applied sciences

MDPI

Review

Polysaccharide-Enriched Bakery and Pasta Products: Advances, Functional Benefits, and Challenges in Modern Food Innovation

Jovana Petrović [1], Jana Zahorec [1], Dragana Šoronja-Simović [1], Ivana Lončarević [1], Ivana Nikolić [1], Biljana Pajin [1], Milica Stožinić [1], Drago Šubarić [2], Đurđica Ačkar [2] and Antun Jozinović [2,*]

[1] Faculty of Technology Novi Sad, University of Novi Sad, Bul. Cara Lazara 1, 2100 Novi Sad, Serbia; jovana.petrovic@uns.ac.rs (J.P.); jana.zahorec@uns.ac.rs (J.Z.); dragana@tf.uns.ac.rs (D.Š.-S.); ivana.loncarevic@uns.ac.rs (I.L.); ivananikolic@uns.ac.rs (I.N.); biljana.pajin@uns.ac.rs (B.P.); milica.stozinic@uns.ac.rs (M.S.)

[2] Faculty of Food Technology Osijek, Josip Juraj Strossmayer University of Osijek, Franje Kuhača 18, 31000 Osijek, Croatia; dsubaric@ptfos.hr (D.Š.); dackar@ptfos.hr (Đ.A.)

* Correspondence: ajozinovic@ptfos.hr

Abstract

The increasing consumer demand for healthier food choices has stimulated research into functional bakery products enriched with bioactive ingredients. This review summarizes recent developments in the application of key polysaccharides—such as inulin and fructooligosaccharides (FOS), β-glucan, arabinoxylan, pectin, cellulose derivatives, resistant starch, maltodextrins, and dextrins—in bread, pasta, and fine bakery systems. Their incorporation affects dough rheology, fermentation behavior, and gas retention, leading to modifications in texture, volume, and shelf-life stability. Technologically, polysaccharides function as hydrocolloids, fat and sugar replacers, or water-binding agents, influencing gluten network formation and starch gelatinization. Nutritionally, they contribute to higher dietary fiber intake, improved postprandial glycemic response, enhanced satiety, and favorable modulation of gut microbiota. From a sensory perspective, optimized formulations can maintain or even improve product acceptability despite structural changes. However, challenges remain related to dosage optimization, interactions with the gluten–starch matrix, and gastrointestinal tolerance (particularly in FODMAP-sensitive individuals). This review summarizes current knowledge and future opportunities for creating innovative bakery products that unite technological functionality with nutritional and sensory excellence.

Keywords: functional bakery products; fructans; β-glucan; arabinoxylan; resistant starch; dough rheology; texture; glycemic response; fiber enrichment

check for updates

Academic Editor: Małgorzata Ziarno

Received: 8 October 2025
Revised: 3 November 2025
Accepted: 4 November 2025
Published: 6 November 2025

Citation: Petrović, J.; Zahorec, J.; Šoronja-Simović, D.; Lončarević, I.; Nikolić, I.; Pajin, B.; Stožinić, M.; Šubarić, D.; Ačkar, Đ.; Jozinović, A. Polysaccharide-Enriched Bakery and Pasta Products: Advances, Functional Benefits, and Challenges in Modern Food Innovation. *Appl. Sci.* **2025**, *15*, 11839. https://doi.org/10.3390/app152111839

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Bakery and pasta products are staple foods worldwide, often accounting for more than one-third of daily caloric intake in many populations. However, their traditional formulations—typically low in dietary fibre—are associated with increased prevalence of obesity, type 2 diabetes, cardiovascular diseases, and other chronic non-communicable diseases [1,2]. Recent umbrella reviews and meta-analyses confirm that higher dietary fibre intake significantly reduces the risk of chronic diseases, systemic inflammation, and overall mortality [1,3]. Given their broad consumption and cultural relevance, breads, pastries, and pasta represent ideal vehicles for fiber enrichment and functional food reformulation [4,5].

Polysaccharides are carbohydrate polymers composed of monosaccharide units, which may function as structural, storage, or functional biopolymers. When non-digestible by

human enzymes, they are classified as dietary fibres, while hydrocolloids represent polysaccharides (or proteins) with high water-binding capacity used as thickeners, stabilizers, or gelling agents. Consequently, polysaccharides have gained considerable interest as multifunctional ingredients capable of improving both technological performance and nutritional quality. They occur naturally in cereals, legumes, fruits, and microbial sources, and are recognised for their dual role: enhancing dough rheology, water-binding, gas retention, crumb structure, and cooking quality, while also acting as dietary fibres and prebiotics [6,7]. From a technological point of view, the incorporation of polysaccharides significantly modifies dough viscoelastic properties, increases water absorption, and affects gluten aggregation and starch gelatinisation, leading to changes in dough stability, gas retention, and baking yield. Their action depends on molecular weight, charge, and branching, which determine whether they reinforce or weaken the gluten–starch matrix [8]. In breads, polysaccharides can improve loaf volume, texture, and shelf life; in pasta and noodles, they reduce cooking losses and increase firmness; and in fine bakery products such as cakes, biscuits, and muffins, they act as fat or sugar replacers and moisture retainers, supporting healthier formulations without compromising sensory quality [7,9]. Polysaccharides such as xanthan gum, guar gum, and cellulose derivatives enhance gas-holding capacity and delay staling, while soluble fibres such as inulin or β-glucan can increase dough elasticity, improve crumb softness, and reduce hardness during storage [10].

Nutritionally, polysaccharides reduce starch digestibility, improve postprandial glycaemic control, enhance satiety, have cholesterol-lowering effects, and beneficially modulate the gut microbiota [6]. They slow glucose release by forming viscous matrices that limit starch hydrolysis and, upon fermentation in the colon, generate short-chain fatty acids that contribute to gut health, lipid metabolism, and immune regulation [11]. Clinical trials with reformulated breads enriched in functional fibres have demonstrated reductions in fasting blood glucose and improved consumer acceptance, underlining their translational potential in daily diets [12]. In addition to health-promoting benefits, polysaccharide incorporation can modify key sensory attributes—improving softness, moisture retention, and overall mouthfeel—while maintaining or even enhancing consumer acceptance when optimal concentrations are applied [13]. Nevertheless, their technological and nutritional outcomes are strongly influenced by structural characteristics such as molecular weight, degree of polymerisation, and solubility, as well as by processing and formulation conditions [7].

Previous reviews have addressed hydrocolloids or dietary fibres in bakery products, yet few have systematically compared individual polysaccharides across breads, pasta, and fine bakery matrices, integrating their technological, sensory, nutritional, and functional effects. The selection of the major polysaccharide classes discussed herein (inulin, β-glucan, arabinoxylan, pectin, cellulose derivatives, resistant starch, and maltodextrins) was based on their documented technological and physiological importance in bakery systems, frequency of appearance in recent scientific literature (2015–2024), and relevance to both industrial formulation and nutritional functionality. These polysaccharides are also among those with established or emerging health claim recognition (e.g., inulin and β-glucan) and proven applicability in improving dough rheology, product structure, and overall nutritional quality. Special emphasis is given to their mechanisms of action, potential to improve product quality and nutritional value, and innovative strategies to overcome formulation challenges.

2. Methods

A structured literature search was conducted to identify studies on the technological, nutritional, and functional effects of polysaccharides in bakery and pasta systems. Scientific articles were retrieved from Scopus, Web of Science, ScienceDirect and Google

Scholar. The search covered primarily the period 2015–2024, with earlier key references included where necessary to explain fundamental mechanisms in dough rheology and polymer interactions. Search terms included "polysaccharides", "dietary fibre", "hydrocolloids", "exopolysaccharides", "bread", "bakery", "pasta", "dough", "inulin", "FOS", "β-glucan", "arabinoxylan", "pectin", "resistant starch", "modified starch", "maltodextrin", "HPMC", "CMC", "xanthan gum". Articles were screened by title, abstract, and full text. Relevant data were synthesised qualitatively to summarise current knowledge and trends in polysaccharide applications in cereal products.

3. Major Classes of Polysaccharides in Bakery and Pasta Products

Polysaccharides in bakery and pasta systems exhibit diverse structures and functionalities, and their classification depends on both biochemical origin and technological behaviour in cereal matrices. In this review, polysaccharides are categorised into five functional–structural groups relevant to dough development, gluten replacement, and product quality:

(1) Soluble fibres (inulin, FOS, β-glucan);
(2) Complex non-starch polysaccharides (arabinoxylan, pectin);
(3) Starch-based polysaccharides, including native, resistant, and modified starches, as well as maltodextrins and dextrins;
(4) Cellulose-based technological polysaccharides (HPMC, CMC);
(5) Microbial exopolysaccharides (xanthan gum and related exopolysaccharides).

Although pectin is nutritionally defined as a soluble dietary fibre, it is grouped here with arabinoxylan due to shared structural features and similar functional behaviour in cereal matrices. A similar classification principle is applied throughout this review for polysaccharides that may nutritionally fall under dietary fibres (e.g., resistant starch or microbial exopolysaccharides) but are discussed within technology-aligned groups to reflect their predominant role in dough systems. This grouping reflects biochemical characteristics, processing origin, and shared technological functions in bakery and pasta systems, enabling meaningful comparison of hydration behaviour, rheological effects, structural contributions, and nutritional roles.

3.1. Soluble Fibres

3.1.1. Fructans—Inulin and Fructooligosaccharides (FOS)

Fructans, including inulin and fructooligosaccharides (FOS), are fructose-based polymers naturally found in thousands of plant species, with chicory root being the main industrial source [14]. Chemically, they are composed of β-(2→1)-linked fructose units that may terminate with a glucose molecule, forming linear or slightly branched chains of variable length. Their molecular size and degree of branching determine solubility and gel-forming ability [15]. Their structural diversity depends on their degree of polymerisation (DP): short-chain fructans (FOS, DP < 10) are more soluble and sweeter, while long-chain inulin (DP > 23) forms gels with low sweetness but a pronounced textural impact [16]. Both types act as prebiotics, bypassing digestion in the small intestine and undergoing fermentation in the colon, where they promote beneficial gut microbiota and support mineral absorption. From a technological perspective, inulin and FOS contribute to water retention, dough softness, and delayed staling; however, excessive addition may weaken gluten and reduce loaf volume [8]. Physiological effects include improved glycaemic control, lipid regulation, satiety and antioxidant activity. However, fructans belong to the FODMAP group and, when rapidly fermented, may cause gastrointestinal discomfort in sensitive individuals, limiting their use in high-fibre or low-FODMAP formulations [17].

Short-Chain Fructans (FOS)

FOS are technically oligosaccharides but are discussed briefly due to their close functional and structural relationship with inulin-type polysaccharides. FOS are increasingly recognised as valuable ingredients in probiotic and synbiotic breads. They are short-chain β-(2→1)-linked fructose oligomers (DP < 10), usually derived from sucrose through enzymatic synthesis or extracted from chicory root and Jerusalem artichoke [18]. Their prebiotic activity supports Bifidobacteria and Lactobacilli, enhancing probiotic survival and functionality. In synbiotic applications, FOS synergistically interact with probiotics, improving dough rheology, crumb softness, and moisture retention [19]. Beyond bread, FOS function as sugar replacers in cakes, cookies, and sweet doughs, lowering caloric value and glycaemic impact while maintaining sensory quality [20]. They have been incorporated into low-carbohydrate pound cakes, increasing fibre by 200%, reducing carbohydrates by 24%, and preserving sensory attributes. In biscuits, maltitol–FOS blends have been tested as fat replacers with positive results [21]. In pasta, FOS improve fibre content and preserve cooking quality, particularly when combined with hydrocolloids or proteins [22]. Recent studies have also investigated innovative production and application strategies. Innovative strategies include enzymatic synthesis from sucrose via invertase, yielding cost-effective bakery products with reduced glycaemic index and preserved moisture [23]. Similarly, the addition of FOS in combination with Bacillus coagulans during sourdough fermentation of whole wheat flour significantly enhanced technological and sensory quality. The FOS–probiotic combination yielded breads with the highest loaf and specific volume, improved crumb elasticity, and favorable sensory attributes, while also ensuring probiotic stability—thus achieving a synbiotic effect [24].

Beyond conventional roles as prebiotics and sugar replacers, FOS are emerging as multifunctional hydrocolloids. Maillard conjugates of cricket protein and FOS displayed excellent emulsifying properties, kinetic stability, and protective effects during simulated gastrointestinal digestion [25]. These conjugates were particularly effective for vitamin D_3 delivery in emulsified systems and may be applicable in bakery products for the stabilization of fat-soluble bioactives, enhanced moisture retention, and improved crumb structure. In tortillas, combining inulin with FOS (50:50) improved dough elasticity, increased moisture retention, lowered glycaemic potential, and maintained consumer acceptance, showing that such fibre systems can be successfully translated to a wide range of bakery matrices [26].

Long-Chain Fructans (Inulin)

Based on its degree of polymerisation (DP), inulin is categorised into short-chain (DP < 10), long-chain (DP > 23), and native (DP 2–60) types. Short-chain inulin is more soluble and sweeter, suitable as a sugar substitute and texture modifier, while long-chain inulin, with higher viscosity and lower solubility, is used as a fat replacer and bulking agent [16].

Inulin contributes to bakery products both nutritionally and technologically. As a prebiotic, it improves gut microbiota composition and supports calcium and magnesium absorption, while regulating glucose and lipid metabolism [27]. Consuming bread with 30% added inulin would provide approximately 23 g/day, which is close to the recommended value of 25–30 g/day [28]. Technologically, inulin enhances mouthfeel and texture, acts as a fat mimetic, and retains moisture, particularly in cakes and fillings [20]. In dough, it reduces water absorption, competes with starch during gelatinisation, and weakens the gluten network, leading to firmer crumbs. Long-chain inulin delays staling, maintains softness, and increases crumb brightness [29]. Crust colour is also affected: short-chain inulin promotes darker crusts due to higher reducing sugars, while long-chain inulin

leads to lighter colouration [8]. Specific volume results vary: in gluten-free breads, inulin increases loaf volume and porosity [30], but in wheat doughs, it can reduce volume due to gluten weakening. Gel forms of inulin offset these effects better than powder. Shelf-life improvements have been observed in breads enriched with 5–20% inulin [13]. At higher levels (30–40%), structural instability occurs, requiring adjustments in formulation and processing [31]. In frozen doughs, long-chain inulin (2.5%) better preserved gluten structure and reduced ice crystal damage compared to 5% short-chain inulin [29,32].

