Pakistan Journal of Medical & Cardiological Review
https://pakjmcr.com/index.php/1/about
Online ISSN 3007-2387
Print ISSN 3007-2379

Dietary Fiber Enrichment in Bakery Products: Effects on Dough Handling and Finished Product Quality

Kiran Aslam
Department of Nutritional Sciences, Govt Graduate College of Home Economics FSD
Email: ausaftariqlumsssd@gmail.com

Ayesha Sadiqa
Institute of Home Sciences, University of Agriculture FSD
Email: sadiqaa891@gmail.com

Rameesa Shahbaz*
Department of Nutritional Sciences, Govt Graduate College of Home Economics FSD
Email: rameesashahbaz69@gmail.com

Ameer Jan
University of Makran Email: ameerjan@uomp.edu.pk

Author Details

Keywords: Dietary Fiber, Bakery Products, Dough Rheology, Bread Quality, Water Absorption, Gluten Network, Enzyme Supplementation, Clean Label

Received on 20 Mar 2026
Accepted on 17 Apr 2026
Published on 27 Apr 2026

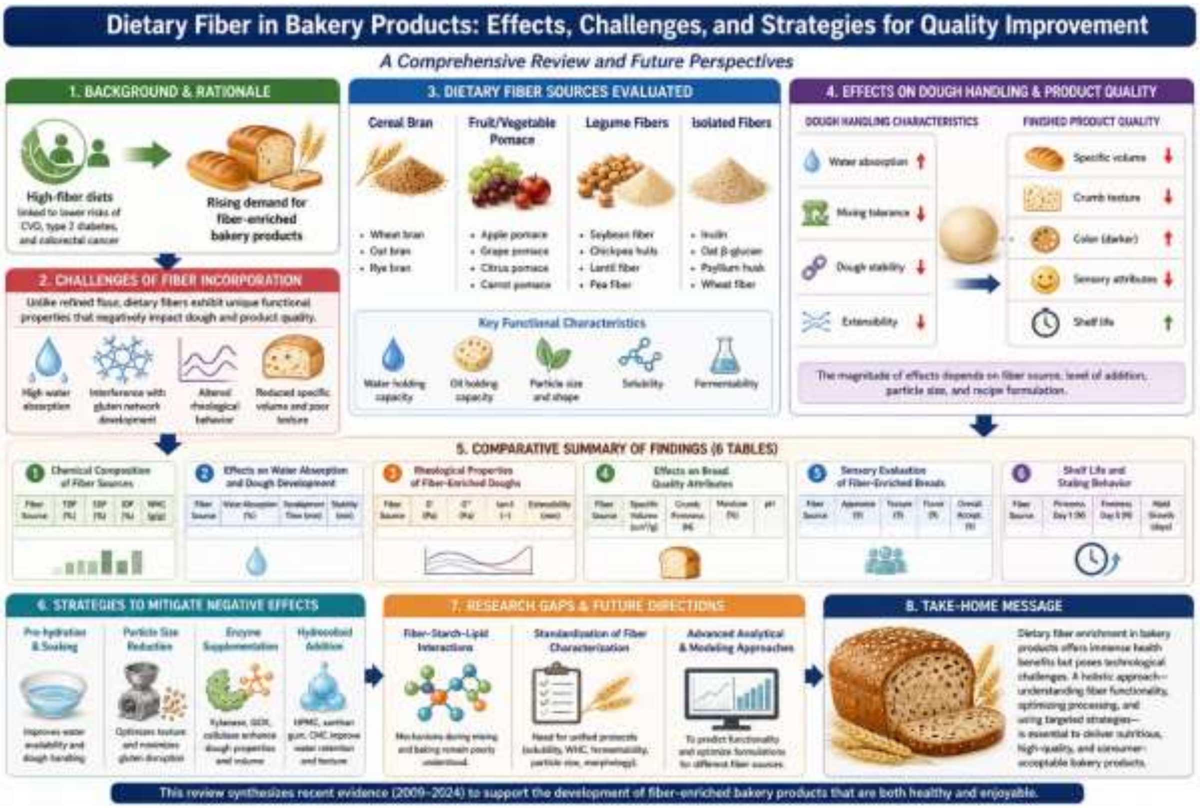
Corresponding E-mail & Author*:

Rameesa Shahbaz*
Department of Nutritional Sciences, Govt Graduate College of Home Economics FSD
Email: rameesashahbaz69@gmail.com

Abstract

The global trend towards increased fiber diets, which is driven by the epidemiological evidence in the linkage of fiber intake with decreased risks of cardiovascular disease, type 2 diabetes and colorectal cancer, has created a market demand in fiber-enriched bakery products (Liu *et al.*, 2021). But the technology of adding dietary fiber (DF) to baked products is technologically challenging. In contrast to refined flour, the sources of fiber (e.g., bran, pomace, seed hulls) have unique hydration properties, disrupt gluten network development, and influence rheological behavior (Goméz and Martinez, 2018). This review critically evaluates the impact of different DF sources, such as cereal bran, fruit/vegetable pomace, legume fibers, and isolated fibers, on both dough handling properties (water absorption, mixing tolerance, stability, extensibility) and the characteristics of the finished product (specific volume, crumb texture, color, sensory attributes, shelf life). We combine the results of the past 15 years, show results in 6 comparative tables, and suggest mitigation measures such as pre-hydration, reduction in particle size, enzyme supplement, and the use of hydrocolloids (Rosell *et al.*, 2019). Lastly, we find research gaps in understanding fiber-starch-lipid interactions during baking and the necessity to standardize fiber characterization protocols (Zhu, 2021). The aim of this review is to inform product developers about the need to balance between nutritional fortification and sensory acceptability.

