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Rethinking Structure: Challenges in the Development of Gluten-Free Pasta and Baked Goods: A Review

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Abstract: The development of gluten-free products entails substantial technological and formulation challenges, primarily due to the difficulty of reproducing the structural, sensory, and nutritional attributes of gluten-containing analogues. The absence of gluten—responsible for the viscoelastic network that confers extensibility, gas retention, and structural integrity to wheat-based doughs—represents a major limitation in processing and product quality. To compensate for this deficiency, gluten-free formulations commonly incorporate optimized combinations of starches, hydrocolloids, and plant proteins to establish an alternative network. Starch gelatinization and the formation of a cohesive, viscous matrix by gums such as xanthan and guar contribute to dough integrity and rheological performance. Concurrently, the interactions between vegetable proteins and these polysaccharide components promote gas retention and stabilize the internal structure during fermentation and baking. This composite system partially replicates the viscoelastic behavior of gluten, thereby improving the texture, stability, and overall quality of gluten-free products.

INTRODUÇÃO

In recent years, the demand for gluten-free foods has surged dramatically, driven by health-related concerns such as celiac disease, non-celiac gluten sensitivity, and the growing popularity of gluten-free diets as a lifestyle choice. However, removing gluten from food formulations presents substantial challenges for the food industry, given gluten's essential role in providing structure and texture to baked goods. This paper explores the technological, nutritional, and sensory hurdles in gluten-free food production, the alternative ingredients employed, the range of products available on the market, and their acceptance by consumers (Simon, et al., 2023).

Starch is typically the primary carbohydrate in many gluten-free formulations, as the absence of gluten creates a void in structure-building (network-forming) functionality. In gluten-free doughs, biscuits, extruded snacks, and analogues, starch and its derivatives must fulfill multiple roles: water absorption and retention, gelatinization and pasting behavior, structural setting (gelation and retrogradation), interaction with proteins and hydrocolloids, texture development (hardness, cohesion, elasticity), and digestibility. Within this context, the internal composition of starch—particularly the ratio of its two major glucan fractions, amylose (essentially linear or sparsely branched) and amylopectin (highly branched)—emerges as a critical variable. The amylose-to-amylopectin ratio (hereafter referred to as the A:A ratio) influences granule architecture, hydration and swelling capacity, pasting and gelling dynamics, retrogradation behavior, digestibility, and ultimately the texture, shelf-life, and nutritional profile of the final product. In gluten-free systems, where starch often replaces gluten's structural function, manipulating the A:A ratio provides a strategic approach to achieving targeted product attributes. Before addressing aspects that imply the exclusion of wheat derivatives, among others that may contain gluten, we will discuss how the gluten network interacts with the components in the production of baked goods or pasta (Russell, et al., 2025).

Structure and Function of Glutenin and its Role in Dough Formation

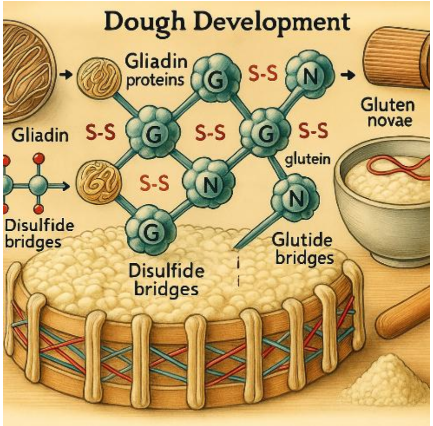
Glutenin, one of the main protein fractions in gluten, is fundamental to the development of dough elasticity and strength. Based on molecular weight, glutenins are classified into high-molecular-weight (HMW) and low-molecular-weight (LMW) subunits. HMW glutenins, due to their long polypeptide chains, contribute more significantly to dough elasticity and strength by forming extended molecular networks that reinforce the gluten structure (Shewry & Halford, 2022; Wieser & Koehler, 2021). A key structural feature of glutenin is the presence of cysteine residues capable of forming disulfide (S–S) bridges. These covalent linkages connect individual glutenin molecules, resulting in a three-dimensional viscoelastic network that provides dough with its elasticity and cohesiveness (Tosi et al., 2020). This network enables the dough to stretch without breaking and to trap gas during fermentation, a property essential for the rise and texture of bread and other baked goods. The cohesive nature of glutenin also imparts structural integrity, allowing the dough to maintain its shape during processing and baking (Kieffer et al., 2019).

