Wheat Bran Modifications

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Contributor: Oluwatoyin Onipe

The established use of wheat bran (WB) as a food ingredient is related to the nutritional components locked in its dietary fibre. Concurrently, the technological impairment it poses has impeded its use in product formulations. For over two decades, several modifications have been investigated to combat this problem.

Keywords: wheat bran ; valorisation ; modification ; flavour profile ; hydration properties ; microstructure ; fibre solubilisation ; functionality

1. Introduction

Bran of cereals such as wheat, rice, and corn are potential cheap raw materials that could be used in bakery products to improve their nutritional quality with minimal effect on consumer acceptability [1][2][3][4][5]. Wheat bran (WB) is a by-product of wheat grain milling and is a great source of dietary fibre up to 45 g/100 g, B-vitamins, minerals, and bioactive compounds [6][7]. Wheat bran has been found to be a beneficial application in animal feed and human food. The nutritional composition and health benefits of WB are linked to its fibre content made up of soluble dietary fibre (SDF) and insoluble dietary fibre (IDF). The SDF is mostly composed of resistant starch, lignin, and some hemicelluloses and cellulose, while IDF is made up of oligosaccharides, arabinoxylans, inulins, and celluloses [8]. Despite this rich nutrient load, the potential of WB is limited due to its poor suitability as a food ingredient enhanced by the presence of anti-nutrients (which forms complexes with minerals, thereby impeding bioaccessibility), sensitive chemicals (glutathione), endogenous enzymes (lipase, xylanase, amylase, and peptidase), and insoluble dietary fibre (IDF), which imparts negative technological effects on the quality of bakery products [9][10].

In recent years, WB has been subjected to several pre-treatments and modifications to improve its functionality and nutritional profile. These fibres have functional groups which react with other food molecules for optimum utilisation [11][12]. However, classic extraction and hydrolysis cannot adequately expose these groups or binding sites. Therefore, to advance the application of DF, many biological, chemical, and physical methods have been exploited to modify DF (composition and microstructure) from different food sources with anticipation of desirable effects on their physiological and functional properties. The link between WB consumption and better gut health, along with a lower risk of metabolic and cardiovascular diseases, has been established [7][9].

The use of WB in bakery products poses technological challenges because of its low gas holding and water binding capacity and poor dough viscosity of dough, thereby negatively impacting loaf volume and texture [9][12]. Cellulose and arabinoxylan in WB are known to be resistant due to their strong associations with other bran compounds and their high molecular weight [13]. Moreover, the IDF of WB is less hydrophilic, and thus impairs bread porosity, leading to denser texture and smaller loaf volume and height [12]. Therefore, any attempts geared toward increasing its hydrophilicity (the quality of a material or a molecule to be attracted to water molecules and tends to be dissolved by water) will improve its hydration, nutrient, and technological properties, accompanied by its impact on baked goods. This paper highlights the benefits and shortcomings of various pre-treatments and modifications to improve the nutritional profile and functionality of WB alone or in combination.

2. Wheat Bran Modifications/Pre-Treatments

Modifications/pre-treatments such as thermal, enzymatic, and mechanical treatments geared towards reducing anti-nutritional content, extracting beneficial components, and improving solubility and functional properties of WB are discussed subsequently. The effect of various modifications on the functional and nutritional profile of WB is presented in **Table 1**.

Table 1. Wheat bran modifications and their impact on the functionality and nutritional properties.

