in dough strength. A decline in dough stability has been observed due to the interaction between PF and WF proteins, as well as gluten dilution and disruption of the starch-gluten matrix (Bhise et al. 2013). Mango peel powder (MPP) and mango seed powder (MSP) were used to partially substitute WF at varying amounts (2.5, 5, 7.5, and 10% w/w flour foundation). Findings indicated that incorporation of MPP and MSP enhanced water absorption while diminishing dough stability (Ibrahim et al. 2018). The reduction in dough stability with the greater incorporation of MPP and MSP signals a decline in dough strength and a diluting effect of MPP and MSP on flour protein. The dough's weakness may stem from the dilution of wheat gluten content due to the incorporation of PF into WF. The farinogram stability generally diminished with an increase in WF dilution, signifying a comprehensive weakening of the dough. Kohajdová et al. (2013) observed an extended DDT, reduced stability, and increased water absorption when WF was substituted with 10–30% lentil and bean flours. Schmiele et al. (2012) reported analogous outcomes in elevated DDT and arrival time attributed to the diluting impact of gluten proteins when wheat bran was incorporated into wheat flour.

Pan bread evaluation

Proximate composition of pan bread. The impact of PF addition at varying concentrations (1, 2, and 3%) on proximate analysis of processed pan bread samples was examined (Table 3). Protein, crude fibre, and ash levels considerably increased ($P \leq 0.05$) with higher PF ratios. Moisture and carbohydrate contents were significantly reduced ($P \leq 0.05$). However, the addition of PF resulted in nonsignificant variations ($P \leq 0.05$) in fat content when compared to the control. The moisture, protein, fat, crude fibre, ash, and total carbohydrates were found to be 26.7, 10.46, 1.3, 1.8, 1.1, and 58.63% in control to 22.33, 12.36, 1.6, 3.53, 2.2, and 57.96% in the blend at replacement level 3% of PF, respectively. The incorporation of fibre into bread enhanced its nutritional value, including protein, fibre, and ash content. These results agree with those of Vergara-Valencia et al. (2007) and Elawad et al. (2016).

Physical properties of pan bread. Table 4 displays the impact of replacing WF with different levels of PF on the weight, loaf volume, and specific volume of pan bread. Substituting WF with varying proportions of PF resulted in an increase in weight from 70 g in the control to 73, 75, and 78 g in the mix at PF replacement levels of 1, 2, and 3%, respectively. The results in Table 4 indicate that replacing WF with varying amounts of PF considerably reduced ($P \leq 0.05$) loaf volume from 220.99 cm^3 in the control to 211.63, 205.99, and 197.52 cm^3 at levels of 1, 2, and 3% of PF, respectively. The specific volume significantly decreased from 3.15 cm^3·g^{-1} in the control to 2.9, 2.74, and 2.53 cm^3·g^{-1} at 1, 2, and 3% of PF, respectively. Increased loaf weight and volume positively impact the economic value of retail bread. Consequently, the reduction of loaf weight during baking is an unfavourable economic factor for bakers, as consumers are typically drawn to bread loaves with greater weight and volume, perceiving them to have more substance for the same price. Specific volume, defined as the ratio of two attributes, is widely recognized in literature as a more dependable metric for loaf size. The volume of the loaf is influenced by flour protein quantity and quality (Ragaee and Abdel-Aal 2006). These findings are in line with those of Purhagen et al. (2012) and Wu et al. (2012).

Pan bread colour characteristics. Colour analysis of processed food is a significant domain, closely linked to market and customer acceptance, as it influences the

Table 3. Proximate composition (%) of the potato fibre-enriched bread

Constituents	Mixture			
	100% WF	99% WF : 1% PF	98% WF : 2% PF	97% WF : 3% PF
Moisture	26.7 ± 0.2^{a}	25.16 ± 0.70^{b}	24.03 ± 0.77^{c}	22.33 ± 0.37^{d}
Protein	10.46 ± 0.15^{b}	10.5 ± 0.60^{b}	10.8 ± 0.60^{ab}	12.36 ± 1.5^{a}
Fat	1.3 ± 0.10^{a}	1.33 ± 0.05^{a}	1.46 ± 0.20^{a}	1.6 ± 0.34^{a}
Crude fibre	1.8 ± 0.10^{c}	1.93 ± 0.05^{c}	2.46 ± 0.30^{b}	3.53 ± 0.45^{a}
Ash	1.1 ± 0.00^{c}	1.1 ± 0.00^{c}	1.7 ± 0.20^{b}	2.2 ± 0.20^{a}
Carbohydrate	58.63 ± 0.35^{ab}	59.96 ± 0.20^{a}	59.53 ± 0.11^{ab}	57.96 ± 1.80^{b}