Interactions between Glutenin and Gliadin

While glutenin is responsible for elasticity and strength, gliadin contributes to dough extensibility and viscosity. Together, these two protein fractions interact synergistically to form a cohesive gluten matrix, balancing elasticity and extensibility (Koehler & Wieser, 2023). This molecular interplay is essential for proper dough performance and determines the final texture and volume of baked products (Day et al., 2022).

Factors Influencing Glutenin Function

Several processing and compositional factors influence glutenin functionality. Adequate hydration is critical, as water enables glutenin molecules to unfold and interact, facilitating network formation. Mechanical kneading further promotes alignment and bonding among glutenin chains, increasing the number of disulfide bridges and strengthening the dough structure (Liu et al., 2021). Redox agents, such as ascorbic acid, can modulate these interactions by affecting the redox balance of cysteine residues, thus enhancing or weakening the gluten network depending on formulation and processing conditions (Wang et al., 2020).



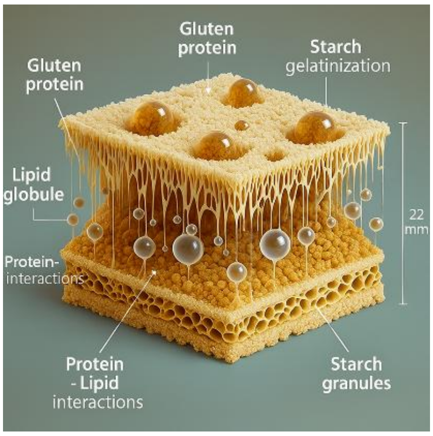


Figure 1: Illustrating the possible interactions between the components, the internal structure of bread crumb, showing how the provably protein (gluten) network forms a matrix that holds starch granules, while lipid droplets are dispersed throughout contributing to the crumb's texture and properties.

Role of Starch in Bread Making

Beyond gluten proteins, starch plays a complementary and indispensable role in bread structure and texture. During baking, starch granules absorb water and swell through gelatinization, forming a gel-like matrix that integrates with the gluten network (Delcour & Hoseney, 2020). This gelatinized starch contributes to crumb structure and softness by retaining moisture within the matrix. Furthermore, starch–gluten interactions stabilize the dough's viscoelastic properties, improving its elasticity and extensibility (Goesaert et al., 2021).

However, upon cooling and storage, starch retrogradation occurs as amylose and amylopectin molecules realign, leading to crumb firming and staling. Moisture retention by gelatinized starch can delay this process, maintaining bread freshness and sensory quality (Zhang et al., 2023).

Functional Benefits of Different Starch Sources and the Role of Lipids in Bread Making

Starches from various botanical origins exhibit distinct physicochemical properties that significantly influence food texture, viscosity, and stability. These variations arise mainly from differences in amylose-to-amylopectin ratio, granule morphology, and gelatinization behavior (Jane et al., 2021; Hoover et al., 2020).

Corn starch is characterized by a relatively high gelatinization temperature and strong viscosity upon heating. It provides a thick and smooth texture in sauces and soups and is widely used in baking for its neutral flavor and consistent performance (Zavareze & Dias, 2021).

Potato starch possesses a low gelatinization temperature and high water-binding capacity due to its large granule size and high phosphate monoester content. These features contribute to light, moist textures in baked goods and make it particularly suitable for gluten-free formulations requiring high moisture retention (Singh et al., 2020).

Tapioca starch, extracted from cassava roots, forms transparent and elastic gels with a glossy appearance. It enhances chewiness in bakery and confectionery applications and thickens sauces and puddings without inducing cloudiness (Numfor et al., 2022).