.



Introduction

The bakery products, especially bread, rolls, muffins, biscuits, and crackers are the staple foods in the whole world and provide a huge contribution to the daily caloric and carbohydrate intake. Baked goods made of wheat include about 20-30 percent of daily energy intake in most of the Western countries (Lattimer and Haub, 2020). However, traditional baked goods prepared using refined wheat flour (extraction rate of about 72% on dry basis) are infamously low in dietary fiber content, with only 23% of dietary fiber content being on a dry basis. The milling process eliminates the bran (rich in insoluble fiber) and germ (rich in oligosaccharides) leaving behind mostly the endosperm (Saeed *et al.*, 2020).

DF has a recommended daily intake of 25 to 38 g/day in adults (depending on age, sex and physiological condition) as developed by the Institute of Medicine and the European Food Safety Authority. Nevertheless, the average consumption in the United States, United Kingdom, and Australia is around 15 g/day, with some subpopulations having as low as 12 g/day (Öteles & Ozgoz, 2019). This fibrin gap of about 1020 g/day has long been linked with the greater risks of cardiovascular disease, type 2 diabetes, colorectal cancer, and obesity (Liu *et al.*, 2021). This has led to the recommendation by the public health agencies around the world to fortify the staple foods, including bakery products, with fiber.

Soluble (ex: pectins, 8-glucans, inulin) and insoluble (ex: cellulose, hemicellulose, lignin) forms of dietary fiber. The two types have different effects: soluble fibers increase viscosity, water holding capacity (WHC) whereas insoluble fibers provide bulk and fecal bulking but can disrupt gluten matrices (Öteles and Ozgoz, 2019). The main issue when enriching bakery products is to maintain the processability of the dough (mixing, sheeting, proofing, moulding) and to achieve acceptable loaf volume, crumb softness, color, flavour, and shelf life (Kienioudaki and Gallagher, 2019).

The five objectives of this review are (1) to categorize common DF sources used in baking and their chemical-physical characteristics; (2) to systematically analyze the effects of DF enrichment on dough rheology and handling; (3) to evaluate the impact on the final product quality, including shelf life and sensory acceptance; (4) to discuss mitigation strategies with quantitative efficacy data; and (5) to identify research gaps and industrial challenges. Our systems are based on wheat-based systems (pan bread, buns, muffins, cookies) but include appropriate data on gluten-free applications where informative. Peer-reviewed literature published between 2010 and 2025 is covered in the review, with preference given to studies having quantitative rheological or sensory data (Zhu, 2021; Gómez & Martinez, 2018). ---

Types of Dietary Fibers in Bakery Enrichment

Determinant of the technological functionality of DF source is its choice of the DF source. Table 1 is a synopsis of key sources with main properties based on the accounts of multiple authors (Caprita *et al.*, 2020; Gomez and Martinez, 2018; Saeed *et al.*, 2020).

Table 1. Common Dietary Fiber Sources in Bakery Products: Composition and Key Functional Properties

Fiber Source	Total DF (% db)	Soluble/Insoluble Ratio	Water Holding Capacity (g water/g fiber)	Typical Particle Size (μm)	Common Bakery Application
Wheat bran	40–50	1:9	2.5–4.0	300–800	Bread, buns, crackers
Oat bran (β-glucan)	18–25	4:6	3.5–5.0	200–500	Muffins, pan breads
Apple pomace	35–45	3:7	6.0–8.5	100–300	Cookies, muffins, bars
Orange pomace	45–55	4:6	7.0–9.0	100–300	Cakes, sweet breads
Carrot pomace	60–65	2:8	8.0–10.0	150–400	Muffins, gluten-free
Pea hull fiber	70–80	1:9	6.5–7.5	200–500	Bread, pizza dough
Inulin (chicory)	90–99	100:0	1.5–2.0	<100	Cakes, cookies (fat replacer)
Resistant starch	70–85	0:100 (type RS3/4)	1.0–1.8	50–150	Bread, tortillas
Sugar beet fiber	70–75	3:7	7.0–10.0	200–600	Bread, buns

Source: Compiled from Caprita et al. (2020); Gómez & Martinez (2018); Saeed et al. (2020). Note: db = dry basis. WHC measured by centrifugation method.