In sugar-reduced bakery products, inulin has shown dual benefits. Replacing 50% of sugar with inulin-enriched honey powder in biscuits resulted in optimal sensory and nutritional outcomes, while higher substitution (75%) negatively impacted texture and flavour. Inulin's performance also depends on matching its DP to product type. When tested as a sugar replacer in cakes and biscuits, low-DP inulin preserved rheological and sensory quality, while high-DP forms caused thicker batters and firmer crumbs [33]. Thus, selecting the appropriate DP range is essential to achieve the desired texture.

Despite these advantages, fructans belong to the FODMAP group (low in fermentable short-chain carbohydrates) and may cause gastrointestinal discomfort in sensitive individuals, such as those with Irritable Bowel Syndrome (IBS) [17]. Rapid fermentation of FOS is a primary concern, requiring careful formulation in low-FODMAP products. Overall, fructans—encompassing both FOS and inulin—are multifunctional prebiotic ingredients that enhance fibre content, lower glycaemic response, support gut health, and improve sensory and technological properties in bakery and pasta products. Their effects depend strongly on chain length and concentration: FOS serve primarily as sweeteners and prebiotic enhancers, while inulin acts as a fat replacer, texture improver, and freshness stabiliser. Together, they represent versatile tools for clean-label, reduced-calorie, and health-oriented bakery innovations, though formulation must account for gastrointestinal tolerance in sensitive populations.

3.1.1.3. β-Glucan

β-glucans are soluble dietary fibres composed of glucose units linked by β-(1→4) and β-(1→3) glycosidic bonds, naturally present in cereals (2.1–6.1%), fungi, and algae [34,35]. Their molecular weight (35–2300 kDa) and the ratio between β-(1→3) and β-(1→4) linkages define solubility and viscosity, which are key for both technological and physiological functionality [36,37]. Clinically, β-glucans lower postprandial glycaemia, reduce cholesterol [38], and decrease colon cancer risk [39]. Health authorities recommend $\geq$3 g/day for beneficial effects [40]. The global β-glucan market, valued at USD 1.23 billion in 2022, is projected to reach USD 2.3 billion by 2033 [41].

The technological and nutritional effects of β-glucan addition in bakery and pasta products are summarised in Table 1. Due to their high water-binding and gel-forming capacity, β-glucans alter dough rheology by increasing viscosity and competing with gluten for water. In wheat bread, higher inclusion levels reduce loaf volume, increase crumb hardness, and create denser textures [42,43]. These effects are caused by water competition and gluten interference, which reduce gas retention and cell expansion. At moderate levels (~2%), β-glucans improve fibre content without major technological drawbacks [44]. Gluten or vital wheat gluten supplementation can mitigate negative impacts. In gluten-free systems, oat β-glucans at 1–2% improve moisture retention, softness, and shelf life, especially when high-molar-mass fractions are used [45]. They also delay staling by slowing retrogradation [46,47]. Results for loaf volume are mixed, depending on dosage, flour type, and β-glucan molecular weight. High-molar-mass fractions (~1.7 MDa) increased loaf volume and reduced crumb hardness by up to 69% [45].

Table 1. Technological and nutritional effects of β-glucan addition in bakery and pasta products.

Product Category	Positive Effects	Negative Effects	Recommendations
Bread (wheat-based)	Enhanced nutritional profile; improved moisture retention; softer crumb at moderate levels [42–44]	Reduced loaf volume; denser texture; firmer crumb at high levels [42,43]	≈2–5% (higher > 10% compromises quality)
Bread (gluten-free)	Improved hydration and softness; delayed staling; higher moisture retention [45–47]	Inconsistent loaf volume and texture depending on dose and molecular weight [45]	1–2% (high-molecular-mass fractions most effective)
Pasta	Increased dough hardness and resilience; acceptable sensory quality at moderate levels [48–51]	Higher cooking loss; darker colour; weaker gluten network [48–50]	1–3% (higher levels impair structure)
Cakes/Cookies/Biscuits	Improved batter viscosity; softer texture; fat replacement; extended freshness [52,53]	Excessive thickening > 4%; reduced aeration and volume [52]	2–3% (optimal texture–moisture balance)

In pasta, β-glucan enrichment increases dough hardness and resilience but reduces cohesiveness and elasticity. It weakens gluten networks, raises water absorption, and increases cooking loss at higher levels [48–50]. Structurally, β-glucan disrupts the protein–starch matrix, producing less cohesive cooked pasta. However, at moderate levels (~3 g per 100 g serving), sensory acceptance remains high [51]. In cakes, β-glucans improve batter viscosity and moisture retention, yielding softer crumbs at 2–3% addition, while higher levels (>4%) cause excessive thickening that reduces aeration and loaf volume [52]. In cookies and biscuits, oat β-glucans act as fat replacers at $\leq$5% without compromising sensory acceptance, while improving freshness and moisture retention [53]. Barley flours enriched with β-glucan and anthocyanins also produced fibre- and colour-enhanced biscuits with good consumer acceptance [54]. In contrast, yeast β-glucans, due to low solubility, showed limited success.

Overall, β-glucans enhance cohesiveness, water-binding capacity, and crumb uniformity, which is particularly beneficial in gluten-free and reduced-fat systems [55]. In addition, β-glucan-rich oat fibre preparations have been shown to reduce acrylamide formation in bread [56], while whole-oat breads have been shown to modulate starch digestibility, supporting glycaemic control [57]. β-glucans thus represent multifunctional hydrocolloids with clinically proven health benefits and significant technological impact on bakery and pasta products. Their successful application, however, requires careful balancing of dosage, molecular weight, and formulation parameters to fully exploit their health benefits while maintaining product quality.

3.2. Complex Non-Starch Polysaccharides

3.2.1. Arabinoxylan (AX)

Arabinoxylan (AX) is one of the most extensively studied non-starch polysaccharides, widely investigated for its nutritional and technological potential in cereal-based foods. It is naturally present in the cell walls of cereal grains such as wheat, rye, barley, and oats, and its content and structure depend on the botanical source and extraction method [58]. Structurally, AX consists of a β-(1→4)-linked xylose backbone with random O-2, O-3, or O-2/O-3 arabinose substitutions [59]. Ferulic acid residues may be ester-linked to arabinose units, allowing cross-linking between AX chains and with other cell-wall components, which affects solubility and technological functionality. AX can be classified into water-extractable (WEAX) and water-unextractable (WUAX) fractions, with WUAX comprising nearly 90% of total wheat bran AX, while WEAX represents less than 10% [60].

AX exhibits multiple health-promoting properties, including regulation of the gut microbiota, reduction of type 2 diabetes risk [61], and immunomodulatory activity [62,63].

AX intake of 3–15 g/day significantly reduced postprandial glucose and insulin responses without impairing starch digestion [64]. These benefits were attributed to increased intestinal viscosity and AX fermentation into short-chain fatty acids, which also contributed to favourable modulation of the gut microbiota. Long-term consumption of AX-enriched products has been further associated with improved glycaemic control indicators, including reductions in HbA1c and fructosamine levels [64]. Although effects on satiety hormones remain inconsistent, AX supplementation shows promise for promoting satiety and regulating appetite [65]. Collectively, these findings support the application of AX as a functional dietary fibre in bakery products designed for glycemic management.

From a technological perspective, the effects of AX in bread and other cereal-based foods depend strongly on its solubility and molecular weight. WEAX, particularly high-molecular-weight fractions, improve gluten viscoelasticity, loaf volume, and crumb texture, whereas WUAX and low-molecular-weight AX can disrupt gluten structure, reduce elasticity, and deteriorate bread quality [58,66–68]. To mitigate the adverse effects of WUAX, enzymatic hydrolysis and ultrasonic treatment have been applied, resulting in improved dough rheology and enhanced quality of whole-wheat baked goods [69]. Importantly, AX remains stable during baking, resists digestion by human enzymes, and exerts prebiotic effects through gut microbiota modulation [70].

The technological effects of different AX fractions in bakery systems, including WEAX and WUAX, are summarised in Table 2. Several studies demonstrate that AX can be incorporated into bread without major negative impacts on dough development, loaf volume, or sensory acceptability. AX-enriched breads exhibited slightly higher firmness but maintained acceptable softness, while colour, flavour, and overall acceptability remained comparable to control breads [70].A broader review emphasised that AX functionality in bread, pasta, cookies, and cakes is strongly influenced by structural features such as molecular weight, degree of branching, and solubility [71]. Low-molecular-weight, soluble fractions improve hydration, texture, and shelf-life, while high-molecular-weight AX can weaken gluten and produce denser crumbs. Recent studies show that hydrolysed, feruloylated AX, at levels up to 5%, helps maintain loaf volume and quality, enhances fibre and moisture content, but further strategies are needed to fully control staling during storage [72].

Table 2. Comparison of WEAX and WUAX effects in bakery products.

AX Fraction	Positive Effects	Negative Effects	Recommendations
WEAX (water-extractable arabinoxylan)	• Improves gluten viscoelasticity and dough handling • Increases loaf volume and crumb softness • Enhances moisture retention and extends freshness [71,72]	• At very high molecular weight may cause excessive viscosity and reduced gas cell expansion	• Use moderate levels (1–2%) • Target high-molecular-weight but soluble fractions
WUAX (water-unextractable arabinoxylan)	• Increases dietary fibre content • Potential prebiotic effects after fermentation	• Disrupts gluten network continuity • Decreases elasticity and loaf volume • Leads to denser crumbs and reduced bread quality [58,66,68]	• Apply enzymatic hydrolysis or ultrasonic treatment to reduce molecular size and improve solubility [64] • Optimal inclusion $\leq$ 5% with modification strategies [72]

3.2.2. Pectin

Pectin, a heteropolysaccharide composed mainly of α-(1→4)-linked D-galacturonic acid with variable degrees of esterification, is widely applied as a hydrocolloid and dietary fibre in bakery and pasta systems. It naturally occurs in plant cell walls, particularly in citrus peels, apple pomace, sugar beet pulp, and other fruit by-products, making it a sustainable and renewable source of functional polysaccharides [73]. Its functionality depends strongly on the degree of esterification (DE): a high-methoxyl (HM) pectin (DE > 50%) gel forms in the presence of high sugar and low pH, whereas low-methoxyl (LM) pectins (DE < 50%) form Ca^{2+}-mediated gels and exhibit stronger water-binding properties at lower sugar levels [74,75]. The presence of neutral sugars such as rhamnose, arabinose, and galactose also affects branching, solubility, and interactions with proteins or starch [76]. This structural diversity underpins the role of pectin in modulating dough rheology, loaf volume, texture, shelf-life, nutritional profile, and sensory acceptance. In addition, supplementation with plant-derived pectin sources aligns with the sustainable and safe use of vegetable raw materials in bread production [75].

In wheat bread, pectin primarily interacts with gluten and starch. At 1–3% (flour basis), HM-pectins stabilise gluten networks and improve gas retention, leading to higher loaf volume [74,77]. Conversely, LM-pectins can stiffen the structure through calcium cross-linking, sometimes increasing crumb firmness when overdosed [78,79]. Recent studies have further highlighted that pectin–gluten interactions reduce the enzyme accessibility of starch, thereby lowering starch digestibility and the predicted glycaemic index [80].

In gluten-free breads, pectin is particularly valuable as a structure-building and moisture-retaining agent. At 2–4%, LM-pectin enhances crumb softness and reduces gumminess, while HM-pectin helps maintain freshness. Apple pectin and citrus fibres increased loaf volume, improved crust colour, and enriched dietary fibre [81,82]. Studies with sourdough breads fortified with nutraceutical ingredients from food by-products confirmed that pectin contributed to extended freshness and consumer acceptance [83,84]. Comparative trials demonstrated that pectin performed competitively with hydrocolloids such as HPMC or raisin juice concentrate in gluten-free breads based on rice and millet, with significant improvements in texture and acceptance [85]. Research on steamed bread quality also demonstrated positive outcomes. In steamed breads, adding 1–2% pectin improved elasticity, specific volume, and crumb texture [86].

In fine bakery products, pectin functions both as a fat replacer and a dietary fibre source. Additions of 2–5% improve spread, moisture retention, and texture, while fruit-derived pectins contribute bioactives and antioxidant capacity. For example, lemon IntegroPectin increased fibre and antioxidant activity [87], pistachio-derived pectin supported the development of functional low-phenylalanine cookies [88], and citrus peel pectin contributed to fibre enrichment and fat replacement [89]. In meat-based sugar snap cookies, structurally different pectins modified water distribution and dough rheology, resulting in improved structural properties [90]. The use of pectin-containing flour confectionery with reduced gluten also confirmed positive textural effects [91]. Fibre-enriched cookies containing pectin lowered acrylamide formation and bioaccessibility by modifying Maillard reaction pathways [92]. More recently, pectin from cocoa pod husk extract improved the physical and chemical properties of cookies and contributed to lower starch digestibility [93].

Pectin application in pasta and noodles is less common than in breads, but recent findings show promising effects. Enrichment with apple pomace, a pectin-rich by-product, improved fibre and bioactive compound content while maintaining acceptable cooking quality [94]. Other studies confirmed that fibre enrichment using agro-industrial by-products, including pectin, can improve the nutritional and sensory profile of pasta, although higher levels (>5%) may raise cooking loss. This effect is attributed to pectin's strong water-

binding capacity and interference with starch gelatinization [95]. Overall, these findings suggest that pectin, particularly when combined with other soluble and insoluble fibres, can enhance the nutritional value of pasta products while preserving desirable textural and cooking properties [96].

Pectin is also applied in edible films and coatings. Studies showed that pectin–carrageenan films prolonged the freshness of baked goods, while blends with tomato paste stabilised volatile compounds and improved flavour retention [97,98]. Such applications extend the functional role of pectin beyond dough systems, positioning it as a multifunctional packaging and encapsulation material.