Modification Type	Impact on Functionality	Effect on Nutritional Properties	Reference
Thermomechanical Treatment			
Milling (900, 750, 500 and 355 μm)	ND	Bound total phenolic content (TPC) and total flavonoid increased by 1.5-fold, total anthocyanin by 2-fold. Zeaxanthin and beta carotene increased in medium bran and lutein in fine bran fraction. Milling did not affect the DPPH content of wheat bran (WB).	[14]
Autoclaving (121 °C for 0.5–2 h pH: 3.5–6.2)	ND	At native pH (6–6.2) no change in phytic acid (PA) occurred. Maximum reduction * (96%) at pH 3.5 and 2 h autoclaving were reported.	[15]
Autoclaving (121 °C for 0.5–1.5 h, pH: 3.5–6.6)	ND	A 96% decrease * of PA at pH 4 and 1 h processing time. Significant increase in insoluble dietary fibre (IDF) and soluble dietary fibre (SDF). Autoclaving increased the bound and total TPC of wheat bran.	[16]
Autoclaving conditions (121 °C for 20–21 min)	Increase in water retention capacity (WRC) and water holding capacity (WHC). No change in microstructure.	Reduction in TPC, PA and IDF. An increase in alkylresorcinol, water-extractable arabinoxylan (WEAX) was observed.	[17][18]
Microwave (800 W, 2 min) and hot air oven, (150 °C for 20 min)	Water absorption capacity and swelling capacity (SC) markedly increased in both treatments by up to 11%. Hot air treatment increased bran lightness.	Both methods increased protein and total dietary fibre content. A decrease in moisture and PA content was also observed	[19]
Extrusion (temperature: 80 and 120℃, screw speed: 120 and 250 rpm)	ND	Extrusion increased WEAX content, SDF content. Fermentable carbohydrates and short-chain fatty acid (SCFA) content were higher in extruded bran.	[20]
Extrusion (temperature:140 °C, screw speed: 150 rpm, 45% moisture) + size reduction (830, 380, 250 and 180 μm)	The surface of extruded bran was full of holes and had an irregular surface structure. WHC < ORC and SC increased with extrusion and size reduction	SDF of extruded WB increased by 70% *. Antioxidant properties increased as dosage (mg/mL) increased.	[21]
Extrusion (temperature: 120 and 145 °C, moisture: 23, 27 and 33% screw speed: 310 rpm)	A greater extent of degradation of the pericarp and aleurone layer of WB was caused by very high shear than low shear extrusion using light microscopy.	A 1.8-fold and 3.5-fold increase in WEAX and free ferulic acid. PA content decreased by 19% * and a small increase in SCFA was reported after 48 h fermentation.	[13]
Milling (420, 280, 170 and 90 μm) Hydrothermal (acetate buffer (pH 4.8) at 55 °C, 60 min and incubation at 5 5°C for 24 h) Yeast fermentation (8 h at 30 °C)	Reduced WHC and swelling power and increase in water solubility index of fermented and hydrothermal bran. Size reduction increased L * values of WB.	34, 57 and 76%* reduction in PA content in milled, fermented, and hydrothermal WB. Hydrothermal and fermentation treatments increased the total dietary fibre (TDF), SDF and reduced the IDF content of WB. Mineral contents were reduced with all treatments.	[22]
Super-heated steam (15.0 m^3/h, 170 °C for 20 min) Hot air processing in an electro-thermostatic blast oven (170 °C for 20 min)	ND	Superheated steam was more efficient in enzyme inactivation, enhancement of non-starch nutrients, reduction of peroxide value, higher soluble phenolic content, and better sensory profile than hot air treatment.	[23]
Milling + Steam explosion (120–160 °C for 5–10 min)	Lightness values of WB treated with steam explosion decreased. Severe disruption of the bran cell wall by grinding and steam explosion was reported.	Milling and steam explosion alone and in combination increased AX solubilisation in fine bran. Loaf volume, SDF increased, and PA content reduced in bread with pre-treated WB.	[24]