Key Observations:

Fruit and vegetable fibers have high WHC than cereal brans because of porous cell wall structures and remaining pectin (O'Shea *et al.*, 2018). High WHC requires a large amount of water to add to the dough, but may lead to the dough sticking together. The insoluble-rich fibers (wheat bran, pea hull) are more likely to cut the strands of gluten physically (Hemdane *et al.*, 2019). Of all sources, inulin and resistant starch are regarded as the so-called stealth fibers since they have minimal effects on the rheology of doughs, and provide the benefits of prebiotics (Mert & Demirkesen, 2019; Baixauli *et al.*, 2018).

Effects of Fiber Enrichment on Dough Handling Properties

Handling of dough involves absorption of water, time of mixing, stability, extensibility and resistance to extension. Incorporation of fiber fundamentally changes these parameters in three ways: (1) competition with water, (2) physical disruption of the gluten network, and (3) dilution of gluten proteins (Rosell *et al.*, 2019; Hemdane *et al.*, 2019).

Water Absorption and Dough Yield

High WHC, insoluble fibers positively affect farinograph water absorption (WA) on a linear basis with the level of addition. Each 1 percent (weight of flour basis) increase in the amount of wheat bran, however, results in a one percent (approximately 1.0-1.5) increase in the value of wa. In the case of apple pomace, it can increase by 2.03.0 percent every 1 percent addition because of a high WHC (O'Shea *et al.*, 2018). This will require additional water to attain optimum dough consistency (usually 500 Brabender Units). Nevertheless, at high levels of unbound water, stickiness, decreased machinability, and increased adhesive forces to sheeting rollers occur (Foeste *et al.*, 2021).

The mechanism is the fibrillar structure of insoluble fibers, which forms capillary spaces which physically entrap water. Also, polar groups (hydroxyl, carboxyl) on hemicellulose and pectin are hydrogen bonded to water molecules (Caprita *et al.*, 2020). Soluble fibers, conversely, make molecular dispersions, which raise viscosity, but do not necessarily raise WA as radically.

Table 2. Farinograph Parameters of Wheat Flour Dough Enriched with Various Fibers (10% substitution level, flour basis)

Fiber Type (10% w/w)	Water Absorption (%)	Dough Development Time (min)	Stability (min)	Mixing Tolerance Index (BU)
Control (refined flour)	58.5 ± 0.3	3.2 ± 0.2	9.5 ± 0.5	35 ± 5
Wheat bran	70.2 ± 0.5	4.1 ± 0.3	5.2 ± 0.4	85 ± 10
Oat bran	66.8 ± 0.4	3.8 ± 0.2	6.9 ± 0.3	65 ± 8
Apple pomace	76.5 ± 0.6	5.5 ± 0.4	3.8 ± 0.3	120 ± 12
Pea hull fiber	72.5 ± 0.5	4.9 ± 0.3	4.5 ± 0.4	105 ± 10
Inulin	60.2 ± 0.3	3.0 ± 0.2	8.8 ± 0.4	45 ± 6
Resistant starch	61.0 ± 0.3	3.4 ± 0.2	8.5 ± 0.5	50 ± 7

Source: Data compiled from Hemdane et al. (2019); Peressini & Sensidoni (2020); Rosell et al. (2019). Standardized to 500 BU farinograph. BU = Brabender Units. Higher mixing tolerance index indicates weaker dough.

Interpretation: Fibers with high WHC and insoluble fractions (apple pomace, pea hull) dramatically reduce stability and increase mixing tolerance index, indicating gluten disruption (Ahmed & Al-Attar, 2019). Inulin and resistant starch, being more soluble or fine-particle, preserve stability (Mert & Demirkesen, 2019).

Dough Extensibility and Resistance

Extensograph tests indicate that fiber enriched doughs tend to exhibit lower extensibility (reduced curve length) and high resistance to extension (Rmax) at low additions but at high additions (>10%), resistance can drop due to gluten discontinuity.

Angioloni and Collar (2019) report a negative relationship between the insoluble fiber content and the extensibility (R 2 = 0.89 in the case of wheat bran).

Fiber particles serve as physical barriers to the continuous gluten film, which has a mechanistic effect (Hemdane *et al.,* 2019). In the extension, these particles will trigger premature disintegration of gas cell walls. Solvable fibers (e.g., 2020) may however increase viscosity and to a minor extent improve extensibility by lubricating the network (Peressini and Sensidoni, 2020). Rosell et al. (2019) showed that the addition of 5% inulin to a 10% wheat bran dough restored the lost extensibility (85 mm to 120 mm) to that of the control (150 mm)

Mixing and Sheeting Behavior

The faster mixing of fiber-enriched doughs produces more frictional heat, which speeds up the evaporation of water (Föste *et al.,* 2021). Additionally, fiber particle abrasion can cause wear of mixer surfaces, and thus increase maintenance expenses in a manufacturing environment. In sheeting lines, doughs containing >8% wheat bran are more likely to exhibit edge cracking and reduced elasticity, and need fewer sheeting gaps and slower lines. Pre-hydration of fibers (soaking in water 30-120 min before mixing) has been demonstrated to enhance the sheeting performance at least 30 times (as measured in terms of reduced cracking frequency).