Rice starch exhibits a fine particle size, low allergenicity, and mild flavor. Its small granules and digestibility make it an excellent choice for hypoallergenic and gluten-free products, particularly for infant foods and delicate formulations (Yuan et al., 2023).

Synergistic Use of Starch Blends

Combining starches from different sources enables customization of texture, viscosity, and stability in formulated foods. Such synergistic effects result from complementary gelatinization temperatures and water-binding capacities (Liu et al., 2022). For example, corn and potato starch blends enhance both thickness and moisture retention in bakery systems. Tapioca and rice starch mixtures yield smooth, glossy textures ideal for sauces and gluten-free applications.

Wheat and corn starch combinations produce balanced elasticity and softness in conventional baked goods. Blending starches allows formulators to tailor functional performance, improving mouthfeel, water retention, and structural integrity in diverse product categories (Waterschoot, et al., 2015).

Role of Lipids in Bread Making

- Lipids play multifaceted roles in dough development and bread quality through their interactions with both proteins and starch (Pareyt et al., 2021; Zhou et al., 2023).
- Dough lubrication: Lipids reduce friction among gluten strands and starch granules, enhancing dough extensibility and workability during mixing and kneading.
- Structure and softness: By partially interfering with gluten network formation, lipids promote a tender crumb and softer texture. They form surface films around gluten and starch, preventing excessive rigidity and improving crumb uniformity (Goesaert et al., 2021).
- Gas retention: Lipids stabilize gas cells within the dough matrix during fermentation, contributing to greater loaf volume and a finer crumb structure (Ribotta & León, 2020).
- Shelf-life extension: By retarding starch retrogradation, lipids delay bread firming and staling, thereby prolonging freshness and sensory quality (Zhang et al., 2023).

Altogether, the strategic use of starches and lipids enables the development of baked products with optimized texture, moisture, and stability, which is crucial both for conventional and gluten-free systems. The Figure 2. The diagram visually represents the internal structure of bread crumb, showing how the provably protein (gluten) network forms a matrix that holds starch granules, while lipid droplets are dispersed throughout. This structure illustrates the interactions between the components, contributing to the crumb's texture and properties.