Pectin contributes to bakery and pasta innovation through multiple mechanisms: (i) gluten–pectin interactions affecting dough rheology and loaf volume; (ii) water binding and viscosity control improving crumb softness and delaying staling; (iii) starch–pectin complexation lowering digestibility and glycaemic response; (iv) fibre enrichment and fat replacement in cookies and cakes; and (v) functional uses in pasta, edible films, and coatings. Reported usage typically ranges from 1 to 3% in wheat breads, 2 to 4% in gluten-free breads, and 2 to 5% in cookies and pasta, with effects dependent on HM vs. LM type and product matrix. Nevertheless, concentrations above optimal ranges may increase firmness or affect dough handling, requiring careful formulation. Overall, current studies confirm that pectin is not only a hydrocolloid improver but also a sustainable functional fibre that enhances both the technological and nutritional quality of bakery products.

3.3. Cellulose-Based Polysaccharides

Hydroxypropyl Methylcellulose (HPMC) and Carboxymethyl Cellulose (CMC)

Cellulose derivatives, primarily hydroxypropyl methylcellulose (HPMC) carboxymethyl cellulose (CMC) and methylcellulose (MC), play key roles in gluten-free bakery systems and, to a lesser extent, in specialised pasta formulations [99–102]. They are obtained by chemical modification of natural cellulose, composed of β-(1→4)-linked D-glucose units, through partial substitution of hydroxyl groups with hydroxypropyl, methyl, or carboxymethyl groups, which increases water solubility and viscosity. These materials are typically produced from plant-based sources such as wood pulp or cotton linters, ensuring a renewable and sustainable origin [102,103].

In gluten-free breads, HPMC effectively mimics gluten's structural function by stabilising gas retention and improving dough viscosity, which leads to higher loaf volume and a softer, more uniform crumb [31,104,105]. In rice–buckwheat gluten-free doughs, the addition of HPMC or CMC increases elasticity, with storage modulus (G′) higher than loss modulus (G″) during heating—an indicator of elastic-dominated behaviour [106]. New approaches, such as microwave treatment of rice flour, can reduce the required HPMC level by approximately 50% while still maintaining acceptable bread texture. This effect is attributed to structural modifications in starch and proteins induced by microwave heating, which enhance water retention and dough stability, thereby partially substituting the technological functionality of hydrocolloids [107].

When resistant starch is added at high levels, loaf volume and crumb quality often deteriorate; adding modified celluloses such as HPMC or CMC counteracts these effects by improving proofing performance, water retention, and crumb softness [108]. Cellulose derivatives also improve proofing tolerance and freeze–thaw stability in steamed and frozen dough products, reinforcing their technological relevance across diverse bakery applications [109]. However, excessive inclusion levels (>2%) can cause undesirably high dough viscosity and reduced gas expansion, leading to denser crumb structure. Therefore, concentration and hydration optimisation are essential to balance elasticity and expansion [110].

In gluten-free pasta, CMC has been evaluated as a structuring additive: incorporation at approximately 1% reduced cooking losses and improved firmness in rice–corn pasta, with rheological measurements confirming an elastic-dominated behaviour ($G' > G''$) that helps maintain product integrity after cooking [111].

In fine bakery products such as cookies, biscuits, cakes, and muffins, cellulose derivatives play complementary roles. They increase moisture retention and delay staling, thereby producing softer texture during storage [31,99]. HPMC can act as a fat replacer by forming gels that mimic the softening effect of lipids, enabling lower-fat formulations without compromising sensory acceptance [31,101]. By increasing batter viscosity and stabilising air incorporation, these polymers can also improve volume and crumb structure in cakes and muffins [99].

Overall, cellulose derivatives are indispensable multifunctional hydrocolloids across bakery and pasta categories. They improve technological stability, rheology, and textural quality, support nutritional reformulation strategies such as fat reduction and fibre enrichment, and help maintain consumer acceptance in breads, pasta, and fine bakery products.

3.4. Starch-Based Polysaccharides

3.4.1. Native Starch

Starch is a glucose polymer composed of amylose (linear α-(1→4)-linked D-glucose) and amylopectin (branched α-(1→4) and α-(1→6) linkages), occurring naturally in cereal grains, tubers, and legumes. Native, waxy, high-amylose, pre-gelatinized, cross-linked, and damaged starches, or combined with proteins or lipids, play a central role in determining bakery quality. It governs dough hydration, gelatinisation, and retrogradation, which in turn affect gas retention, loaf volume, staling, and digestibility in breads, pastries, and pasta [112–114].

In yeast-leavened breads, partial flour replacement with starch-rich ingredients such as potato flour, or adjustment of starch gelatinisation degree, can optimise pasting behaviour and improve loaf volume, crumb structure, and crust colour when used at appropriate levels [115,116]. Differences among cultivars in starch content, granule size, and molecular structure also influence bread and noodle quality [117,118]. High-amylose starches, in particular, slow retrogradation and starch digestibility, thereby improving texture stability and lowering glycaemic impact during storage [119].

In gluten-free bread, waxy starch acts as a key structure-forming and anti-staling component. When combined with physical or chemical modifications such as pre-gelatinisation or cross-linking, it helps delay retrogradation and extend product freshness [120,121]. Under frozen or freeze–thaw conditions, starch–protein interactions (or starch–gluten interactions in conventional doughs) become critical for maintaining structural integrity and post-bake quality [122,123].

In biscuits and cookies, starch-centred strategies include the incorporation of resistant dextrin, high-amylose or native starches, and starch-based bigels as fat replacers. These ingredients maintain spread, crispness, and sensory acceptance while reducing the predicted glycaemic response [124–126]. Starch also has application in edible films, coatings, and encapsulation systems. Such uses can extend shelf-life, lower crust acrylamide, and serve as carriers of bioactive compounds such as curcumin or resveratrol [127–130]. Porous or modified starches can entrap essential oils, providing antifungal protection and prolonged freshness [128–131].

In pasta and noodles, native, pre-gelatinised, or cross-linked starches are incorporated to control cooking loss, firmness, and chewiness. Excessive inclusion, however, can weaken the protein–starch matrix and reduce quality [131–136]. Advanced formulations also

employ starch–lipid complexes that lower the glycaemic index and increase the fraction of slowly digestible or resistant starch.

Overall, starch and its derivatives remain fundamental to the texture, shelf-life, and nutritional functionality of bakery and pasta products. Collectively, these approaches highlight starch as a versatile structuring and nutritional component, integral to advancing quality and health attributes in contemporary cereal-based foods.

3.4.2. Resistant Starch (RS)

Resistant starch (RS), including RS2 from high-amylose sources, heat- and moisture-derived RS3, chemically cross-linked RS4, and lipid–amylose complexes classified as RS5, is increasingly incorporated in bakery systems to enhance dietary-fibre levels and attenuate starch digestibility, thereby lowering glycaemic response to [137,138].

In yeast-leavened breads, RS consistently lowers the in vitro starch digestion rate and increases RS content. However, because it dilutes gluten and modifies pasting and gelatinisation, it often reduces loaf volume and increases crumb firmness when added above ~10–15% of flour weight. At moderate levels (5–10%), RS can enhance nutritional quality with only minor effects on dough handling and sensory properties. The main mechanisms involve the formation of retrograded amylose (RS3), which increases matrix rigidity and water immobilisation, and the partial replacement of starch fractions available for gelatinisation, leading to lower gas retention. To mitigate these effects, hydrocolloids or modified celluloses improve water distribution, enzymes such as amylases weaken rigid RS domains, and optimised mixing/fermentation/cooling protocols restore machinability and delay staling, thereby maintaining consumer acceptance [139–142]. For par-baked and frozen doughs, controlling retrogradation and cooling regimes is key because RS3 formation accelerates during storage [137]. Approaches such as slow cooling and controlled hydration have been suggested to limit excessive retrogradation, reduce crumb firming, and help maintain bread quality in formulations containing 5–8% RS [143].

In fine bakery products such as cakes and cookies, incorporation of RS-rich flours or physically modified high-amylose starches at levels of 5–20% can substantially lower predicted and measured glycaemic index. Successful formulations require rebalancing of fat, sugar, and water to compensate for the higher water-binding capacity and reduced spreadability of RS-enriched doughs. When optimally reformulated, RS-enriched cookies exhibit desirable fracture behaviour, crispness, and flavour, whereas cakes preserve volume and moisture, demonstrating the feasibility of low-GI product development in fine bakery systems [144,145].

In pasta and noodles, up to 10% RS substitution maintains firmness and acceptable cooking quality. At higher levels ($\geq$15–20%), RS increases cooking loss and softens texture due to weaker gluten–starch matrices, unless die design, extrusion shear, and water content are carefully controlled. The mechanism reflects the reduced gelatinisation of resistant starch granules and their limited ability to integrate into the gluten–starch network [96,146].

Beyond technological aspects, RS fractions, especially RS3 and RS4, escape small-intestinal digestion and are fermented in the colon to short-chain fatty acids such as butyrate, which support gut microbiota and metabolic regulation. Human intervention studies with RS-fortified breads have demonstrated improved bowel regularity and glycaemic markers without sensory drawbacks [143,147,148].

3.4.3. Chemically Modified Starches

Chemically modified starches (CMS) are increasingly applied in bakery and pasta systems to overcome the limitations of native starch, such as low shear resistance, tendency to retrogradation, and poor freeze–thaw stability. Chemical modifications—including acety-

lation, oxidation, phosphorylation, and hydroxypropylation—alter gelatinisation, swelling, retrogradation, and water-binding properties, thereby broadening their functionality across breads, pastries, cookies, and pasta [149]. Among these, acetylated distarch adipate (ADA) shows strong cryoprotective effects in frozen dough and par-baked breads: it reduces free water migration, stabilises gluten–starch networks, and enhances viscoelasticity, resulting in loaves with greater volume and softer crumb after thawing [150,151]. Similarly, oxidised and cross-linked starches have been incorporated into sourdough breads, where they enhanced textural attributes while simultaneously increasing the proportions of slowly digestible and resistant starch fractions, thus lowering the estimated glycaemic index [152]. Resistant starch type IV (RS-IV; distarch phosphate) functions both as a technological aid and as a dietary fibre: studies confirm its ability to improve crumb softness, enrich fibre content, reduce starch digestibility, and lower predicted glycaemic index in both gluten-containing and gluten-free breads [137].

Hydroxypropyl starch (HPS) and hydroxypropyl distarch phosphate (HDP) enhance crumb softness, reduce gumminess, and modulate viscoelastic behaviour in breads and cakes, although high inclusions (>10%) can decrease loaf or cake volume [149]. Beyond breads and cakes, modified starches are also applied in cookies, biscuits, and tortillas, where their water-binding and viscosity-controlling properties improve dough handling, maintain crispness, and prolong freshness without impairing sensory quality [149]. Furthermore, studies with chemically modified potato flour confirmed that such starch modifications can improve both chemical characteristics and sensory properties of biscuits, supporting their use in fine bakery products [153].

From a regulatory and safety perspective, chemically modified starches are approved food additives (E1400–E1452) under Codex Alimentarius and EFSA evaluations, provided that substitution levels and residual reagents remain within specified limits [154]. Taken together, these findings indicate that acetylated, oxidised, phosphorylated, and hydroxypropylated starches—including RS-IV as a chemically derived resistant starch—serve as multifunctional ingredients that enhance cryoprotection, texture, and nutritional value in bakery and pasta products.

3.4.4. Maltodextrins and Dextrins

Although maltodextrins are partially hydrolysed starch derivatives with lower degrees of polymerisation, they are considered low-molecular-weight polysaccharides due to their polymeric nature and technological relevance in bakery matrices. Maltodextrins consist mainly of α-(1→4)-linked D-glucose units, occasionally containing α-(1→6) branch points, produced enzymatically from corn, potato, wheat, or tapioca starch. They form, together with dextrins, a continuum of starch-derived ingredients with diverse technological and nutritional roles. Digestible MDs act primarily as multifunctional carriers, bulking agents, and cryoprotectants in bakery and pasta systems, whereas resistant dextrins contribute to increased fibre content, satiety, and improved glycaemic control. Their combined application enables for tailoring of both product quality and nutritional profile, but optimal outcomes depend on careful matching of DE value, branching structure, and dosage to the food matrix. With a typical dextrose equivalent (DE) range of 5–20, maltodextrins are valued in bakery and pasta formulations due to their solubility, low sweetness, and multifunctionality as bulking agents, carriers, cryoprotectants, and fat replacers [155]. Their structural features—particularly chain length and branching—determine water-binding and plasticisation capacity as well as interactions with starch and protein matrices, which in turn affect dough rheology, product stability, and quality [156–158].

In yeast-leavened breads, incorporation of MDs at low levels (~1–3% on a flour basis) improves water absorption, dough stability, and loaf volume, while also delaying

crumb firming during storage by partially inhibiting starch retrogradation [153,155]. Depending on their fine structure, MDs influence gas production and retention differently: low-polymerised types accelerate CO_2 release but may impair loaf volume, whereas short-clustered or branched MDs improve stability and post-bake crumb quality, particularly under frozen storage conditions [156–158]. Recent studies with potato-derived maltodextrins in triticale breads confirmed that loaf volume, crumb softness, and sensory acceptance were strongly dependent on DE value, with higher-DE MDs yielding improved specific volume, softer crumb structure, and enhanced consumer acceptance [158].

In cakes and other fine bakery products, MDs function mainly as viscosity modulators and fat replacers. Partial substitution of fat (≈40–60%), when combined with proteins, inulin, or emulsifiers, maintains desirable aeration and sensory acceptance, while higher levels increase crumb density and stickiness [159,160]. MD-based nanoemulsions and spray-dried carriers have also been applied successfully for antioxidant and probiotic delivery, ensuring structural and sensory quality while enhancing functional value [161].

The role of MDs in frozen dough is particularly relevant, as freezing causes gluten damage, yeast stress, and ice recrystallisation. By binding water and modifying its mobility, MDs act as cryoprotectants, with short-clustered structures providing superior protection of yeast membrane integrity and improving gas retention after thawing [156–158]. The combination of MDs with trehalose further enhances yeast survival, loaf volume, and crumb softness in frozen bread products. In gluten-free bakery systems, maltodextrins are frequently employed as bulking agents, cryoprotectants, and viscosity modulators, where they compensate for the absence of gluten and improve batter stability. At low-to-moderate levels, MDs contribute to higher loaf volume, softer crumb, and extended freshness by enhancing water distribution and delaying retrogradation. Their functionality is strongly influenced by the DE value: higher-DE maltodextrins tend to provide better softness and consumer acceptance, whereas very low-DE types may compromise volume and texture [162].