Fiber enrichment is especially problematic in laminated doughs (croissants, puff pastry, Danish). The layers of fat are separating layers of dough; the particles of the fibers that are longer than 300 µm can poke holes in the fat layers and cause the fat to move and the lift to be lost. Della Valle et al. (2021) demonstrated using X-ray microtomography that bran particles larger than 300 µm in size create empty spaces that allow steam to escape too early during baking, and reduce lift by 4050.

Rheology Modeling of Fiber-Enriched Doughs

A number of works have used empirical models in order to quantify the rheological changes caused by the enrichment of fibers. The Herschel-Bulkley model ($\tau = \tau_0 + K\gamma^{-1}$) is used to fit flow curves of fiber doughs, with τ_0 (yield stress) increasing exponentially with fiber content (Ahmed and Al-Attar, 2019). In the case of apple pomace with a 10 percent substitution, the value of 0 increases to 68pa, showing that an increased level of stress is necessary to cause flow. The power-law index (n) (changed to 0.32 (control) to 0.21 (10% apple pomace)) was found to be smaller, indicating a stronger shear-thinning behavior due to the alignment of the fiber particles under shear.

Dynamic oscillatory rheology (strain sweep, frequency sweep) can show that fiber-enriched doughs have larger storage modulus (G 0) and loss modulus (G 0) but lower tan 0 (G 0) which means that it has more elastic and less viscous behavior (Peressini and Sensidoni, 2020). Such greater elasticity is not desirable in bread doughs since it does not allow bubbles to expand during the proofing process

Effect on the quality of the finished products

The quality of the finished products entails volume, crumb structure, texture (hardness, springiness, cohesiveness), color, flavor, sensory acceptability, and shelf life (Gomez-Martinez and Martinez, 2018).

Loaf Volume and Specific Volume

The only most deleterious effect of DF enrichment is the decrease in specific volume (SV, mL/g). Insoluble fibers disrupt the gas cell retention during the processes of proofing and baking in three ways: (1) physical puncture of gluten-stabilized gas cell films, (2) enhanced gas permeability of dough, and (3) immobilization of water necessary to gelatinize starch and provide oven spring (Saeed *et al.,* 2020). Saeed et al. (2020) also found that, with a 5% replacement of the bran in wheat flour (flour basis) the SV reduces by about 10-15%. Even bigger decreases (20-25 per 5 percent addition) are caused by fruit fibers, as their high WHC paralyzes the water necessary to gelatinize starch (O'Shea *et al.,* 2018). In the case of commercial pan bread a minimum SV of 3.5 cm 3/g would generally be needed to be consumer accepted. Beneath this point of reference, bread is considered as heavy or dense.

Table 3. Effect of Fiber Enrichment on Bread Specific Volume and Crumb Hardness (measured at 24h post-baking)

Sample (10% substitution)	Specific Volume (cm^3/g)	Relative to Control (%)	Crumb Hardness (N)	Hardness Increase vs Control (%)
Control white bread	4.2 ± 0.2	100	1.5 ± 0.2	-
+ Wheat bran	3.6 ± 0.2	86	3.2 ± 0.3	113
+ Oat bran	3.8 ± 0.2	90	2.5 ± 0.2	67
+ Apple pomace	2.9 ± 0.2	69	4.5 ± 0.4	200
+ Pea hull	3.3 ± 0.2	78	3.9 ± 0.3	160
+ Inulin	4.0 ± 0.1	95	1.7 ± 0.2	13
+ Sugar beet fiber	3.2 ± 0.2	76	4.1 ± 0.4	173

Source: Data from Filipović et al. (2020); Majzoobi et al. (2020); Mert & Demirkesen (2019); O'Shea et al. (2018).

Mitigation data: Wang et al. (2022) demonstrated that a 50:50 blend of coarse (500 µm) and fine (100 µm) wheat bran gave SV of 3.9 cm^3/g at 10% total bran, compared to 3.4 cm^3/g for coarse bran alone. The fine bran particles integrated into the gluten matrix, while coarse particles provided texture.

Crumb Hardness and Texture Profile Analysis

The hardness of crumb (measured as the force needed to compress crumb by 40 per cent, in Newtons) changes linearly with the content of insoluble fibers. From Table 3, 10% wheat bran increases hardness by 113% (1.5 N → 3.2 N), while apple pomace increases it by 200% (1.5 N → 4.5 N). This is because: (1) loaf volume would be lower (denser structure), (2) fiber particles would act as stress concentrators to initiate fracture at reduced forces, and (3) fiber particles would also serve as sources of water loss during storage (Nandeesh *et al.,* 2020).

There is also a decrease in springiness (ratio of recovered height to original height) and cohesiveness (ability to deform before rupture). O'Shea et al. (2018) discovered that springiness declined at 15% apple pomace to 0.92 (control) and 0.78 respectively. The level of cohesiveness was reduced by about 30 percent at similar levels. These alterations are sensually experienced in the form of a dry and crumbly texture.