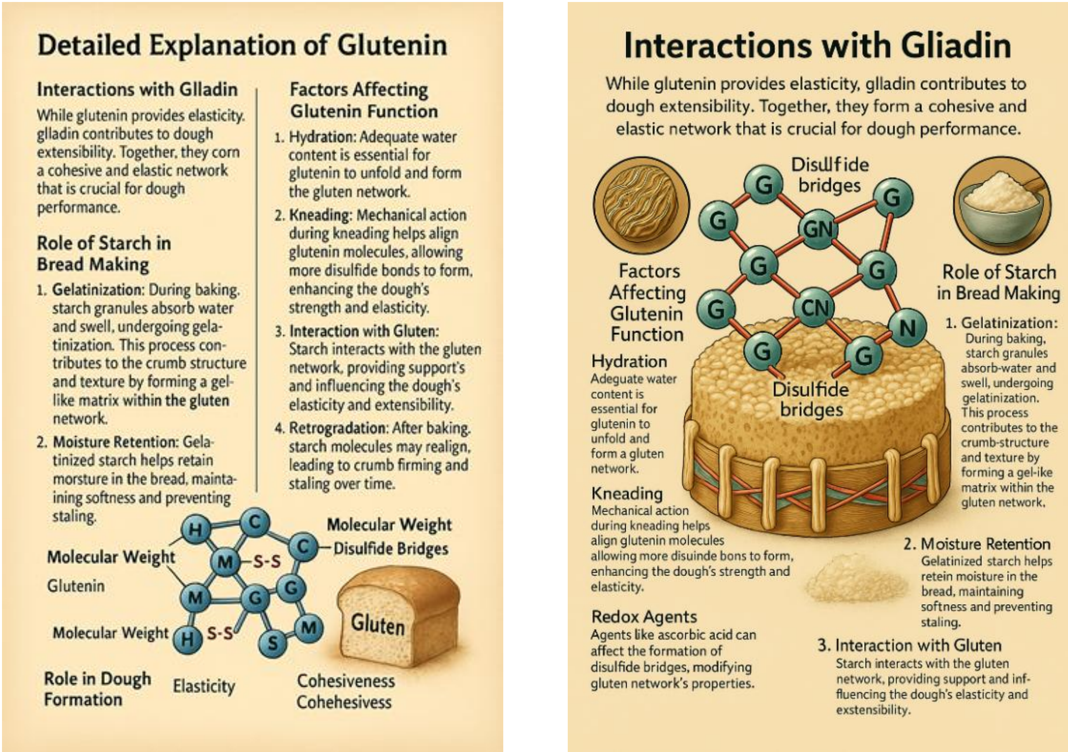


Figure 2: Summary of the possible main interactions between glutenin and gliadin, the main components of gluten.

FUNDAMENTAL DIFFERENCES BETWEEN AMYLOSE AND AMYLOPECTIN

Molecular Structure and Architecture

To understand the importance of the amylose-to-amylopectin (A:A) ratio, it is essential to consider their structural and functional distinctions. Amylose is a predominantly linear polymer composed of α-(1→4)-linked D-glucose units, with few branch points, and it tends to adopt helical conformations that aggregate within starch granules. In contrast, amylopectin is a highly branched molecule containing α-(1→6) linkages approximately every 20–25 glucose residues, typically representing 70–80% of most native starches. These two fractions co-exist within the starch granule and jointly influence crystallinity, lamellar organization, swelling behavior, and retrogradation kinetics (Zavareze & Dias, 2011; Tester et al., 2004).

Granule Swelling, Gelatinization, and Pasting Behavior

Amylopectin-rich starches exhibit greater granule swelling and higher peak viscosities during pasting due to their branched architecture and enhanced hydration capacity. Abdelgadir et al. (2022) reported that starches with elevated amylopectin contents show higher swelling power and lower gelatinization temperatures. Conversely, amylose restricts swelling, reduces peak viscosity, and promotes stronger or earlier gel formation as linear chains re-associate upon cooling. According to Wang (2024), an increased amylose/amylopectin ratio substantially affects gelatinization, pasting, and swelling characteristics. Parameters such as gelatinization temperature, enthalpy, pasting temperature, and breakdown viscosity are strongly modulated by the A:A ratio (Liu et al., 2019; Hoover, 2010).

Gel Strength, Retrogradation, and Texture

Amylose typically forms firm gels that retrograde rapidly, often accompanied by syneresis (water expulsion), due to linear chain alignment during storage. In contrast, amylopectin retrogrades more slowly and forms softer gels or crumb structures. Waxy starches (very high in amylopectin) yield softer and more elastic pastes (Sajilata et al., 2006). Thus, the A:A ratio greatly influences textural parameters such as firmness, chewiness, and staling behavior in starch-based foods including breads and cakes (Perera & Hoover, 2019).

Digestibility and Nutritional Implications

Higher amylose content is associated with increased resistant starch (RS) formation, slower enzymatic hydrolysis, and a lower glycaemic response — all desirable nutritional attributes (Li et al., 2022). Horstmann et al. (2017) demonstrated that high-amylose starches reduce digestibility and glycaemic index in gluten-free systems. Conversely, starches rich in amylopectin (low in amylose) exhibit higher rapidly digestible starch (RDS) fractions and elevated glycaemic indices, which are less favorable for health-targeted formulations (Zhu et al., 2020).

Importance of the A:A Ratio in Gluten-Free Formulations and Extruded Products

In gluten-free systems, where the absence of gluten leads to weaker structural integrity, higher starch dependence, and accelerated staling, the careful selection and blending of starches with different A:A ratios becomes a key formulation strategy (Monteiro et al., 2021; Morales-Polanco et al., 2020).