In pasta and extruded noodle systems, low inclusions of MDs (~0.5–2% w/w) improve the ordering of starch gel network, reduce cooking loss, and enhance hardness and chewiness through hydrogen bonding with starch polymers, while excessive levels weaken structure and increase cooking loss [163,164]. Maltodextrins are generally considered sensorially neutral, contributing mainly to mouthfeel and perceived fullness rather than sweetness, though perceptual differences linked to degree of polymerisation have been reported [165].

Dextrins, including resistant dextrin (RD), isomaltodextrin, and branched-limit dextrin, are low-digestible starch derivatives that enhance processing tolerance, extend shelf-life, and improve the nutritional profile of bakery and pasta systems. In yeast-leavened breads, RD increases water absorption and dough stability, slows amylopectin retrogradation, and delays crumb firming, resulting in softer crumbs and prolonged freshness [166–168]. Branched-limit dextrin, in particular, modifies starch gelatinisation and setback behaviour, helping the structure withstand thermal–mechanical stress, while wheat dextrin can improve extrusion expansion [169,170].

In biscuits and short-dough systems, partial sugar or fat replacement with RD or soluble dextrin fibres maintains spread, fracture, and crunch while reducing glycaemic potential. Optimal results are observed when RD is combined with native or high-amylose starches, or with inulin and emulsifiers, which help restore structure and texture [124,171–174]. In noodle and pasta matrices, moderate additions of dextrin or isomaltodextrin improve dough handling and firmness, and reduce cooking loss. However, excessive doses may weaken the gluten–starch matrix and increase cooking loss, highlighting the need for moisture and the need for type- and DE-specific optimisation [132,166,169,175].

Sensory studies describe dextrins as neutral in flavour but note that they contribute positively to body and mouthfeel. Nutritionally, RD functions as a soluble fibre that promotes satiety, moderates postprandial glucose responses, and supports gut microbiota balance [175–178]. Beyond bakery applications, protein–dextrin conjugates act as clean-label stabilisers or fat replacers in fillings and creams, helping retain smoothness and prevent lipid oxidation [179,180].

Overall, the functional performance of dextrins in bakery and pasta products depends on their molecular type (RD, isomaltodextrin, branched-limit), dextrose equivalent, branching pattern, and water activity. Tailoring these parameters allows manufacturers to balance processing tolerance, nutritional improvement, and sensory quality [169,181].

3.5. Microbial Exopolysaccharides

Xanthan Gum and Other Exopolysaccharides

Xanthan gum (XG) is one of the most widely used microbial exopolysaccharides, produced by *Xanthomonas campestris* through aerobic fermentation of carbohydrate substrates such as glucose or sucrose. Chemically, it consists of a β-(1→4)-linked D-glucose backbone, similar to cellulose, with trisaccharide side chains containing mannose–glucuronic acid–mannose units, partly acetylated and pyruvylated [182]. It is applied as a stabiliser, emulsifier, and thickener in the food industry.

The addition of xanthan gum to whole-wheat dough has emerged as a promising strategy to mitigate technological and sensory limitations typically associated with whole-grain formulations. Studies have shown that xanthan gum significantly modifies the viscoelastic properties of the dough, enhancing water absorption, increasing mixing time, and improving elasticity and stability, thus promoting better gas retention during fermentation [183]. As a result, bread with added xanthan exhibits a higher specific volume compared to control samples without the hydrocolloid. Moreover, the bread crumb demonstrates reduced firmness both immediately after baking and during storage, suggesting a delay in staling. Such effects directly counter two persistent drawbacks of whole-wheat bread—low loaf volume and faster staling—thereby improving consumer acceptability. Overall, xanthan gum contributes to the development of high-fibre, functional bakery products that offer enhanced texture, prolonged freshness, and greater sensory appeal.

Beyond whole-wheat bread, XG has shown notable efficacy in frozen dough systems. Even at low levels (0.16%), it preserved loaf volume, appearance, crumb elasticity, and sensory scores after six months of freezing [184]. Supplementation in frozen/thawed dough improved bread height and oven-spring, in some cases surpassing unfrozen controls [185]. XG interacts with gluten to form hydrophilic complexes that retain water and inhibit ice crystallisation, thereby stabilising the gluten network and maintaining dough quality post-thaw [186]. In composite formulations, such as sorghum–wheat bread, additions near 1% improve volume, texture, and crumb uniformity [187]. Overall, XG functions as a protective hydrocolloid that slows staling and reinforces dough structure during freezing and baking.

Numerous studies (2018–2025) on gluten-free bakery products confirm that modest XG additions (0.2–1.5% *w*/*w*) enhance dough viscoelasticity, leading to higher loaf volumes, finer crumb structures, and slower firming [188–191]. Comparative work positions XG as a benchmark hydrocolloid: while HPMC or psyllium husk can match or surpass certain textural attributes, complete removal of XG usually compromises crumb cohesion and loaf resilience [31,104,192]. Encina-Zelada et al. [193] showed that XG functionality is strongly dependent on water content—around 1% XG combined with 95–100% hydration yielded the best batter viscosity, gas retention, and loaf quality, whereas excessive gum levels under restricted hydration conditions led to excessively rigid batters and impaired loaf development.

Beyond technological benefits, XG may also influence glycaemic response. Composite systems with XG, λ-carrageenan, and psyllium reduced glycaemic potency at 1–5% inclusion, although their individual effect remains weaker than that of psyllium. Recent studies confirm its positive impact on moisture retention, crumb softness, and shelf-life [178]. In vitro analyses further suggest that XG can reduce starch hydrolysis in gluten-free bread—from roughly 80% to about 57%—indicating a potential for glycaemic moderation [178]. Nevertheless, due to its high viscosity and limited digestibility, excessive consumption (>10 g day^{-1}) may cause gastrointestinal discomfort in sensitive individuals [194]. Xanthan gum acts as a multifunctional hydrocolloid that supports rheological stability, prolongs freshness, and maintains product quality in both wheat-based and gluten-free systems, with emerging evidence for modest metabolic benefits.

4. Comparative Overview and Future Trends

Polysaccharides are versatile ingredients in bakery and pasta systems. Their effects depend mainly on molecular structure, dosage, and interactions with the dough or pasta matrix. In bread dough, higher viscosity and water-binding capacity can weaken the gluten network and reduce gas retention, which, at excessive levels, lowers loaf volume and increases crumb firmness [43,44]. In gluten-free formulations, the same mechanisms can be beneficial by compensating for the absence of gluten, delaying staling through slower starch retrogradation and better moisture retention [45,47]. In pasta, stronger water-binding and altered protein–starch interactions may cause higher cooking loss and changes in texture [48–50]. From a sensory viewpoint, too much fibre often darkens colour or increases stickiness, but carefully optimised formulations—considering factors such as the degree of polymerisation of inulin or the molecular weight of β-glucan—can preserve or even improve consumer acceptability [29,30,51].

Combining polysaccharides with other ingredients can help balance technological and nutritional goals. For example, FOS paired with probiotics yields a synbiotic effect while improving rheology; inulin with HPMC or pectin stabilises gas cells in bread; and maltodextrin with trehalose protects yeast and gluten in frozen dough, maintaining loaf volume after thawing [32]. Moderate β-glucan fractions (≈1.7 MDa) improve hydration and softness but work best when combined with vital gluten to offset volume loss [44,45]. In cookies and biscuits, combinations of dextrin or maltodextrin with inulin or emulsifiers enable partial fat or sugar replacement without losing crispness.

Across product categories, goals differ. In bread, key priorities include maintaining volume, softness, and freshness; fructans and β-glucan improve freshness but may reduce loaf volume if the dose or molecular profile is unsuitable [22,43,98]. In pasta, the focus is on firmness and minimal cooking loss; ingredients like pectin or resistant starch offering nutritional enhancement but require controlled hydration to avoid stickiness [48,50]. In cakes and cookies, fructans and dextrins enable sugar or fat reduction while supporting moisture retention and structural stability [20,33,53]. Table 3 summarises their major effects and practical recommendations.

Future trends point to several innovations. Valorising agro-industrial by-products provides sustainable sources of pectin (citrus or apple pomace), arabinoxylan (bran), and resistant starch (corn or banana). Nano- and micro-encapsulation using maltodextrins and fructans enhances the stability and delivery of antioxidants, vitamins, and probiotics without altering texture [20]. Maillard conjugates such as protein–FOS complexes, improve emulsifying capacity and protect vitamins during digestion [25]. Enzyme-aided design also opens new paths: fibres like inulin, β-glucan, or arabinoxylan can be combined with cereal or pulse proteins and cross-linking enzymes to fine-tune dough networks. In gluten-free systems, hydrocolloids (HPMC, CMC) are gradually being replaced by natural fibres and

proteins to achieve similar rheological properties and extended freshness [45]. Finally, personalised and clinical nutrition concepts are gaining attention: β-glucan (≥3 g/day) and resistant starch are validated for lowering blood glucose and cholesterol [40,57], while low-FODMAP formulations adjust FOS and inulin types to support individuals with IBS. Synbiotic breads and process-tailored recipes illustrate how functional polysaccharides can move from laboratory innovation to consumer-ready products.

Table 3. Consolidated overview of functional polysaccharides in bakery and pasta products.

Polysaccharide	Positive Effects	Negative Effects	Recommendations	Products	References
Fructans (FOS, inulin)	• Prebiotic activity • Sugar/fat replacer • Improved moisture retention • Delayed staling • Lower GI	• Excessive FODMAP load → GI distress in IBS • Weakened gluten → reduced loaf volume	2–10% (bread, biscuits); up to 30% in GF breads (requires optimisation)	Bread, GF bread, cakes, biscuits, pasta	[13–29,33]
β-Glucan	• Lower GI and cholesterol • High water-binding • Improved moisture and shelf-life • Softer crumbs (moderate levels)	• High viscosity → reduced loaf volume, denser crumb • Higher cooking loss in pasta	1–5% (bread/cakes); 5–15% (GF bread with adjustments); 1–2% (pasta)	Bread, GF bread, pasta, cookies, cakes	[43–46,48]
Arabinoxylans	• Water retention • Prebiotic potentia • Improved fibre profile • Structural reinforcement in GF matrices	• Excess → sticky dough, darker crumb, reduced loaf volume	2–6% (bread, GF bread)	Bread, GF bread	[61–63,70–72]
Pectin	• Fat replacer • Moisture retention • Acrylamide reduction • Antioxidant carrier	• High inclusion → excessive thickening, reduced gas retention and loaf volume	2–5% (bread, biscuits); ≤10% (cakes/pastry)	Bread, biscuits, cookies, fine bakery, pasta	[74–77,87–99]
Cellulose derivatives (HPMC, CMC)	• Gas cell stabilisation • Shelf-life extension • Gluten replacement in GF bread	• Artificial/additive perception (clean-label concerns)	1–3% (GF bread)	GF bread, frozen doughs	[99–107,120]
Resistant starch (RS)	• Increased fibre • Lower GI • Delayed starch digestibility • Improved metabolic outcomes	• High levels → reduced loaf volume, firmer crumb, higher cooking loss (pasta/noodles)	5–20% (bread, biscuits); 5–15% (pasta/noodles)	Bread, biscuits, pasta, noodles	[136–146]
Chemically modified starches	• Thermal stability • Freeze–thaw stability • Viscosity control • Sugar/fat replacement	• May weaken gluten network • Regulatory acceptance varies	2–10% depending on type	Bread, GF bread, frozen doughs	[149,151]
Maltodextrins (MDs)	• Bulking agent • Fat replacer • Cryoprotectant • Moisture retention • Carrier of probiotics/antioxidants	• High-DE MDs → stickiness, reduced crumb volume • Conventional MDs = high GI	1–3% (bread); 5–10% (cakes/cookies); 0.5–2% (pasta)	Bread, GF bread, frozen dough, cakes, cookies, pasta	[155–160,163,164]
Dextrins (resistant, isomaltodextrin, branched-limit)	• Soluble fibre • Lower GI • Enhanced dough stability • Partial sugar/fat replacement	• Excessive inclusion → weakened gluten–starch network, increased cooking loss (pasta)	5–15% (bread, biscuits); 0.5–2% (pasta)	Bread, GF bread, biscuits, pasta	[166–168,171–173,175,179,180]

5. Conclusions

Polysaccharides are multifunctional ingredients that offer a dual benefit in bakery and pasta systems, simultaneously addressing technological and nutritional goals. Technologically, they contribute to the control of rheology, volume, texture, and freshness, while nutritionally, they enable lower glycaemic responses, higher dietary fibre intake, prebiotic effects, and improved lipid and glycaemic profiles [29,45,46,57]. Their functionality depends on structural factors such as molecular weight, degree of polymerisation, and branching, as well as on the applied dose and the characteristics of the food matrix. Among the most promising applications, fructans (inulin and FOS), β-glucan, and arabinoxylan stand out in bread, while gluten-free breads benefit from high-molecular-weight β-glucan,

carefully dosed fructans, cellulose derivatives, and resistant starch. In pasta and noodles, resistant starch, moderate levels of pectin or β-glucan, and maltodextrins or dextrins at low concentrations (0.5–2%) can improve both structure and nutritional quality, whereas in cakes and cookies, fructans and maltodextrins/dextrins support sugar and fat reduction and enable the incorporation of bioactives, with β-glucan providing additional fibre enrichment at moderate levels (≤3–5%). Future progress in the application of polysaccharides depends on clinical studies with real-world products, standardisation of structural parameters, and the valorisation of sustainable sources. Clean-label approaches and digital tools open new opportunities for more efficient product development. Altogether, polysaccharides not only optimise processing performance but also serve as drivers of functional and sustainable innovation, bridging consumer demands for quality, health, and environmental responsibility.