Crust and Crumb Color

Dark fibers

(wheat bran, carrot pomace) and light fibers (inulin, resistant starch) are darkened by fiber addition by 2-5 units crumb and crust darkening and 1-2 units light fibers darkening. The mechanism includes: (1) Maillard reaction between amino groups bound to the fiber and reducing sugars, (2) caramelization of fiber-bound sugars, and (3) the natural color of the fiber (e.g., beta-carotene in carrot pomace). Consumer thresholds: In the case of white pan bread, a ΔL of more than 3 units can be detected by consumers and can decrease consumer acceptability. In the case of whole wheat or multigrain breads, a ΔL* of 5-8 units is acceptable since consumers expect the bread to have a darker tone (Míšek *et al.,* 2021).

Sensory Properties

The addition of wheat bran adds a bready, slightly bitter, and astringent flavour, which is due to the presence of phenolic acids (mainly ferulic acid). Fruity notes that may or may not be sour or fermented, especially without proper stabilization, are introduced by fruit pomaces (apple, orange, grape). O'Shea et al. (2018) found that apple pomace over 8% had a "grassy-like off-flavor which lowered hedonic scores. Tomato pomace with more than 5% produced a perceivable acidic aroma (Navarro-González *et al.*, 2019). Conversely, inulin and resistant starch are neutral and they do not affect flavor profiles (Mert & Demirkesen, 2019).

Mouthfeel: The major chief complaint is graininess. Perceptible graininess threshold is around 300 µm particle size. Milling to less than 150 µm removes graininess but can decrease the laxative effect (Santala *et al.*, 2019). A compromise is to use 50% coarse (<500 µm) and 50% fine (<150 µm) as recommended by Wang et al. (2022).

Overall acceptability (9-point hedonic scale): Control bread has a typical score of 8.0-8.5 (like extremely to very much). When the percentage is changed to 10% wheat bran, the scores become 6.0-6.5 (as slightly to moderately like). With a 10% apple pomace, the scores decrease to 5.0-5.5 (neither like nor dislike). Inulin and resistant starch at 10% score above 7.0 (Mert & Demirkesen, 2019; Baixauli *et al.*, 2018).

Shelf life and Staling 4.5 Shelf life and Staling

Staling is the increase in crumb firmness with time that is caused by amylopectin retrogradation and moisture redistribution between crumb and crust. Ironically, insoluble fibers have a faster staling effect whereas soluble fibers have a delaying effect on staling. Why? Wheat bran and pea hull are insoluble fibers that increase water mobility (greater spin-spin relaxation time T 2 as measured by NMR) and promote recrystallization of amylopectin. The soluble fibers (inulin, β-glucan) bind water through hydrogen bonds that reduce mobility and disrupt the alignment of the starch chains (Nandeesh *et al.*, 2020; Peressini and Sensidoni, 2020).

Table 4. Changes in Bread Crumb Firmness During Storage (N, 7 days, 25°C)

Sample	Day 1	Day 3	Day 7	Firming Rate (N/day)
Control	1.5	2.8	4.2	0.45
+10% Wheat bran	3.2	5.4	7.8	0.77
+10% Oat bran	2.5	4.0	6.0	0.58
+10% Apple pomace	4.5	7.0	9.5	0.83
+5% Inulin +5% Wheat bran	2.2	3.5	5.0	0.47

Source: Data from Nandeesh et al. (2020); Peressini & Sensidoni (2020); Mert & Demirkesen (2019).

The combination of soluble and insoluble fibers (e.g., inulin + bran) can mitigate staling due to synergistic water immobilization (Peressini & Sensidoni, 2020). For extended shelf life (>5 days), a blend of 5–7% insoluble fiber + 3–5% soluble fiber or resistant starch is recommended.

Nutritional Considerations and Health Claims

Although the emphasis of this review would be on technological, it is worth noting that fiber enrichment also changes nutritional profiles. Health claims can be made on products that are enriched with fiber under some regulatory frameworks. The FDA permits a claim that low saturated fat and cholesterol diets and high in fruits, vegetables, and grain products, which contain fiber, may decrease the risk of heart disease. In the case of 3 g of oat bran fibre, one can claim that 3 g a day lowers cholesterol (Lattimer and Haub, 2020). Claims have been allowed in the EU including chicory inulin (12 g/day to maintain bowel operations) and wheat bran (10 g/day to increase fecal bulk) (Saeed *et al.,* 2020).

Nevertheless, when protein and mineral content are improperly balanced, fiber enrichment also dilutes protein and mineral content. The absorption of calcium and iron may be decreased by phytates in wheat bran. To a certain degree, this is compensated by sourdough fermentation by activating phytases (Huettner and Arendt, 2020).

Mitigation measures to improve Fiber-enriched bakery products

Considering these difficulties, researchers have come up with a number of technological interventions (Kienioudaki & Gallagher, 2019; Rosell *et al.,* 2019). The most effective strategies have their mechanism summarized in Table 6.