Structural and Textural Implications

In gluten-free bakery products, moderate amylose levels have been linked to improved specific volume and crumb structure under optimized conditions. Monteiro et al. (2021) reported that rice flour breads containing approximately 19–22% amylose exhibited greater specific volume. However, excessive amylose can restrict swelling and expansion, yielding denser crumbs, as Li et al. (2021) observed in wheat systems showing increased hardness and reduced porosity with higher amylose levels. In extruded snacks and pasta systems, where expansion, porosity, and crispness are key quality attributes, high amylose content can limit swelling and expansion, resulting in harder textures. Conversely, starches with excessive amylopectin (waxy starches) may cause over-swelling, collapse upon drying, or reduced mechanical strength in the final product (Liu et al., 2019; Wójtowicz et al., 2020).

Processing Behavior and Extrusion-Specific Considerations

During extrusion of gluten-free blends (e.g., rice, millet, chickpea, or bean flours), operational parameters such as specific mechanical energy (SME), barrel temperature, feed moisture, screw speed, and die geometry must be carefully optimized. The starch component must undergo controlled gelatinization, expansion (in snacks), or structure setting (in noodles or meat analogues), and the A:A ratio plays a decisive role in these transformations.

High amylopectin starches tend to gelatinize at lower temperatures, swell more readily, and promote expansion — desirable traits for puffed snacks — but may lead to weak structures and greater solubilization of solids (Korkerd et al., 2016). Conversely, high-amylose starches confer thermal stability, reduced swelling, and enhanced structural integrity, which is advantageous in high-moisture extrusion (e.g., noodles, analogues). However, excessive amylose can increase melt viscosity, torque, and die pressure, thus reducing expansion (Lazou & Krokida, 2010).

Nutritional and Shelf-life Considerations

Increasing amylose content enhances resistant starch formation, lowers glycaemic response, and aligns with health-oriented product development, particularly in gluten-free foods. Li et al. (2022) demonstrated that substituting 50% high-amylose wheat increased resistant starch content sixfold. Regarding shelf-life, starch retrogradation — a primary mechanism of firming and staling — is largely driven by amylose realignment. Balancing or blending starches with differing A:A ratios can thus modulate staling kinetics and moisture retention, mitigating textural deterioration in gluten-free products (Zavareze & Dias, 2011; Perera & Hoover, 2019).

Practical Implications for Blending Starches in Gluten-Free Product Development

The selection and combination of starch sources in gluten-free systems must be guided by their **amylose-to-amylopectin (A:A) ratio** and associated functional behavior. In formulations such as extruded gluten-free *fusilli*, cookies, or high-moisture meat analogues—where blends of rice, millet, chickpea, and other pulse flours are common—this ratio determines swelling, texture, digestibility, and structural integrity (Monteiro et al., 2021; Wójtowicz et al., 2020). Understanding these functional mechanisms enables the formulation of tailor-made starch matrices optimized for each product category.

Selection of Starches and Target Functionality

The first step is to select starches or flour fractions with a **characterized A:A ratio** and defined techno-functional profile. For instance, Japanese rice flour exhibits moderate amylose content, chickpea starch is typically higher in amylose, whereas millet fractions often show intermediate values (Li et al., 2021; Morales-Polanco et al., 2020). Recent frameworks proposed by Wang (2024) allow the prediction of structural and functional responses during processing. Intentional blending—e.g., combining a high-amylopectin starch (for expansion and plasticity) with a high-amylose starch (for structure, slower digestion, and firmness)—enables precise control over product behavior.

Defining Product-Specific Functional Outcomes

For extruded snacks, where high expansion, crispness, and lightness are desired, a moderate-to-high amylopectin fraction enhances swelling and bubble growth. Nevertheless, mechanical integrity and drying stability must be maintained; therefore, incorporating a structural, amylose-rich fraction helps stabilize the expanded network and reduce soluble solid losses (Korkerd et al., 2016; Lazou & Krokida, 2010).

For gluten-free *fusilli* or pasta analogues, the target properties include adequate hydration, optimal cooking time, controlled mass and volume increase, minimal soluble loss, and desirable textural parameters such as hardness, elasticity, and cohesiveness. An intermediate A:A ratio often provides the best compromise—sufficient swelling and pasting while maintaining structural integrity and minimizing cooking losses. Wang (2024) noted that elevated amylose content prolongs cooking duration and reduces water uptake but enhances firmness.