$^{a-d}$different letters in the same row indicate significantly different means (Tukey's HSD test, $P \leq 0.05$); 100% WF = control
PF – potato fibre; WF – wheat flour

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Table 4. Impact of potato fibre (PF) incorporation to wheat flour (WF, 72% extraction) on the weight, loaf volume, and specific volume of pan bread

Parameters	Mixture			
	100% WF	99% WF : 1% PF	98% WF : 2% PF	97% WF : 3% PF
Weight (g)	70 ± 3[b]	73 ± 3[ab]	75 ± 2[ab]	78 ± 1[a]
Loaf volume (cm^3)	220.99 ± 2.5[a]	211.63 ± 1.9[b]	205.99 ± 2[c]	197.52 ± 2[d]
Specific volume ($cm^3 \cdot g^{-1}$)	3.15 ± 0.09[a]	2.9 ± 0.09[b]	2.74 ± 0.04[c]	2.53 ± 0.05[d]

[a–d]different letters in the same row indicate significantly different means (Tukey's HSD test, $P \leq 0.05$); 100% WF = control

initial impression of any food product. Colour changes between the control pan bread and the changed formula are quantified using L^*, a^*, and b^* measurements. Table 5 presents colour values, namely, the Hunter values of L^*, a^*, and b^*, recorded for PF-enriched bread. All replacement samples exhibited no significant alterations ($P \leq 0.05$) in L^* values relative to the control. All bread containing PF at different levels had significantly ($P \leq 0.05$) lower redness (a^*) values than the control. The increasing percentage of added PF to WF significantly ($P \leq 0.05$) increased the yellowness values (b^*) in all fortified samples. Overall, the incorporation of PF slightly reduced redness and enhanced yellowness, yet the colour remained within acceptable limits for consumer preference (Figure 2).

Sensory evaluation of pan bread and its mixtures. Taste, colour, flavour, texture, appearance, and overall acceptability were evaluated by a panel of 15 trained members using a nine-point hedonic scale, where 1 represented 'dislike extremely' and 9 indicated 'like extremely'. The sensory scores are listed in Table 6. The control bread (100% WF) achieved the highest overall acceptability (8.83), indicating strong consumer preference. Compared to the control, samples with 1% (8.6) and 2% (8.5) PF substitution showed only slight, nonsubstantial decreases in acceptability, suggesting that low