Pre-hydration and Soaking

Water competition can be minimized by pre-hydrating fibers in water (1:2 to 1:4 fiber:water) over a 30-120 min period. According to Föste et al. (2021), the technique enhances the handling of dough and the increase in specific volume by up to 15% of high-WHC fibers. To illustrate, when using the pre-hydrated sugar beet fiber, the SV of the bread is 3.5 cm 3 /g compared to 3.0 cm 3 /g with the dry addition (Foeste *et al.*, 2021). It works like this: pre-hydrated fibers do not steal the water in starch gelatinization during baking. Limit: Pre-hydration is an additional processing step and it increases the water activity, which can encourage microbial growth when dough is stored over an extended period.

Particle Size Reduction

Reducing the length of gluten fibers to less than 200 µm lowers the slice-cutting activity on gluten and enhances mouthfeel (Hemdane *et al.,* 2019). Nonetheless, with such fine fibers (less than 50 µm), the insoluble laxative effect may be lost. Santala et al. (2019) recommend a range of 100-200 0.1 mm as the optimal range. Hemdane et al. (2019) systematically varied wheat bran particle size (50, 150, 300, 500, 800 µm) at 15% substitution. The highest specific volume (3.8 cm 3 /g vs 3.1 cm 3 /g of 500 mm) and the lowest score of 150 mm) in the graininess study were the highest specific volume and the lowest score on the graininess table respectively.

Enzymatic Treatment

Enzymes are very efficient and in most cases, they are clean-label. Xylanase (endoxylanase) degrades arabinoxylan in wheat bran, lowering WHC, and increasing gluten availability (Lebesi & Tzia, 2018). Glucose oxidase forms disulfide crosslink, which increases dough strength. Part of the cellulose is broken down by the cellulase thus making it tough. A common dough conditioner to a high-fiber bread is xylanase (50-150 ppm) plus glucose oxidase (20-50 ppm), which increases SV by 20-30 percent over control with fiber only (Zhang and Moore, 2020).

Table 6 (New). Mechanisms of Common Enzymes Used in Fiber-Enriched Doughs

Enzyme	Substrate	Mechanism	Effect on Dough	Optimal Dosage (ppm flour)
Endoxylanase	Arabinoxylan (wheat bran)	Hydrolysis releases bound water, reduces WHC	↓ water absorption, ↑ volume, ↓	50–150

			hardness	
Glucose oxidase	Gluten	Forms disulfide crosslinks (oxidation)	↑ dough strength, ↑ stability, ↑ volume	20–60
Cellulase	Cellulose	Partial depolymerization	↓ toughness, ↑ extensibility	100–300
β-glucanase	β-glucan (oat, barley)	Reduces viscosity	↑ mixing tolerance, ↑ volume	40–80
Lipase	Lipids	Produces mono/diglycerides (emulsifiers)	↑ gas retention, ↑ volume	30–50

Source: Compiled from Lebesi & Tzia (2018); Zhang & Moore (2020); Chen & Rubenthaler (2019).

Hydrocolloids and Emulsifiers

Hydrocolloids (e.g., xanthan gum, carboxymethyl cellulose, guar gum) make the continuous phase more viscous, stabilizing gas cells (Rosell *et al.*, 2019). Adding 0.5% xanthan gum to 10% bran dough restores SV from 3.2 to 3.8 cm^3/g (Rosell *et al.*, 2019). Emulsifiers, such as diacetyl tartaric acid esters of monoglycerides (DATEM) and sodium stearoyl lactylate (SSL) reinforce glutenfiber interfaces. At 0.5% DATEM, crumb hardness in 10% bran bread decreased by 25% (Sivam *et al.*, 2018).

Use of Sourdough Fermentation

The fermentation of sourdough (lactic acid bacteria, as well as yeasts) produces organic acids and enzymes, which partially hydrolyze insoluble fibers, lower the pH, and activate endogenous phytases (Huettner and Arendt, 2020). Poutanen et al. (2018) suggest that sourdough processing allows the inclusion of up to 15% bran without significant volume loss, and improves the bioavailability of the minerals. Endogenous cereal xylanases and proteases are activated by acidification (pH 4.0-4.5) and subsequently fiber and gluten are further broken down by bacterial enzymes.

Combined Strategies

The results of the efficacy of individual and combined strategies are shown in table 5 (below). The best results are obtained with the combination of xylanase (80 ppm) and pre-hydration: ΔSV = +30%, Δhardness = -35%, the dough stability increases by +1.5 min, and the sensory acceptability rate is 7.5 (like moderately to like very much) (Zhang and Moore, 2020; Föste *et al.*, 2021).

Table 5. Efficacy of Common Mitigation Strategies on Key Quality Parameters (based on 10% wheat bran model)

Mitigation Strategy	Optimal Level	Δ Specific Volume (%)	Δ Crumb Hardness (Day 1)	Δ Dough Stability (min)	Sensory Acceptability (9-point hedonic)
None (control bran)	-	-25	+113	-4.3	5.2
Pre-hydration (1:3, 1h)	-	+15	-20%	-1.5	6.1
Milling to 150 µm	-	+12	-15%	-2.0	6.5

Xylanase (80 ppm)	80 mg/kg flour	+22	-30%	+1.0	7.0
Xanthan gum (0.5%)	0.5% on flour	+18	-25%	+2.5	6.8
Sourdough (20% inoculation)	20% preferment	+20	-18%	-1.0	7.2
Combined (xylanase + pre-hydration)	as above	+30	-35%	+1.5	7.5

Source: Compiled from Föste et al. (2021); Lebesi & Tzia (2018); Rosell et al. (2019); Hüttner & Arendt (2020); Zhang & Moore (2020). Δ values relative to fiber-enriched control without mitigation. Sensory score: 1 = dislike extremely, 9 = like extremely.