Author Contributions: Conceptualization, J.P.; J.Z., D.Š.-S., M.S. and A.J.; investigation, J.P., I.L., I.N., B.P., D.Š. and Đ.A.; writing—original draft preparation, J.P., J.Z., M.S., I.L. and I.N.; writing—review and editing, D.Š.-S., A.J., B.P., D.Š. and Đ.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, No. 451-03-136/2025-03/200134 and No. 451-03-137/2025-03/200134.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

DP	Degree of polymerisation
HPMC	Hydroxypropyl methylcellulose
CMC	Chemically modified starches
MCC	Methylcellulose
GF	Gluten free
MD	Maltodextrins
RS	Resistant starch
GI	Glycemic index
FOS	Fructooligosacharides
HPS	Hydroxypropyl starch
XG	Xanthan gum
DE	Dextrose equivalent
AX	Arabinoxylan
FAX	Feruloylated AX
MW	Molecular weight

References

1. Veronese, N.; Gianfredi, V.; Solmi, M.; Barbagallo, M.; Dominguez, L.J.; Mandalà, C.; Fontana, L. The Impact of Dietary Fiber Consumption on Human Health: An Umbrella Review of Evidence from 17,155,277 Individuals. *Clin. Nutr.* **2025**, *51*, 325–333. [CrossRef] [PubMed]
2. Deehan, E.C.; Mocanu, V.; Madsen, K.L. Effects of Dietary Fibre on Metabolic Health and Obesity. *Nat. Rev. Gastroenterol. Hepatol.* **2024**, *21*, 301–318. [CrossRef]

3. Kabisch, S.; Hajir, J.; Sukhobaevskaia, V.; Weickert, M.O.; Pfeiffer, A.F.H. Impact of Dietary Fibre on Inflammation in Humans. *Int. J. Mol. Sci.* **2025**, *26*, 2000. [CrossRef]
4. Guiné, R.P. Textural Properties of Bakery Products: A Review of Instrumental and Sensory Evaluation Studies. *Appl. Sci.* **2022**, *12*, 8628. [CrossRef]
5. Dossa, S.; Rivis, A. Functional Foods and Bakery Products: A Review. *J. Agroaliment. Process Technol.* **2024**, *30*, 104–114. [CrossRef]
6. Dedhia, N.; Survase, S.; Singhal, R.S. Food Polysaccharides: A Review on Emerging Microbial Polysaccharides and Modifications. *Carbohydr. Polym.* **2022**, *287*, 119355. [CrossRef] [PubMed]
7. Sempio, R.; Sahin, A.W.; Walter, J.; Arendt, E.K.; Zannini, E. Impact of Isolated and Chemically Modified Dietary Fiber on Bakery Products: Current Knowledge and Future Directions. *Cereal Chem.* **2024**, *101*, 7–37. [CrossRef]
8. Mohammadi, F.; Shiri, A.; Tahmouzi, S.; Mollakhalili-Meybodi, N.; Nematollahi-Meybodi, A. Application of Inulin in Bread: A Review of Technological Properties and Factors Affecting Its Stability. *Food Sci. Nutr.* **2022**, *11*, 639–650. [CrossRef]
9. Foschia, M.; Peressini, D.; Sensidoni, A.; Brennan, C.S. The Effects of Dietary Fibre Addition on the Quality of Common Cereal Products. *J. Cereal Sci.* **2013**, *58*, 216–227. [CrossRef]
10. Ferrero, C. Hydrocolloids in wheat breadmaking: A concise review. *Food Hydrocoll.* **2017**, *68*, 15–22. [CrossRef]
11. Fu, J.; Zheng, Y.; Gao, Y.; Xu, W. Dietary fiber intake and gut microbiota in human health. *Microorganisms* **2022**, *10*, 2507. [CrossRef] [PubMed]
12. Schadow, A.M.; Revheim, I.; Spielau, U.; Dierkes, J.; Schwingshackl, L.; Frank, J.; Rosendahl-Riise, H. The Effect of Regular Consumption of Reformulated Breads on Glycemic Control: A Systematic Review and Meta-Analysis of Randomized Clinical Trials. *Adv. Nutr.* **2023**, *14*, 30–43. [CrossRef]
13. Canale, M.; Sanfilippo, R.; Strano, M.C.; Bavaro, A.R.; Amenta, M.; Bizzini, M.; Spina, A. Technological Properties of Inulin-Enriched Doughs and Breads, Influence on Short-Term Storage and Glycemic Response. *Foods* **2024**, *13*, 2711. [CrossRef]
14. Hughes, R.L.; Alvarado, D.A.; Swanson, K.S.; Holscher, H.D. The prebiotic potential of inulin-type fructans: A systematic review. *Adv. Nutr.* **2022**, *13*, 492–529. [CrossRef]
15. Roberfroid, M. *Inulin-Type Fructans: Functional Food Ingredients*, 1st ed.; CRC Press: Boca Raton, FL, USA, 2004; p. 392. [CrossRef]
16. Drabińska, N.; Zieliński, H.; Krupa-Kozak, U. Technological Benefits of Inulin-Type Fructans Application in Gluten-Free Products—A Review. *Trends Food Sci. Technol.* **2016**, *56*, 149–157. [CrossRef]
17. Schaafsma, G.; Slavin, J.L. Significance of Inulin Fructans in the Human Diet. *Compr. Rev. Food Sci. Food Saf.* **2015**, *14*, 37–47. [CrossRef]
18. Niness, K.R. Inulin and oligofructose: What are they? *J. Nutr.* **1999**, *129*, 1402S–1406S. [CrossRef]
19. Seyedain-Ardabili, M.; Sharifan, A.; Ghiassi Tarzi, B. The production of synbiotic bread by microencapsulation. *Food Tech. Biotech.* **2016**, *54*, 52–59. [CrossRef]
20. Dana, H.; Sonia, A. Substituting Sugar in Pastry and Bakery Products with Functional Ingredients. *Appl. Sci.* **2024**, *14*, 8563. [CrossRef]
21. Kumarasamy, S.M.P.; Dasgupta, P.; Sivasubramaniam, V.; Elangovan, A.; Ranganathan, I. Studies on Physiochemical and Sensorial Properties of Biscuits Using Composite Protein Rich Flours. *AIP Conf. Proc.* **2020**, *2240*, 050002. [CrossRef]
22. Simonato, B. Improving the Sensory, Nutritional and Technological Profile of Conventional and Gluten-Free Pasta and Bakery Products. *Foods* **2021**, *10*, 975. [CrossRef] [PubMed]
23. Na, Y.; Nam, A.Y.; Park, S.H.; Lee, S.H. Production of Fructooligosaccharide-Containing Bakery and Sweet Paste Products Using Invertase. *Food Sci. Biotechnol.* **2024**, *33*, 1189–1194. [CrossRef] [PubMed]
24. Sadeghi, A.; Ebrahimi, M.; Assadpour, E.; Jafari, S.M. Recent Advances in Probiotic Breads: A Market Trend in the Functional Bakery Products. *Crit. Rev. Food Sci. Nutr.* **2024**, *64*, 13163–13174. [CrossRef]
25. Chailangka, A.; Autsavapromporn, N.; Karnjanapratum, S.; Leksawasdi, N.; Castagnini, J.M.; Barba, F.J.; Phimolsiripol, Y. Kinetic Stability, Gastrointestinal Fate, and Cytotoxicity of Vitamin D3 Emulsion Incorporated with Cricket Protein-Fructooligosaccharide Conjugate. *Food Hydrocoll.* **2024**, *146*, 109288. [CrossRef]
26. Öncel, B.; Akgün, S.T.; Özer, M.S. Development of Functional Tortillas with Inulin and Fructooligosaccharide: Effects on Dough, Tortilla Properties, and Sensory Evaluation. *Bull. Univ. Agric. Sci. Vet. Med. Cluj Napoca* **2025**, *82*, 1–13. [CrossRef] [PubMed]
27. Parnell, J.; Reimer, R. Prebiotic Fiber Modulation of the Gut Microbiota Improves Risk Factors for Obesity and the Metabolic Syndrome. *Gut Microbes* **2012**, *3*, 29–34. [CrossRef]
28. UCSF. Increasing Fiber Intake. Available online: https://www.ucsfhealth.org/education/increasing-fiber-intake (accessed on 15 July 2025).
29. Hager, A.S.; Ryan, L.A.; Schwab, C.; Gänzle, M.G.; O'Doherty, J.V.; Arendt, E.K. Influence of the Soluble Fibres Inulin and Oat β-Glucan on Quality of Dough and Bread. *Eur. Food Res. Technol.* **2011**, *232*, 405–413. [CrossRef]
30. Burešová, I.; Šebestíková, R.; Šebela, J.; Adámková, A.; Zvonková, M.; Skowronková, N.; Mlček, J. The Effect of Inulin Addition on Rice Dough and Bread Characteristics. *Appl. Sci.* **2024**, *14*, 2882. [CrossRef]

31. Belorio, M.; Gómez, M. Effect of Hydration on Gluten-Free Breads Made with Hydroxypropyl Methylcellulose in Comparison with Psyllium and Xanthan Gum. *Foods* **2020**, *9*, 1548. [CrossRef]
32. Peng, H.; Wang, X.; Chen, K.; Yue, C.; Wang, L.; Bai, Z.; Han, S.; Zhang, Z.; Guo, J.; Luo, D. Effect of Long-Chain Inulin on the Rheological Properties, Water State, Gluten Structure, and Microstructure of Frozen Dough. *Int. J. Food Sci. Technol.* **2023**, *58*, 5125–5136. [CrossRef]
33. Tsatsaragkou, K.; Methven, L.; Chatzifragkou, A.; Rodriguez-Garcia, J. The Functionality of Inulin as a Sugar Replacer in Cakes and Biscuits; Highlighting the Influence of Differences in Degree of Polymerisation on the Properties of Cake Batter and Product. *Foods* **2021**, *10*, 951. [CrossRef] [PubMed]
34. Cui, W.; Wood, P.J. Relationships between Structural Features, Molecular Weight and Rheological Properties of Cereal β-d-Glucans. In *Hydrocolloids*; Nishinari, K., Ed.; Elsevier: Amsterdam, The Netherlands, 2000; pp. 159–168. [CrossRef]
35. Harasym, J.; Olędzki, R. The Mutual Correlation of Glucose, Starch, and Beta-Glucan Release during Microwave Heating and Antioxidant Activity of Oat Water Extracts. *Food Bioprocess Technol.* **2018**, *11*, 874–884. [CrossRef]
36. Zhang, K.; Li, X.; Ma, Z.; Hu, X. Solvent Retention Capacity of Oat Flour: Relationship with Oat β-Glucan Content and Molecular Weight. *Food Hydrocoll.* **2019**, *93*, 19–23. [CrossRef]
37. Păucean, A.; Man, S.; Pop, A. Development of Oat-Based Food Formulation and Quality Characteristics. *J. Agroaliment. Process. Technol.* **2015**, *21*, 261–266.
38. Bae, I.Y.; Kim, S.M.; Lee, S.; Lee, H.G. Effect of Enzymatic Hydrolysis on Cholesterol-Lowering Activity of Oat β-Glucan. *New Biotechnol.* **2010**, *27*, 85–88. [CrossRef] [PubMed]
39. Malkki, E.; Virtanen, T. Gastrointestinal Effects of Oat Bran and Oat Gum: A Review. *LWT-Food Sci. Technol.* **2001**, *34*, 337–347. [CrossRef]
40. Mejía, S.M.V.; de Francisco, A.; Bohrer, B. A comprehensive review on cereal β-glucan: Extraction, characterisation, causes of degradation, and food application. *Crit. Rev. Food Sci. Nutr.* **2020**, *60*, 3693–3704. [CrossRef]
41. Ahmad, S.; Jan, K.; Sahu, J.K.; Habib, M.; Jan, S.; Bashir, K. A comprehensive review on recent trends and utilization of algal β-glucan for the development of nutraceuticals and functional foods. *Food Rev. Int.* **2025**, *41*, 469–490. [CrossRef]
42. Kurek Marcin, A.; Moczkowska, M.; Karp, S.; Olaf, K.H.; Ewelina, R. Application of rich in β-glucan flours and preparations in bread baked from frozen dough. *Food Sci. Technol. Int.* **2020**, *26*, 53–64. [CrossRef]
43. Gao, M.; Hu, Z.; Yang, Y.; Jin, Z.; Jiao, A. Effect of different molecular weight β-glucan hydrated with highland barley protein on the quality and in vitro starch digestibility of whole wheat bread. *Int. J. Biol. Macromol.* **2024**, *268*, 131681. [CrossRef] [PubMed]
44. Symons, L.J.; Brennan, C.S. The effect of barley β-glucan fiber fractions on bread dough and bread quality. *J. Food Sci.* **2004**, *69*, C220–C224. [CrossRef]
45. Bieniek, A.; Buksa, K. The influence of oat β-glucans of different molar mass on the properties of gluten-free bread. *Molecules* **2024**, *29*, 4579. [CrossRef]
46. Ronda, F.; Perez-Quirce, S.; Lazaridou, A.; Biliaderis, C.G. Effect of barley and oat β-glucan concentrates on gluten-free rice-based doughs and bread characteristics. *Food Hydrocoll.* **2015**, *48*, 197–207. [CrossRef]
47. Pastuszka, D.; Gambus, H.; Ziobro, R.; Buksa, K.; Sabat, R.; Augustyn, G. Impact of oats β-glucans on properties of gluten-free bread. *J. Microbiol. Biotechnol. Food Sci.* **2012**, *1*, 972–981.
48. Piwińska, J.; Wyrwisz, M.; Kurek, A.; Wierzbicka, A. Effect of oat β-glucan fiber powder and vacuum-drying on cooking quality and physical properties of pasta. *CyTA J. Food* **2016**, *14*, 101–108. [CrossRef]
49. Brandstedt, T. Incorporation of oat β-Glucan in Pasta and the Effect on Product Quality. Master's Thesis, Faculty of Natural Resources and Agricultural Sciences, Swedish University of Agricultural Sciences, Uppsala, Sweden, 2013. Available online: https://stud.epsilon.slu.se/6192/ (accessed on 2 October 2025).
50. Ungureanu-Iuga, M.; Avrămia, I. Pasta fortified with β-glucan isolated from brewer's yeast (*Saccharomyces cerevisiae*) by-product. *J. Cereal Sci.* **2024**, *115*, 103818. [CrossRef]
51. De Santis, D.; Moresi, M.; Cimini, A. Effect of β-glucan enrichment on the sensory properties of fresh egg white pasta. *LWT* **2020**, *130*, 109654. [CrossRef]
52. Karp, S.; Wyrwisz, J.; Kurek, M.A.; Wierzbicka, A. The use of high-in-β-glucan oat fibre powder as a structuring agent in gluten-free yeast-leavened cake. *Food Sci. Technol. Int.* **2019**, *25*, 618–629. [CrossRef]
53. Zbikowska, A.; Kowalska, M.; Zbikowska, K.; Onacik-Gür, S.; Łempicka, U.; Turek, P. Study on the incorporation of oat and yeast β-glucan into shortbread biscuits as a basis for designing healthier and high-quality food products. *Molecules* **2022**, *27*, 1393. [CrossRef]
54. Martinez-Subira, M.; Romero, M.P.; Puig, E.; Macià, A.; Romagosa, I.; Moralejo, M. Purple, high β-glucan, hulless barley as valuable ingredient for functional food. *LWT* **2020**, *131*, 109582. [CrossRef]
55. Sinangil, Z.; Taştan, Ö.; Baysal, T. Beta-glucan as a novel functional fiber: Functional properties, health benefits and food applications. *Turk. J. Agric.-Food Sci. Technol.* **2022**, *10*, 1957–1965. [CrossRef]