Modification Type	Impact on Functionality	Effect on Nutritional Properties	Reference
Thermomechanical Treatment			
Steam explosion (0.8 MPa, 170 °C, 5 min) + grinding (425–75 μm)	Steam explosion and milling increased WB porosity, WHC and SC.	Fat, starch, protein, SDF, TPC, total flavonoids and DPPH contents increased with steam explosion and size reduction.	[25]
Steam explosion (0.3, 0.5 & 0.8 MPa, at 170 °C, for 5 min)	Lipase and peroxidase activity reduced and shelf life increased.	Protein and lipid content remains unchanged. SDF, TPC, TFC and DPPH values increased at maximum steam (0.8 MPa).	[26]
Microwave (2450 MHz at 1.5–2.5 min) Hot air oven (100 & 110 °C, 15, 20 & 25 min) Steaming (100, 110 & 115 °C, 15, 20 at 25 min)	All treatments increased bulk density and darkened the bran samples.	Microwave treatment at 2.5 min caused a significant reduction of PA, polyphenols, saponins, trypsin inhibitors and toxicants	[27]
Milling (ultra-centrifugal mill-500 μm) + Extrusion	Structural modification of WEAX was more distinct in extruded bran.	Milling increased WEAX content (26% *) and reduced the molecular weight of WB. No significant change in TPC, but 38% * increase in free TPC of milled bran.	[28]
Milling + Extrusion	A 1.5-fold increase in WHC and IDF content of bran fractions and a decrease in SDF content after the extrusion process.	Antioxidant capacity increased as the particle sizes of the milled bran reduced up to 180μm.	[29]
Bioprocessing (Fermentation and Enzymatic Treatments)			
Fermentation at 2–8 h with Saccharomyces cerevisiae (3–9%)	ND	A reduction (≤96%) in phytic acid content with an increase in fermentation time and yeast concentration.	[15]
Lactobacillus brevis and Kazachstania exigua (20 °C for 24 h) + enzymes (xylanase, endoglucanase and β-glucanase)	Partial degradation of the bran cell wall.	A sixfold increase * in WEAX in fermented bran and up to 11.5-fold increase * when fermentation was combined with enzymes. A 50% increase * in peptide content was observed in bioprocessed bran compared to native bran	[30]
Fermentation with L. rhamnosus (37 °C for 24–48 h)	ND	Free TPC and WEAX increased significantly. Caffeic acid was notable in fermented bran. A reduction in phytic acid (PA) content was observed.	[18]
Fermentation with S. cerevisiae (30 °C for 6 h)	Increase in water absorption capacity of WB.	An 86% decrease * of PA at pH 4 and 1 h processing time. TDF of bran was not affected by fermentation.	[10]
Fermentation with S. cerevisiae at (30 °C for 6 days)	ND	A significant increase in the TPC, DPPH, antioxidant activity of WB was observed on day 3 of fermentation.	[31]
Spontaneous and yeast fermentation (20 & 32 °C for 20 h)	ND	A significant increase (≥40%*) in folates, free ferulic acid and soluble AX in yeast-fermented bran. Acidification of bran slurries at maximum fermentation temperature.	[32]
Fermentation with L. brevis (28 °C for 16 h)	An increase in gas retention of dough and bread volume was observed with the inclusion of fermented WB. Significant reduction in bread staling compared to bread with unfermented WB. Improved viscoelasticity of dough	There was a two- and four-fold increase * in WEAX and SDF of fermented WB compared to native bran.	[33]

Modification Type	Impact on Functionality	Effect on Nutritional Properties	Reference
Thermomechanical Treatment			
Enzymatic treatment (cellulase and xylanase)	WRC increased by 16%. Enzymatic treatment improved oil holding and swelling capacity. Glucose adsorption capacity improved by 1.4-fold. Loose structure, wall structure damaged/degradation of wall PS.	A twofold increase of TPC and antioxidant properties of enzyme-treated WB compared to the control sample.	[34]
Treatment with Lactobacillus bulgaricus, Streptococcus thermophiles and Saccharomyces cerevisiae (alone and in combination)–37 °C for 24 h & 48 h	The WHC and WRC improved significantly in fermented WB. Partial degradation of aleurone cells.	Five-fold increase in WEAX content, 60% increase in phenolic lipids, 2-fold increase in SDF, 23–27% reduction in PA.	[17]
Extrusion (115 and 130 °C; screw speeds: 16, 20, and 25 rpm) + fermentation (L. plantarum and L. uvarum)	ND	The combination of both treatments lowered mycotoxin content by 80.6% * and increased biogenic amines by 42.9% * of bran samples. Fructose content increased by 15% * after fermentation.	[35]
Enzymatic treatment (β-endoxylanase and α-L-arabinofuranosidase)	WRC and fat binding capacity increased in single and combined enzyme-treated WB. Improved porosity of enzyme-treated bran dough	TPC and DPPH content increased in single and combined enzyme-treated WB. pH reduced in WB treated with xylanase and combined enzymes.	[36]

ND—not determined, *—statistically significant ($p < 0.05$).