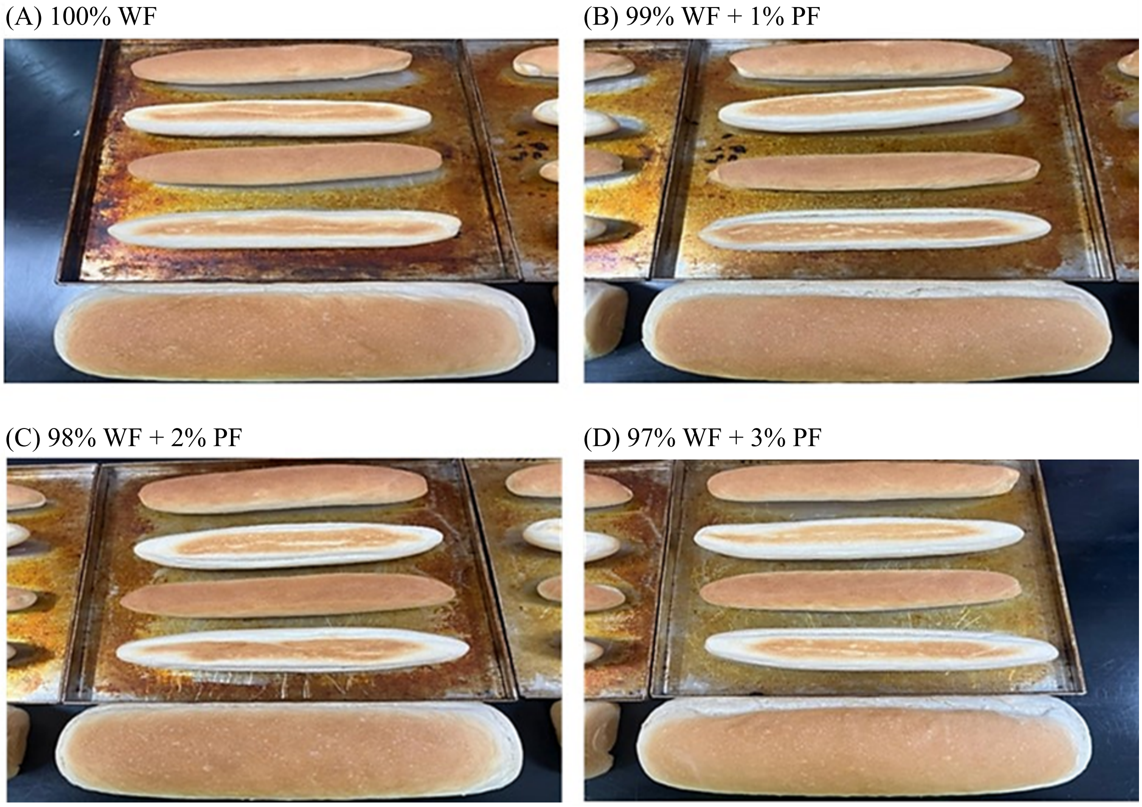

Figure 2. Impact of potato fibre (PF) incorporation to wheat flour (WF, 72% extraction) on the general appearance of pan bread. 100% WF = control

Table 5. Impact of potato fibre (PF) incorporation to wheat flour (WF, 72% extraction) on lightness (L^*), redness (a^*), and yellowness (b^*) values of pan bread

Parameters	Mixture			
	100% WF	99% WF : 1% PF	98% WF : 2% PF	97% WF : 3% PF
Lightness (L^*)	90.8 ± 0.39^a	90.6 ± 0.2^a	90.6 ± 0.07^a	90.54 ± 0.1^a
Redness (a^*)	24 ± 1^a	22.33 ± 2.5^{ab}	20 ± 3^{ab}	18 ± 1^b
Yellowness (b^*)	9.46 ± 0.01^b	9.8 ± 0.19^a	9.81 ± 0.11^a	9.95 ± 0.03^a

[a,b]different letters in the same row indicate significantly different means (Tukey's HSD test, $P \leq 0.05$); 100% WF = control

Table 6. Impact of potato fibre (PF) incorporation to wheat flour (WF, 72% extraction) on the sensory characteristics of pan bread

Parameters	Mixture			
	100% WF	99% WF : 1% PF	98% WF : 2% PF	97% WF : 3% PF
Taste	8.36 ± 0.15^a	8.13 ± 0.15^{ab}	7.93 ± 0.05^b	7.56 ± 0.15^c
Colour	8.4 ± 0.1^a	8.26 ± 0.05^{ab}	8.1 ± 0.1^{bc}	7.9 ± 0.1^c
Flavour	7.5 ± 0.1^a	7.43 ± 0.15^a	7.26 ± 0.15^{ab}	7.13 ± 0.15^b
Texture	7.56 ± 0.05^a	7.4 ± 0.1^{ab}	7.26 ± 0.15^{bc}	7.1 ± 0.1^c
Appearance	8.43 ± 0.05^a	8.36 ± 0.15^a	8.26 ± 0.05^{ab}	8.1 ± 0.1^b
Overall acceptability	8.83 ± 0.05^a	8.6 ± 0.1^b	8.5 ± 0.1^{bc}	8.33 ± 0.05^c

[a–c]different letters in the same row indicate significantly different means (Tukey's HSD test, $P \leq 0.05$); 100% WF = control

levels of PF incorporation can maintain desirable sensory attributes. However, increasing PF to 3% resulted in the lowest scores for taste, texture, and overall acceptability (8.33), reflecting a modest but perceptible decline in consumer appeal. Overall, the findings indicate that up to 2% PF can be added without markedly compromising sensory quality.

CONCLUSION

The properties of the dough were altered when PF was added to WF as a DF source. The data demonstrated that adding 1, 2, and 3% PF to WF significantly increased water absorption, which went from 57.2% for the control sample to 65.5, 73.3, and 77.6%, respectively. The pan bread's protein, fat, crude fibre, and ash content all rose when it contained varying amounts of PF (1, 2, and 3%). Moreover, the addition of PF to 72% extraction WF altered bread's physical characteristics. Sensory evaluation of bread showed high acceptability even at a 3% supplementation level. As a result, PF has significant potential as a functional ingredient in pan bread formulations and for enhancing the bread's nutraceutical qualities. Future research should investigate the effects of higher PF supplementation levels, as well as extensographic measurements, to gain deeper insights into dough rheology and bread quality.

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