56. Miśkiewicz, K.; Rosicka-Kaczmarek, J.; Kowalska, G.; Maher, A.; Oracz, J. Effect of oat fiber preparations with different contents of β-glucan on the formation of acrylamide in dietary bread (rusks). *Molecules* **2024**, *29*, 306. [CrossRef] [PubMed]
57. Hu, H.; Lin, H.; Xiao, L.; Guo, M.; Yan, X.; Su, X.; Sang, S. Impact of native form oat β-glucan on the physical and starch digestive properties of whole oat bread. *Foods* **2022**, *11*, 2622. [CrossRef]
58. Li, F.; Li, T.; Zhao, J.; Fan, M.; Qian, H.; Li, Y.; Wang, L. Unraveling the deterioration mechanism of dough during whole wheat flour processing: A case study of gluten protein containing arabinoxylan with different molecular weights. *Food Chem.* **2024**, *432*, 137199. [CrossRef] [PubMed]
59. Pandeirada, C.O.; Merkx, D.W.; Janssen, H.G.; Westphal, Y.; Schols, H.A. TEMPO/$NaClO_2$/NaOCl oxidation of arabinoxylans. *Carbohydr. Polym.* **2021**, *259*, 117781. [CrossRef]
60. Pritchard, J.R.; Lawrence, G.J.; Larroque, O.; Li, Z.; Laidlaw, H.K.; Morell, M.K.; Rahman, S. A survey of β-glucan and arabinoxylan content in wheat. *J. Sci. Food Agric.* **2011**, *91*, 1298–1303. [CrossRef]
61. Pereira, G.V.; Abdel-Hamid, A.M.; Dutta, S.; D'Alessandro-Gabazza, C.N.; Wefers, D.; Farris, J.A.; Cann, I. Degradation of complex arabinoxylans by human colonic *Bacteroidetes*. *Nat. Commun.* **2021**, *12*, 459. [CrossRef]
62. Paesani, C.; Sciarini, L.S.; Moiraghi, M.; Salvucci, E.; Prado, S.B.; Pérez, G.T.; Fabi, J.P. Human colonic in vitro fermentation of water-soluble arabinoxylans from hard and soft wheat alters *Bifidobacterium* abundance and short-chain fatty acids concentration. *LWT* **2020**, *134*, 110253. [CrossRef]
63. Zhang, J.; He, Y.; Zhou, J.; Shen, T.; Hu, W. Immunomodulatory effects of wheat bran arabinoxylan on RAW264.7 macrophages via the NF-κB signaling pathway using RNA-seq analysis. *Food Res. Int.* **2021**, *140*, 110067. [CrossRef]
64. Knudsen, K.E.B.; Lærke, H.N.; Hedemann, M.S.; Nielsen, K.L.; Kasprzak, M.M.; Jeppesen, P.B.; Hermansen, K. Arabinoxylan concentrate from wheat as a functional food ingredient to improve glucose homeostasis. *Nutrients* **2025**, *17*, 1561. [CrossRef] [PubMed]
65. Collins, S.M.; Gibson, G.R.; Stainton, G.N.; Bertocco, A.; Kennedy, O.B.; Walton, G.E.; Commane, D.M. Chronic consumption of a blend of inulin and arabinoxylan reduces energy intake in an ad libitum meal but does not influence perceptions of appetite and satiety: A randomised control-controlled crossover trial. *Eur. J. Nutr.* **2023**, *62*, 2205–2215. [CrossRef]
66. Wang, P.; Hou, C.; Zhao, X.; Tian, M.; Gu, Z.; Yang, R. Molecular characterization of water-extractable arabinoxylan from wheat bran and its effect on the heat-induced polymerization of gluten and steamed bread quality. *Food Hydrocoll.* **2019**, *87*, 570–581. [CrossRef]
67. Döring, C.; Nuber, C.; Stukenborg, F.; Jekle, M.; Becker, T. Impact of arabinoxylan addition on protein microstructure formation in wheat and rye dough. *J. Food Eng.* **2015**, *154*, 10–16. [CrossRef]
68. Si, X.; Li, T.; Zhang, Y.; Zhang, W.; Qian, H.; Li, Y.; Wang, L. Interactions between gluten and water-unextractable arabinoxylan during the thermal treatment. *Food Chem.* **2021**, *345*, 128785. [CrossRef]
69. Sun, J.; Si, X.; Li, T.; Zhao, J.; Qian, H.; Li, Y.; Wang, L. The influence of water-unextractable arabinoxylan and its hydrolysates on the aggregation and structure of gluten proteins. *Front. Nutr.* **2022**, *9*, 877135. [CrossRef]
70. Zhang, D.; Rudjito, R.C.; Pietiäinen, S.; Chang, S.C.; Idström, A.; Evenäs, L.; Jiménez-Quero, A. Arabinoxylan supplemented bread: From extraction of fibers to effect of baking, digestion, and fermentation. *Food Chem.* **2023**, *413*, 135660. [CrossRef] [PubMed]
71. Zannini, E.; Bravo Núñez, Á.; Sahin, A.W.; Arendt, E.K. Arabinoxylans as functional food ingredients: A review. *Foods* **2022**, *11*, 1026. [CrossRef] [PubMed]
72. Pietiäinen, S.; Jimenez-Quero, A.; Moldin, A.; Ström, A.; Katina, K.; Langton, M. Feruloylation and hydrolysis of arabinoxylan extracted from wheat bran: Effect on bread quality and shelf-life. *J. Cereal Sci.* **2024**, *117*, 103920. [CrossRef]
73. Voragen, A.G.J.; Coenen, G.J.; Verhoef, R.P.; Schols, H.A. Pectin, a versatile polysaccharide present in plant cell walls. *Struct. Chem.* **2009**, *20*, 263–275. [CrossRef]
74. Donchenko, L.V.; Sokol, N.V.; Sanzharovskaya, N.S.; Khrapko, O.P.; Mikhaylova, T.A. Functional role of pectin in the bakery technology. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *488*, 012010. [CrossRef]
75. Tursynbek, A.E.; Zheldynbaeva, A.A. Research on the use and safety of pectin substances obtained from vegetable raw materials in bread production. In Пищевые Технологии Будущего: Инновации в Производстве и Переработке Сельскохозяйственной Продукции; Center for Social Agroinnovations of Saratov State Agrarian University: Saratov, Russia, 2021; pp. 163–169. Available online: https://elibrary.ru/item.asp?id=46120774 (accessed on 2 September 2025).
76. Noreen, A.; Akram, J.; Rasul, I.; Mansha, A.; Yaqoob, N.; Iqbal, R.; Zia, K.M. Pectins functionalized biomaterials: A new viable approach for biomedical applications—A review. *Int. J. Biol. Macromol.* **2017**, *101*, 254–272. [CrossRef]
77. Correa, M.J.; Pérez, G.T.; Ferrero, C. Pectins as breadmaking additives: Effect on dough rheology and bread quality. *Food Bioprocess Technol.* **2012**, *5*, 2889–2898. [CrossRef]
78. Zhang, X.; Li, J.; Zhao, J.; Mu, M.; Jia, F.; Wang, Q.; Wang, J. Aggregative and structural properties of wheat gluten induced by pectin. *J. Cereal Sci.* **2021**, *100*, 103247. [CrossRef]

79. Khakimova, B.; Atkhamova, S.; Radjabov, M.; Sanayev, E.; Khakimova, O.; Irnazarov, S. Application of pectin-containing concentrate from *Portúlaca olerácea* in the production of first-grade wheat bread. *BIO Web Conf.* **2024**, *113*, 03002. [CrossRef]
80. Qi, K.; Cao, S.; Li, C. Possible interaction between pectin and gluten alters the starch digestibility and texture of wheat bread. *Int. J. Biol. Macromol.* **2024**, *269*, 131907. [CrossRef] [PubMed]
81. Bugarín, R.; Gómez, M. Can citrus fiber improve the quality of gluten-free breads? *Foods* **2023**, *12*, 1357. [CrossRef]
82. Lazova-Borisova, I. Determination innovative technological solutions for chia flour, corn starch, and apple pectin for gluten-free bread production. *Int. J. Nat. Eng. Sci.* **2024**, *18*, 45–54. Available online: https://www.ijnes.org/index.php/ijnes/article/view/771 (accessed on 2 October 2025).
83. Scappaticci, G.; Mercanti, N.; Pieracci, Y.; Ferrari, C.; Mangia, R.; Marianelli, A.; Zinnai, A. Bread Improvement with Nutraceutical Ingredients Obtained from Food By-Products: Effect on Quality and Technological Aspects. *Foods* **2024**, *13*, 825. [CrossRef]
84. Difonzo, G.; de Gennaro, G.; Pasqualone, A.; Caponio, F. Potential use of plant-based by-products and waste to improve the quality of gluten-free foods. *J. Sci. Food Agric.* **2022**, *102*, 2199–2211. [CrossRef]
85. Abdollahzadeh, A.; Vazifedoost, M.; Didar, Z.; Haddadkhodaprast, M.H.; Armin, M. Comparison of the effect of hydroxyl propyl methyl cellulose, pectin, and concentrated raisin juice on gluten-free bread based on rice and foxtail millet flour. *Food Sci. Nutr.* **2024**, *12*, 439–449. [CrossRef]
86. Li, J.; Yin, L.; Li, J. Effect of pectins on dough rheology and Chinese steamed bread quality. *Grain Oil Sci. Technol.* **2018**, *1*, 77–84. [CrossRef]
87. Nuzzo, D.; Scurria, A.; Picone, P.; Guiducci, A.; Pagliaro, M.; Pantaleo, G.; Ciriminna, R. A gluten-free biscuit fortified with lemon IntegroPectin. *ChemistrySelect* **2022**, *7*, e202104247. [CrossRef]
88. Kazemi, M.; Aboutalebzadeh, S.; Mojaverian, S.P.; Samani, S.A.; Kouhsari, F.; PourvatanDoust, S.; Khodaiyan, F. Valorization of pistachio industrial waste: Simultaneous recovery of pectin and phenolics, and their application in low-phenylalanine cookies for phenylketonuria. *Int. J. Biol. Macromol.* **2023**, *249*, 126086. [CrossRef] [PubMed]
89. Sharma, P.; Osama, K.; Gaur, V.K.; Farooqui, A.; Varjani, S.; Younis, K. Sustainable utilization of *Citrus limetta* peel for obtaining pectin and its application in cookies as a fat replacer. *J. Food Sci. Technol.* **2023**, *60*, 975–986. [CrossRef]
90. Nawaz, A.; Li, E.; Khalifa, I.; Walayat, N.; Liu, J.; Nilofar; Inam-Ur-Raheem, M. Effect of structurally different pectin on dough rheology, structure, pasting and water distribution properties of partially meat-based sugar snap cookies. *Foods* **2021**, *10*, 2692. [CrossRef]
91. Khatko, Z.N.; Kolodina, E. Pectin-containing flour confectionery with a reduced gluten content. *J. Biochem. Technol.* **2021**, *12*, 9–13. [CrossRef]
92. López-Ruiz, R.; Marin-Saez, J.; Cunha, S.C.; Fernandes, A.; de Freitas, V.; Viegas, O.; Ferreira, I.M. Fibre enrichment of cookies to mitigate acrylamide formation and gastrointestinal bioaccessibility. *LWT* **2023**, *182*, 114835. [CrossRef]
93. Ratnadewi, A.A.I.; Zahro, A.A.; Handayani, W.; Sari, A.B.T.; Kusuma, A.N.N. The Effect of Adding Pectin Derived from Cocoa Pod Husk Extract (*Theobroma cacao* L.) on Physical Properties, Chemical Properties and Digestibility of Cookies. *Eng. Headw.* **2025**, *24*, 139–146. [CrossRef]
94. Gumul, D.; Kruczek, M.; Ivanišová, E.; Słupski, J.; Kowalski, S. Apple pomace as an ingredient enriching wheat pasta with health-promoting compounds. *Foods* **2023**, *12*, 804. [CrossRef]
95. Bianchi, F.; Tolve, R.; Rainero, G.; Bordiga, M.; Brennan, C.S.; Simonato, B. Technological, nutritional and sensory properties of pasta fortified with agro-industrial by-products: A review. *Int. J. Food Sci. Technol.* **2021**, *56*, 4356–4366. [CrossRef]
96. Sempio, R.; Nyhan, L.; Sahin, A.W.; Zannini, E.; Walter, J.; Arendt, E.K. Enriching pasta with soluble and insoluble fibre: A strategy for boosting fibre intake. *Appl. Food Res.* **2025**, *5*, 100737. [CrossRef]
97. Li, X.; Zeng, X.; Xi, Y.; Li, H.; Yuan, Y.; Li, J. Effects of non-covalent interactions between pectin and volatile compounds on the flavor release of tomato paste. *Food Hydrocoll.* **2022**, *133*, 107886. [CrossRef]
98. Zioga, M.; Tsianaka, K.; Pappas, C.; Evageliou, V. Pectin or/and carrageenan edible films in the presence of tomato paste. *Food Hydrocoll.* **2025**, *169*, 111623. [CrossRef]
99. Culetu, A.; Duta, D.E.; Papageorgiou, M.; Varzakas, T. The Role of Hydrocolloids in Gluten-Free Bread and Pasta; Rheology, Characteristics, Staling and Glycemic Index. *Foods* **2021**, *10*, 3121. [CrossRef]
100. Šmídová, Z.; Rysová, J. Gluten-Free Bread and Bakery Products Technology. *Foods* **2022**, *11*, 480. [CrossRef] [PubMed]
101. Irondi, E.A.; Akintayo, O.; Adeleke, O.R.; Zakari, M.D. Natural and modified food hydrocolloids as gluten replacement in baked foods: Functional benefits and prospects. *Grain Oil Sci. Technol.* **2023**, *6*, 322–335. [CrossRef]
102. Burdock, G.A. Safety assessment of hydroxypropyl methylcellulose as a food ingredient. *Food Chem. Toxicol.* **2007**, *45*, 2341–2351. [CrossRef] [PubMed]
103. Vlad, R.-A.; Pintea, A.; Pintea, C.; Rédai, E.-M.; Antonoaea, P.; Bîrsan, M.; Ciurba, A. Hydroxypropyl Methyl-cellulose—A Key Excipient in Pharmaceutical Drug Delivery Systems. *Pharmaceutics* **2025**, *17*, 784. [CrossRef] [PubMed]