3. Modified Wheat Bran as a Functional Ingredient in Selected Food Products

3.1. Bread

Bread produced from dough supplemented with fermented WB had better loaf volume, softer crumb, and reduced staling compared to non-fermented WB [32][37][38]. The folate content of bread loaves supplemented with fermented WB had 32–62% higher folate content [32]. Bread loaves produced from fermented bran had a better shelf life. This is probably because fermented bran retards starch retrogradation and alters water distribution between starch and gluten in the bread crumb [39]. The effectiveness of bioprocessing on improved bread properties can be linked to lower pasting viscosity of starch, solubilization of arabinoxylans, improved rheology, and faster carbon dioxide production [33][40]. The development time of dough with pre-fermented WB (3.9 min) was higher than wheat flour (2.8 min), but was significantly lower than unfermented WB (5.8 min). The specific volume of bread with 20% fermented WB was comparable to control.

3.2. Cookies and Cakes

The utilisation of heat-stabilized WB (using microwave and hot air) in cookie production improved the spread ratio and reduced hardness compared to cookies with untreated bran. Moreover, the cookies enriched with stabilized bran were more acceptable for assessors at a 5% incorporation level [41]. The specific volume and firmness of the cake made from small particle sizes of WB (50 and 80 µm) increased significantly up to 24% substitution level in the cake batter formulation. Sensory scores of cakes with 24% WB substitution were not significantly different from control cake. This implies that acceptable fibre-rich cakes can be produced from the incorporation of ≤20% of the small particle size of WB in batter formulations [42].

3.3. Noodles and Pasta

The incorporation of 30% superfine WB (27.9 µm) reduced hardness (%) and increased the adhesiveness of cooked wheat noodles. At 20% incorporation of milled bran, the appearance, taste, smell, and palatability of the noodles were comparable to control (no bran) noodles [43]. Steam treatment increased the stability of WB during storage (90 days), reducing lipase activity by 50%. Substitution of 40% of heat-treated WB in pasta formulation reduced cooking loss by 27%, increasing TDF five-fold with higher sensory scores compared to control pasta [44]. Chen et al. [45] concluded that production of fibre and acceptable Chinese noodles was possible by substituting 5–10% fine bran (210 µm) or 5% medium bran (530 µm) in wheat flour.

3.4. Fried Dough

The utilisation of milled WB of various particle sizes (6.87, 200, 250, and 500 µm) in deep-fried dough product formulations reduced fat content ranging from 2.7% to 44% [46][47] and glycemic index [48] depending on the level of addition, ranging from 1 to 20%.

3.5. Gluten-Free Products

The appreciably high nutrient contents of WB may be exploited for use in the development of gluten-free products, but its gluten content (110 g/kg) may hinder that [49]. Therefore, gluten degradation has been carried out using peptidase enzyme. Enzymatic attempts to degrade the gluten content of plant products were adequately reviewed by Scherf et al. [49]. These enzymes can be gotten from plants (cereal germination), insects (Rhizopertha dominica), fungi (Aspergillus sp.), bacteria (Bacillus and Lactobacillus spp.), and through genetical engineering.

4. Conclusions

The enhanced properties in modified WB depended on the processing method, extraction, and analysis method used which differed from one study to the other. This implies that the anticipated outcomes will determine the prospective modification methods to be used. Bioprocessing tremendously dephytinized WB, improving its antioxidant and flavour profile. Autoclaving and grinding reduced phytic acid significantly, superheated steam deactivated endogenous enzymes quickly, and extrusion increased solubility, modifying the structure of arabinoxylan. Although dry heat treatment was unfavourable for phytochemicals in WB, recent efforts in steam explosion showed good promise for the production of modified WB with improved antioxidant activity, flavour profile, shelf life, and chemical composition. A combination of pre-treatments showed promising results for the creation of functional WB with an improved nutritional profile. However, there are sequential combination treatments that have not been used, thus requiring more research. Only a fraction of the studies reviewed in this paper used the modified WB for food enrichment. Hence, follow-up studies on the use of modified WB as a functional food ingredient remain an open research prospect.

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