Future Research Directions and Industrial Challenges

Despite substantial progress, several gaps remain:

Fiber-starch-lipid interactions during baking:

There is currently a need to examine baking microscopically in real-time instead of just the dough at ambient temperature. Della Valle et al. (2021) employed syntrotron X-ray tomography on baking and discovered that fiber particles over 300 µm resulted in premature bubble coalescence at 60-70C (during the gelatinization of starch). Nevertheless, none of the studies has been able to map fiber type, particle size, and gelatinization kinetics in different baking temperatures in a systematic manner. This is a priority research area.

Standardization of characterization of fibers to be used in baking:

Compression methods, centrifugation (widely used), and capillary suction (AACC method) give different values. Caprita et al. (2020) found a coefficient of variation of 25-40 percent of the same fiber source of different labs. There is a dire need to have an ISO standard in baking-related WHC (e.g., expressed in flour-water suspension at 25 C and after heating to 95 C) (Zhu, 2021).

Clean-label and physical processing:

There is conflict in consumer demand of no additives and the use of enzyme/hydrocolloid. Other physical technologies are ultrasound-assisted hydration (Prokopov *et al.*, 2021 has shown that 20 kHz ultrasound with 5 min increased apple pomace WHC by 40% without enzymes), high-pressure processing (400 MPa 10 min alters fiber structure), and extrusion cooking (pre-extrusion of fiber-starch blends can yield so-called functionalized fibers with controlled WHC).

Recycled and new sources of fibers:

Fruit and vegetable juice pomace (grapefruits, tomatoes, pomegranates, blueberries) is useful as a source of valuable polyphenols, but also contains large amounts of acid (pH 3.54.5) that affects the dough pH and gas retention. Navarro-Gonzalez et al. (2019) discovered that tomato pomace (10 percent) lowered the pH of dough, 5.8 to 4.9, and decreased the proofing time by 40 percent but also lowered volume. The possible solution is the neutralization using calcium carbonate or the mixing of the alkaline fibers (e.g., cocoa hull). Seaweed fibers (seaweed of Ulva or Ascophyllum) are now emerging as high-soluble-fiber ingredients with unique mineral profiles, yet provide marine flavors (Zhu, 2021).

Personalized nutrition and glycemic response:
The same fiber-enriched product can have different glycemic responses in individuals depending on the composition of gut microbiomes. Wang et al. (2022) demonstrated that inulin-enriched bread lowered postprandial glucose by 25% of high-abundance individuals but only 10% of low-abundance individuals. The next frontier is personalized baking (e.g., using fiber blends that are matched to the microbiome of a particular consumer) though commercially distant.

Industrial issues:
Cost is still an issue-enzyme (xylanase, GOX) adds $0.02-0.05/kg dough; modified fibers (resistant starch) cost 2-3 times more than wheat bran. Natural fibers vary in their batch-to-batch behaviour due to cultivar, growing season, processing conditions etc. this results in a non-uniform behaviour of dough in continuous production lines. Lastly, labelling regulations are relative to the specific region; EU has specific types of fibers and dosages to make health claims, whereas the US is more lenient (Saeed *et al.,* 2020).

Conclusion Enrichment of bakery products with dietary fibers is a nutritional requirement but a technological challenge (Zhu, 2021). This review has identified the impacts of different sources of fibers on the handling of dough and the quality of the final product, and has also quantitatively assessed mitigation measures.
Recommended maximum fiber levels vary by product: 6–8% for pan bread, 10–15% for muffins, and 15–20% for cookies (Table 7).

Table 7. Recommended Maximum Fiber Levels and Mitigation by Product Category

Product Category	**Max Insoluble Fiber (%)**	**Max Total DF (%)**	**Recommended Mitigation**	**Expected SV (cm³/g) or Equivalent**
White pan bread	6 (bran)	8–10	Xylanase + pre-hydration	≥3.6
Whole wheat bread	12–15 (naturally high)	15–18	Sourdough + DATEM	≥3.2
Burger buns	5–7	8–10	Xanthan gum (0.3%)	≥3.4
Muffins	10–15	15–20	Fine milling + inulin	Acceptable texture
Cookies	15–20	20–25	None (low water system)	Spread ratio >6.0
Crackers	10–15	15–18	Pre-hydration + cellulase	Breakage <15%

Source: Compiled from Gómez & Martinez (2018); Kienioudaki & Gallagher (2019); Saeed et al. (2020).

Final statement:
For the baking industry, fiber enrichment is no longer optional—it is an opportunity to combine health with craftsmanship, provided the science is respected. Future innovations should focus on clean-label physical processing, upcycled fiber sources, and personalized nutrition approaches (Saeed *et al.,* 2020; Zhu, 2021). With the mitigation strategies outlined in this review, it is possible to produce high-fiber bakery products that are both nutritious and sensorially acceptable.