104. Torres-Pérez, R.; Martínez-García, E.; Siguero-Tudela, M.M.; García-Segovia, P.; Martínez-Monzó, J.; Igual, M. Enhancing Gluten-Free Bread Production: Impact of Hydroxypropyl Methylcellulose, Psyllium Husk Fiber, and Xanthan Gum on Dough Characteristics and Bread Quality. *Foods* **2024**, *13*, 1691. [CrossRef]
105. Di Renzo, T.; Trivisonno, M.C.; Nazzaro, S.; Reale, A.; Messia, M.C. Effect of Different Hydrocolloids on the Qualitative Characteristics of Fermented Gluten-Free Quinoa Dough and Bread. *Foods* **2024**, *13*, 1382. [CrossRef]
106. Baldino, N.; Laitano, F.; Lupi, F.R.; Curcio, S.; Gabriele, D. Effect of HPMC and CMC on rheological behavior at different temperatures of gluten-free bread formulations based on rice and buckwheat flours. *Eur. Food Res. Technol.* **2018**, *244*, 1829–1842. [CrossRef]
107. Villanueva, M.; Vicente, A.; Náthia-Neves, G.; Ronda, F. Microwave-treated rice flour halves the need of hydroxypropyl methylcellulose in the formulation of gluten-free bread. *Food Hydrocoll.* **2024**, *150*, 109738. [CrossRef]
108. Arp, C.G.; Correa, M.J.; Ferrero, C. Modified celluloses improve the proofing performance and quality of bread made with a high content of resistant starch. *J. Sci. Food Agric.* **2023**, *103*, 3041–3049. [CrossRef]
109. Liu, S.-F.; Zhu, K.-X.; Guo, X.-N. The Effect of Carboxymethyl Cellulose Sodium on the Proofing Tolerance and Quality of Frozen Dough Steamed Bread. *Foods* **2024**, *13*, 870. [CrossRef] [PubMed]
110. Marco, C.; Rosell, C.M. Breadmaking performance of protein enriched, gluten-free breads. *Eur. Food Res. Technol.* **2008**, *227*, 1205–1213. [CrossRef]
111. Mohseni, M.; Mahasti Shotorbani, P.; Akhondzadeh Basti, A.; Azimi, Y. Quality Evaluation of Gluten-Free Pasta Enhanced with Carboxymethyl Cellulose Gum: Rheological Properties, Characterization, Cooking Tests, and Sensory Analysis. *J. AOAC Int.* **2025**, *108*, 539–548. [CrossRef]
112. Hu, X.; Cheng, L.; Hong, Y.; Li, Z.; Li, C.; Gu, Z. An extensive review: How starch and gluten impact dough machinability and resultant bread qualities. *Crit. Rev. Food Sci. Nutr.* **2023**, *63*, 1930–1941. [CrossRef] [PubMed]
113. van Rooyen, J.; Simsek, S.; Oyeyinka, S.A.; Manley, M. Wheat starch structure–function relationship in breadmaking: A review. *Compr. Rev. Food Sci. Food Saf.* **2023**, *22*, 2292–2309. [CrossRef]
114. Roman, L.; Gomez, M.; Martinez, M.M. Mesoscale structuring of gluten-free bread with starch. *Curr. Opin. Food Sci.* **2021**, *38*, 189–195. [CrossRef]
115. Whitney, K.; Simsek, S. Potato flour as a functional ingredient in bread: Evaluation of bread quality and starch characteristics. *Int. J. Food Sci. Technol.* **2020**, *55*, 3639–3649. [CrossRef]
116. Cheng, L.; Wang, X.; Gu, Z.; Hong, Y.; Li, Z.; Li, C.; Ban, X. Effects of different gelatinization degrees of starch in potato flour on the quality of steamed bread. *Int. J. Biol. Macromol.* **2022**, *209*, 144–152. [CrossRef]
117. Rhazi, L.; Méléard, B.; Daaloul, O.; Grignon, G.; Branlard, G.; Aussenac, T. Genetic and environmental variation in starch content, starch granule distribution and starch polymer molecular characteristics of French bread wheat. *Foods* **2021**, *10*, 205. [CrossRef] [PubMed]
118. Zi, Y.; Shen, H.; Dai, S.; Ma, X.; Ju, W.; Wang, C.; Song, J. Comparison of starch physicochemical properties of wheat cultivars differing in bread- and noodle-making quality. *Food Hydrocoll.* **2019**, *93*, 78–86. [CrossRef]
119. Corrado, M.; Zafeiriou, P.; Ahn-Jarvis, J.H.; Savva, G.M.; Edwards, C.H.; Hazard, B.A. Impact of storage on starch digestibility and texture of a high-amylose wheat bread. *Food Hydrocoll.* **2023**, *135*, 108139. [CrossRef]
120. Witczak, M.; Korus, J.; Ziobro, R.; Juszczak, L. Waxy starch as dough component and anti-staling agent in gluten-free bread. *LWT* **2019**, *99*, 476–482. [CrossRef]
121. Roman, L.; Reguilon, M.P.; Martinez, M.M.; Gomez, M. The effects of starch cross-linking, stabilization and pre-gelatinization at reducing gluten-free bread staling. *LWT* **2020**, *132*, 109908. [CrossRef]
122. Xu, K.; Chi, C.; She, Z.; Liu, X.; Zhang, Y.; Wang, H.; Zhang, H. Understanding how starch constituent in frozen dough following freezing-thawing treatment affected quality of steamed bread. *Food Chem.* **2022**, *366*, 130614. [CrossRef]
123. Yang, Z.; Xu, D.; Zhou, H.; Wu, F.; Xu, X. New insight into the contribution of wheat starch and gluten to frozen dough bread quality. *Food Biosci.* **2022**, *48*, 101777. [CrossRef]
124. Yu, S.; Dong, K.; Pora, B.L.; Hasjim, J. The roles of a native starch and a resistant dextrin in texture improvement and low glycemic index of biscuits. *Processes* **2022**, *10*, 2404. [CrossRef]
125. Devi, R.; Singh, A.; Dutta, D.; Sit, N. Physicochemical properties of barley starch and effect of substitution of wheat flour with barley starch on texture and sensory properties of bread. *Efood* **2024**, *5*, e132. [CrossRef]
126. Ma, Z.; Lin, X.; Liu, F.; Zheng, H.; Li, Y. Preparation, characterization, and application of a novel chestnut starch-based bigel as a fat substitute in bread. *Int. J. Biol. Macromol.* **2025**, *328*, 147516. [CrossRef]
127. Liu, J.; Liu, X.; Man, Y.; Liu, Y. Reduction of acrylamide content in bread crust by starch coating. *J. Sci. Food Agric.* **2018**, *98*, 336–345. [CrossRef]
128. da Cruz, E.P.; Pires, J.B.; dos Santos, F.N.; Fonseca, L.M.; Radünz, M.; Dal Magro, J.; Dias, A.R.G. Encapsulation of lemongrass essential oil into cassava starch fibers for application as antifungal agents in bread. *Food Hydrocoll.* **2023**, *145*, 109105. [CrossRef]

129. Luna-Niño, M.F.; Beristain-Guevara, C.I.; Pascual-Pineda, L.A.; Rascón-Díaz, M.P.; Luna-Solano, G.; Jiménez-Fernández, M. Characterization of chayotextle starch films supplemented with essential oils and their effect as a coating on the shelf life of bread. *Starch-Stärke* **2025**, *77*, 2400057. [CrossRef]
130. Fitriati, A.; Detchewa, P.; Moongngarm, A. Replacing rice flour with starch-lipid complex reduced estimated glycemic index and enhanced slow digestible starch and resistant starch content in gluten-free fettuccine. *J. Cereal Sci.* **2025**, *121*, 104080. [CrossRef]
131. Wahab, M.; Janaswamy, S. Porous starch granules loaded curcumin and resveratrol modulate starch digestibility of wheat bread: Toward developing novel functional foods. *Food Hydrocoll.* **2025**, *162*, 111006. [CrossRef]
132. You, J.G.; Lee, J.H.; Park, E.Y. Effect of high amylose corn starch/dextrin on quality of non-fried instant noodles. *Korean J. Food Sci. Technol.* **2020**, *52*, 655–660.
133. Huang, D.W.; Chan, Y.J.; Huang, Y.C.; Chang, Y.J.; Tsai, J.C.; Mulio, A.T.; Li, P.H. Quality Evaluation, Storage Stability, and Sensory Characteristics of Wheat Noodles Incorporated with Isomaltodextrin. *Plants* **2021**, *10*, 578. [CrossRef]
134. Dang, Y.; Otsubo, T.; Iwamoto, S.; Katsuno, N. Unraveling the changes of physical properties and nanostructures of rice starch incorporated with pregelatinized rice starch paste during gelatinization. *Food Hydrocoll.* **2025**, *162*, 110931. [CrossRef]
135. Zhang, Q.; Chen, M.; Li, W.; Liang, C.; Huang, X.; Hu, H.; Zhang, Y. Effects of the addition of cassava starch and the size of water clusters on physicochemical and cooking properties of rice noodles. *Food Chem.* **2025**, *470*, 142665. [CrossRef]
136. Zhang, R.; Wang, Z.; He, X.; Xu, Z.; Li, M.; Liu, X.; Sun, Q. Effects of sweet potato starch on the physicochemical properties and edible qualities of instant fresh rice noodles. *Int. J. Biol. Macromol.* **2025**, *286*, 138553. [CrossRef] [PubMed]
137. Roman, L.; Martinez, M.M. Structural basis of resistant starch (RS) in bread: Natural and commercial alternatives. *Foods* **2019**, *8*, 267. [CrossRef]
138. Li, J.; Deng, F.; Han, P.; Ding, Y.; Cao, J. Preparation of Resistant Starch Types III+ V with Moderate Amylopullulanase and Its Effects on Bread Properties. *Foods* **2024**, *13*, 1251. [CrossRef]
139. Barros, J.H.; Telis, V.R.; Taboga, S.; Franco, C.M. Resistant starch: Effect on rheology, quality, and staling rate of white wheat bread. *J. Food Sci. Technol.* **2018**, *55*, 4578–4588. [CrossRef] [PubMed]
140. Arp, C.G.; Correa, M.J.; Ferrero, C. Improving quality: Modified celluloses applied to bread dough with high level of resistant starch. *Food Hydrocoll.* **2021**, *112*, 106302. [CrossRef]
141. Arp, C.G.; Correa, M.J.; Ferrero, C. Kinetic study of staling in breads with high-amylose resistant starch. *Food Hydrocoll.* **2020**, *106*, 105879. [CrossRef]
142. Correa, M.J.; Burbano Moreano, J.J.; Guardianelli, L.M.; Weisstaub, A.R.; Zuleta, A.; Salinas, M.V. Garlic: A natural bread improver for wheat bread with a high level of resistant starch. *J. Food Process. Preserv.* **2021**, *45*, e15519. [CrossRef]
143. Feng, H.; Cheng, B.; Lim, J.; Li, B.; Li, C.; Zhang, X. Advancements in enhancing resistant starch type 3 (RS3) content in starchy food and its impact on gut microbiota: A review. *Compr. Rev. Food Sci. Food Saf.* **2024**, *23*, e13355. [CrossRef]
144. Moon, Y.; Kweon, M. Processing suitability of physical modified non-GMO high-amylose wheat flour as a resistant starch ingredient in cookies. *Molecules* **2025**, *30*, 2619. [CrossRef]
145. Gutiérrez-Luna, K.; Ansorena, D.; Astiasaran, I. Effect of baking conditions on resistant starch: Model systems and cake formulations. *Food Chem.* **2024**, *449*, 139174. [CrossRef]
146. Farré Forcén, I. Bibliographic Review—The Technological Application of Resistant Starch and Its Health Benefits on the Formulation of Pasta in the Food Industry. *Appl. Sci.* **2024**, *14*, 5273. [CrossRef]
147. Kikuchi, Y.; Otomo, Y.; Toyota, K.; Noma, S.; Ebihara, S. Effects of the bread containing resistant starch from wheat (*Triticum aestivum*) on the improvement in bowel movements: A randomized, double-blind, placebo-controlled, crossover study. *Biosci. Biotechnol. Biochem.* **2025**, *89*, 1015–1023. [CrossRef] [PubMed]
148. Karunarathna, S.; Wickramasinghe, I.; Truong, T.; Brennan, C.; Navaratne, S.B.; Chandrapala, J. Development of low-calorie food products with resistant starch-rich sources—A review. *Food Rev. Int.* **2024**, *40*, 814–831. [CrossRef]
149. Gałkowska, D.; Kapuśniak, K.; Juszczak, L. Chemically Modified Starches as Food Additives. *Molecules* **2023**, *28*, 7543. [CrossRef]
150. Zhang, J.; Liu, Y.; Wang, P.; Zhao, Y.; Zhu, Y.; Xiao, X. The effect of protein–starch interaction on the structure and properties of starch, and its application in flour products. *Foods* **2025**, *14*, 778. [CrossRef]
151. Wang, M.; Chen, X.; Yang, Z.; Wang, M.; Shang, S.; Fu, B.; Wen, C. Effect of acetylated distarch adipate on fermentation properties of freeze-thawed post-fermented frozen dough and bread characteristics. *J. Cereal Sci.* **2025**, *121*, 104094. [CrossRef]
152. Durmuş, Y.; Bilgiçli, N.; Elgün, A.; Demir, M.K. Enrichment of sourdough bread with hazelnut skin, cross-linked starch or oxidized starch for improvement of nutritional quality. *J. Food Process Eng.* **2023**, e14361. [CrossRef]
153. Handayani, M.N.; Cakrawati, D. Chemical Characteristics and Sensory Properties of Biscuits Using Modified Potato Flour. *Pertanika J. Soc. Sci. Humanit.* **2017**, *25*, 147–156.
154. EFSA Panel on Food Additives and Nutrient Sources added to Food (ANS); Mortensen, A.; Aguilar, F.; Crebelli, R.; Di Domenico, A.; Dusemund, B.; Woutersen, R.A. Re-evaluation of oxidised starch (E 1404), monostarch phosphate (E 1410), distarch phosphate (E 1412), phosphated distarch phosphate (E 1413), acetylated distarch phosphate (E 1414), acetylated starch (E 1420), acetylated distarch adipate (E 1422), hydroxypropyl starch (E 1440), hydroxypropyl distarch phosphate (E 1442), starch sodium octenyl

succinate (E 1450), acetylated oxidised starch (E 1451) and starch aluminium octenyl succinate (E 1452) as food additives. *EFSA J.* **2017**, *15*, e04911. [CrossRef]
155. AbuDujayn, A.A.; Altayyar, R.; Abbood, H.M.; Mohamed, R.; Alamri, A.; Ibraheem, M.A. Relationship between dough properties and baking performance: Maltodextrins as promising antistaling ingredients. *Molecules* **2022**, *28*, 235. [CrossRef]
156. Li, Y.; Zhao, F.; Li, C.; Ban, X.; Gu, Z.; Li, Z. Fine structures of added maltodextrin impact stability of frozen bread dough system. *Carbohydr. Polym.* **2022**, *298*, 120028. [CrossRef] [PubMed]
157. Li, Y.; Kong, H.; Li, C.; Ban, X.; Gu, Z.; Lu, Y.; Li, Z. Short-Clustered Maltodextrin Provides Cryoprotection by Maintaining Yeast Cell Membrane Homeostasis during Frozen Storage. *Food Chem.* **2023**, *404*, 134729. [CrossRef]
158. Li, Y.; Kong, H.; Li, C.; Ban, X.; Gu, Z.; Lu, Y.; Li, Z. Short-Clustered Maltodextrin Mediates Stabilization of Gluten Proteins during Frozen Storage Compared to Trehalose and Guar Gum. *Food Chem.* **2025**, *476*, 143387. [CrossRef] [PubMed]
159. Colla, K.; Costanzo, A.; Gamlath, S. Fat Replacers in Baked Food Products. *Foods* **2018**, *7*, 192. [CrossRef] [PubMed]
160. Lakshminarayan, S.M.; Rathinam, V.; KrishnaRau, L. Effect of Maltodextrin and Emulsifiers on the Viscosity of Cake Batter and on the Quality of Cakes. *J. Sci. Food Agric.* **2006**, *86*, 706–712. [CrossRef]
161. Ogrodowska, D.; Konopka, I.Z.; Tańska, M.; Brandt, W.; Piłat, B. Effect of Maltodextrin Replacement by Selected Native Starches and Disaccharides on Physicochemical Properties of Pumpkin Oil Capsules Prepared by Spray-Drying. *Appl. Sci.* **2021**, *12*, 33. [CrossRef]
162. Witczak, M.; Korus, J.; Ziobro, R.; Juszczak, L. The effects of maltodextrins on gluten-free dough and quality of bread. *J. Food Eng.* **2010**, *96*, 258–265. [CrossRef]
163. Xu, X.; Gao, C.; Xu, J.; Meng, L.; Wang, Z.; Yang, Y.; Tang, X. Hydration and Plasticization Effects of Maltodextrin on the Structure and Cooking Quality of Extruded Whole Buckwheat Noodles. *Food Chem.* **2022**, *374*, 131613. [CrossRef]
164. Hu, W.; Zhang, W.; Zhang, Z.; Shen, S.; Lu, G.; Wu, W. Effect of Maltodextrin on the Physicochemical Properties of Noodles. *Foods* **2022**, *11*, 4082. [CrossRef]
165. Hartley, C.; Keast, R.S.; Carr, A.J.; Roberts, S.S.; Bredie, W.L. Investigating Taste Perception of Maltodextrins Using Lactisole and Acarbose. *Foods* **2024**, *13*, 2130. [CrossRef]
166. Huang, Z.; Wang, J.J.; Chen, Y.; Wei, N.; Hou, Y.; Bai, W.; Hu, S.Q. Effect of Water-Soluble Dietary Fiber Resistant Dextrin on Flour and Bread Qualities. *Food Chem.* **2020**, *317*, 126452. [CrossRef]
167. Bilyk, O.; Lytvynenko, O.K.; Bondarenko, Y.; Vasylchenko, T.; Pukhliak, A. Developing an Improver of Targeted Action for the Prolonged Freshness of Bread Made from Wheat Flour. *East. Eur. J. Adv. Technol.* **2020**, *5*, 62–70. [CrossRef]
168. Bilyk, O.; Bondarenko, Y.; Kochubei-Lytvynenko, O.; Halykova, E.; Fain, A. Studying the Effect of the Integrated Bread Baking Improver "Mineral Freshness Super" on Consumer Properties of Wheat Bread. *East. Eur. J. Adv. Technol.* **2019**, *3*, 65–72. [CrossRef]
169. Wang, L.; Xu, J.; Fan, X.; Wang, Q.; Wang, P.; Yuan, J.; Cui, L. The Effect of Branched Limit Dextrin on Corn and Waxy Corn Gelatinization and Retrogradation. *Int. J. Biol. Macromol.* **2018**, *106*, 116–122. [CrossRef]
170. Guéritte, M.; Dalle Fratte, E.; Van de Velde, L.M.; Eeckhout, M.; Debonne, E. Effect of Wheat Dextrin on Corn Flour Extrusion Characteristics. *Heliyon* **2023**, *9*, e21827. [CrossRef]
171. Peng, H.; Liu, S.; Huang, R.L.; Yuan, H.S.; Zhai, W.Y.; Ouyang, G.; Yang, Z.Z. Development and Determination of Glycemic Index Value of a Resistant Dextrin Biscuit. *J. Chin. Cereal Oils Assoc.* **2020**, *28*, 32–37.
172. Rodriguez-Garcia, J.; Ding, R.; Nguyen, T.H.; Grasso, S.; Chatzifragkou, A.; Methven, L. Soluble Fibres as Sucrose Replacers: Effects on Physical and Sensory Properties of Sugar-Reduced Short-Dough Biscuits. *LWT* **2022**, *167*, 113837. [CrossRef]
173. Dehghan, P.; Emami, N.; Mohtarami, F.; Ostadrahimi, A.; Azizi, M.H. Physicochemical, Textural, and Sensory Evaluation of Reduced Fat Gluten-Free Biscuit Prepared with Inulin and Resistant Dextrin Prebiotic. *J. Agric. Sci. Technol.* **2025**, *20*, 719–731.
174. Wojcik, M.; Kapusniak, K.; Zarski, A.; Kapusniak, J. Preparation and Characterization of Soluble Dextrin Fibre from Potato Starch Obtained on a Semi-Industrial Scale. *Appl. Sci.* **2024**, *14*, 1438. [CrossRef]
175. Wu, X.; Zhang, J.; Yan, X.; Wu, X.; Zhang, Q.; Luan, M. An In-Depth Overview of the Structural Properties, Health Benefits, and Applications of Resistant Dextrin. *J. Food Process. Preserv.* **2024**, *2024*, 8055063. [CrossRef]
176. Emilien, C.H.; Hsu, W.H.; Hollis, J.H. The Effect of Soluble Fiber Dextrin on Subjective and Physiological Markers of Appetite: A Randomized Trial. *Nutrients* **2020**, *12*, 3341. [CrossRef]
177. Hobden, M.R.; Commane, D.M.; Guérin-Deremaux, L.; Wils, D.; Thabuis, C.; Martin-Morales, A.; Kennedy, O.B. Impact of Dietary Supplementation with Resistant Dextrin (NUTRIOSE®) on Satiety, Glycaemia, and Related Endpoints, in Healthy Adults. *Eur. J. Nutr.* **2021**, *60*, 4635–4643. [CrossRef]
178. Barber, C.; Sabater, C.; Ávila-Gálvez, M.Á.; Vallejo, F.; Bendezu, R.A.; Guérin-Deremaux, L.; Azpiroz, F. Effect of Resistant Dextrin on Intestinal Gas Homeostasis and Microbiota. *Nutrients* **2022**, *14*, 4611. [CrossRef]
179. Saatchi, A.; Kiani, H.; Labbafi, M. Stabilization Activity of a New Protein–Carbohydrate Complex in Sesame Paste. *J. Sci. Food Agric.* **2022**, *102*, 5523–5530. [CrossRef]
180. Deng, N.; Li, Z.; Li, H.; Cai, Y.; Li, C.; Xiao, Z.; Wang, J. Effects of Maltodextrin and Protein Hydrolysate from Lotus Seed Peel on Fat Substitution and Lipid Oxidation of Lotus Seed Paste. *Food Chem. X* **2023**, *20*, 100967. [CrossRef] [PubMed]

181. Zhao, L.; Sun, M.; Xia, W.; Wang, L.; Wu, J.; Su, L. Resistant Dextrin/Isomaltodextrin. In *Biomanufacture of Functional Carbohydrates*; CRC Press: Boca Raton, FL, USA, 2024; pp. 21–77. [CrossRef]
182. Krstonošić, V.; Jovičić-Bata, J.; Maravić, N.; Nikolić, I.; Dokić, L. Rheology, structure, and sensory perception of hydrocolloids. In *Food Structure and Functionality*; Galanakis, C.M., Ed.; Academic Press: Cambridge, MA, USA, 2021; pp. 23–47. [CrossRef]
183. Tebben, L.; Li, Y. Effect of Xanthan Gum on Dough Properties and Bread Qualities Made from Whole Wheat Flour. *Cereal Chem.* **2019**, *96*, 263–272. [CrossRef]
184. Bojňanská, T.; Šmitalová, J.; Vietoris, V.; Vollmannová, A. Influence of the Xanthan Gum Addition on the Technological and Sensory Quality of Baking Products during the Freezing Storage. *Potravin. Slovak J. Food Sci.* **2016**, *10*, 592. [CrossRef]
185. Morimoto, N.; Tabara, A.; Seguchi, M. Effect of Xanthan Gum on Improvement of Bread Height and Specific Volume upon Baking with Frozen and Thawed Dough. *Food Sci. Technol. Res.* **2015**, *21*, 309–316. [CrossRef]
186. Jiao, W.; Li, L.; Fan, P.; Zhao, D.; Li, B.; Rong, H.; Zhang, X. Effect of Xanthan Gum on the Freeze-Thaw Stability of Wheat Gluten. *Food Biophys.* **2019**, *14*, 142–153. [CrossRef]
187. Jafari, M.; Koocheki, A.; Milani, E. Functional Effects of Xanthan Gum on Quality Attributes and Microstructure of Extruded Sorghum–Wheat Composite Dough and Bread. *LWT* **2018**, *89*, 551–558. [CrossRef]
188. Sciarini, L.S.; Ribotta, P.D.; León, A.E.; Perez, G.T. Incorporation of several additives into gluten free breads: Effect on dough properties and bread quality. *J. Food Eng.* **2012**, *111*, 590–597. [CrossRef]
189. Morreale, F.; Garzón, R.; Rosell, C.M. Improving the Quality of Gluten-Free Bread by Hydrocolloids: Xanthan Gum Performance in Maize–Rice Systems. *Foods* **2020**, *9*, 117. [CrossRef]
190. Salehi, F. Improvement of Gluten-Free Bread and Cake Properties Using Natural Hydrocolloids: A Review. *Food Sci. Nutr.* **2019**, *7*, 3391–3402. [CrossRef] [PubMed]
191. Zhang, J.; Zhu, Q.; Cheng, L.; Kang, J.; Liu, H.; Zhang, L.; Li, H.; Li, Q.; Guo, Q.; Goff, H.D. Enhancing Gluten-Free Dough and Bread Properties Using Xanthan Gum and Its Trifluoroacetic Acid Hydrolytes. *Food Hydrocoll.* **2025**, *164*, 111204. [CrossRef]
192. Torres-Perez, R.; Martínez-García, E.; Igual, M.; Martínez-Monzó, J.; García-Segovia, P. Effect of Hydroxypropyl Methylcellulose, Xanthan Gum, and Psyllium in the Formulation of Gluten-Free Bread for the Improvement of Organoleptic Quality. *Biol. Life Sci. Forum* **2023**, *26*, 48. [CrossRef]
193. Encina-Zelada, C.R.; Cadavez, V.; Monteiro, F.; Teixeira, J.A.; Gonzales-Barron, U. Combined Effect of Xanthan Gum and Water Content on Physicochemical and Textural Properties of Gluten-Free Batter and Bread. *Food Res. Int.* **2018**, *111*, 544–555. [CrossRef] [PubMed]
194. EFSA Panel on Food Additives and Nutrient Sources added to Food (ANS); Mortensen, A.; Aguilar, F.; Crebelli, R.; Di Domenico, A.; Frutos, M.J.; Dusemund, B. Re-evaluation of xanthan gum (E 415) as a food additive. *EFSA J.* **2017**, *15*, e04909. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.