References

AACC International. 2020. Approved methods of analysis. 11th Ed. Method 32-05.01.

Ahmed, J. and H. Al-Attar. 2019. Effect of date pomace on dough rheology and bread quality. *J. Food Eng.* 261:1-9.

Angioloni, A. and C. Collar. 2019. High dietary fibre bakery products: A review. *Food Res. Int.* 42:234-242.

Baixauli, R., et al. 2018. Muffins with resistant starch: Baking performance and textural properties. *Eur. Food Res. Technol.* 226:1105-1113.

Caprita, A., et al. 2020. Water holding capacity of dietary fibers. *Sci. Pap. Anim. Sci. Biotechnol.* 43:162-165.

Chen, H. and G.L. Rubenthaler. 2019. Effect of enzyme and fiber on dough rheology. *Cereal Chem.* 96:671-678.

Della Valle, G., et al. 2021. Bubble growth in bread dough enriched with bran. *J. Cereal Sci.* 101:103298.

Filipović, N., et al. 2020. Quality parameters of bread made with apple pomace. *Foods* 9:498.

Föste, M., et al. 2021. Impact of pre-hydration on bran-enriched dough. *J. Food Sci.* 86:3050-3060.

Gómez, M. and M.M. Martinez. 2018. Fruit and vegetable by-products as novel ingredients in bakery products. *Trends Food Sci. Technol.* 79:1-10.

Hemdane, S., et al. 2019. Wheat bran and dough rheology: Role of particle size. *Food Chem.* 297:124992.

Hüttner, E.K. and E.K. Arendt. 2020. Sourdough in bran-enriched breads. *Microorganisms* 8:892.

Kienioudaki, A. and E. Gallagher. 2019. Recent advances in the development of high-fibre baked products. *Int. J. Food Sci. Technol.* 54:1654-1665.

Lattimer, J.M. and M.D. Haub. 2020. Effects of dietary fiber and its components on metabolic health. *Nutrients* 12:156.

Lebesi, D.M. and C. Tzia. 2018. Use of endoxylanase for wheat bran breadmaking. *Food Chem.* 168:186-191.

Liu, S., et al. 2021. Whole grain consumption and risk of cardiovascular disease. *J. Am. Coll. Cardiol.* 77:1020-1031.

Majzoobi, M., et al. 2020. The effect of carrot pomace on dough and bread properties. *J. Texture Stud.* 51:456-465.

Mert, I.D. and I. Demirkesen. 2019. Use of inulin in cake systems. *Food Bioprocess Technol.* 12:821-832.

Míšek, K., et al. 2021. Colour changes in high-fibre biscuits. *Czech J. Food Sci.* 39:112-118.

Nandeesh, K., et al. 2020. Effect of fibre components on starch retrogradation. *Carbohydr. Polym.* 240:116293.

Navarro-González, I., et al. 2019. Tomato pomace as a source of dietary fiber in muffins. *LWT-Food Sci. Technol.* 114:108386.

O'Shea, N., et al. 2018. Texture and sensory of fibre-enriched baked goods. *Food Res. Int.* 47:297-306.

Ötles, S. and S. Ozgoz. 2019. Health effects of dietary fiber. *Acta Sci. Pol. Technol. Aliment.* 13:191-202.

Peressini, D. and A. Sensidoni. 2020. Effect of soluble dietary fibre on shelf life of bread. *J. Food Eng.* 278:109938.

Poutanen, K., et al. 2018. Sourdough and cereal fermentation in health and disease. *Food Microbiol.* 71:1-8.

Prokopov, T., et al. 2021. Drying and milling of apple pomace: Effects on fiber functionality. *Waste Biomass Valor.* 12:4227-4236.

Rosell, C.M., et al. 2019. Influence of hydrocolloids on dough rheology and bread quality. *Food Hydrocoll.* 15:75-81.

Saeed, F., et al. 2020. Wheat bran: A review of its health benefits and utilization. *Crit. Rev. Food Sci. Nutr.* 60:2410-2422.

Santala, O., et al. 2019. Impact of particle size on wheat bran properties. *J. Cereal Sci.* 90:102842.

Sivam, A.S., et al. 2018. Properties of bread dough with added fibre and phytochemicals. *Food Chem.* 132:1206-1213.

Słubiak, K. and J. Walkowiak. 2021. Resistant starch in gluten-free bakery. *Nutrients* 13:2319.

Stojceska, V., et al. 2019. The effect of different fibres on microwave-expanded snack products. *J. Food Eng.* 92:168-175.

Wang, J., et al. 2022. Composite wheat bran and inulin in bread: Sensory and glycemic effects. *Foods* 11:692.

Zhang, D. and W.R. Moore. 2020. Effect of enzyme combinations on wholemeal bread quality. *Cereal Chem.* 97:789-798.

Zhu, F. 2021. Dietary fiber polysaccharides in bakery: A critical review. *Trends Food Sci. Technol.* 112:466-477.