For high-moisture meat analogues, optimal performance depends on gelation, water binding, emulsion stability, and minimal syneresis. A slightly higher amylose proportion can improve gel strength and reduce syneresis, provided swelling and gelatinization are balanced to maintain matrix cohesion and elasticity (Li et al., 2022; Wójtowicz et al., 2020).

Processing Parameters and Starch–Process Interactions

During extrusion or baking, the starch gelatinization and pasting behavior must align with process variables such as moisture content, screw speed, barrel temperature, and specific mechanical energy (SME). High-amylose starches may require higher thermal input or longer residence time for complete gelatinization, whereas high-amylopectin starches gelatinize at lower temperatures but are more prone to shear degradation or melt collapse (Hoover, 2010).

The A:A ratio directly affects viscosity and breakdown—key determinants of screw torque, die pressure, and expansion kinetics. Starches rich in amylose typically display higher setback viscosities, influencing expansion and post-drying stability. Blending starches with distinct A:A ratios allows tuning of pasting and gelling behaviors; for instance, a moderate-amylopectin starch may promote rapid swelling and expansion, while a higher-amylose component "locks in" the structure after gelatinization, minimizing collapse during cooling or drying (Tester et al., 2004).

Texture and Sensory Optimization

The A:A ratio exerts a pronounced effect on textural and sensory attributes—firmness, cohesiveness, elasticity, and chewiness. In noodle and pasta systems, higher amylose correlates with increased firmness and lower stickiness (Li et al., 2021). Conversely, formulations dominated by low-amylose starches often exhibit excessive softness, greater mass gain during cooking, and reduced mechanical strength. Adjusting the ratio upward (by partial substitution with a higher-amylose source) can correct these defects, whereas overly firm or dense textures can be softened by including a higher-amylopectin starch to enhance expansion and mouthfeel (Monteiro et al., 2021).

The A:A ratio also modulates sensory shelf-life. Rapid retrogradation in high-amylose systems may yield tough or rubbery textures in cookies and snacks, while excessive amylopectin can produce stickiness or structural collapse if not stabilized through matrix design or drying control (Perera & Hoover, 2019).

Nutritional and Label Positioning

From a nutritional standpoint, higher amylose content enhances resistant starch (RS) formation, slows enzymatic hydrolysis, and lowers glycaemic response—traits aligned with

EU and U.S. *health-claim frameworks* (Sajilata et al., 2006; Di Rosa et al., 2023). Di Rosa et al. (2023) reported that bakery products enriched with high-amylose flour significantly reduced post-prandial glycaemia. This feature provides an opportunity to position gluten-free products as both "gluten-free" and "slow-digesting starch systems." For clean-label extruded snacks emphasizing dietary fibre and sustainable sourcing (e.g., Amazonian crops), blending pulse-derived or high-amylose rice starches can deliver added nutritional value and marketing differentiation.

Shelf-life and Retrogradation Control

Post-processing retrogradation—manifested as crumb firming, syneresis, and texture deterioration—is primarily driven by amylose realignment. If extended shelf-life or texture retention is a priority, amylose content should be moderated or complemented with hydrocolloids, lipids, or emulsifiers to disrupt reassociation (Wang, 2024; Zhu et al., 2020). In blended starch systems, including a higher-amylopectin component attenuates retrogradation, balancing firmness and moisture retention. Thus, the design of composite starch systems enables optimization of both immediate functionality and long-term sensory stability. Table 1 and Figure 3 summarize the main physicochemical, functional, processing, nutritional, and sensory implications of varying amylose content in starch-based and gluten-free systems.

Table 1: Comparative effects of low vs. high amylose content in starches used for gluten-free formulations.

Property / Characteristic	**Low Amylose (High Amylopectin)**	**High Amylose (Low Amylopectin)**	**Implications for Gluten-Free Product Design**
Molecular structure	Highly branched; dominant amylopectin chains; amorphous regions more hydrated	Linear chains; compact packing; higher crystalline regions	Governs granule swelling, gelatinisation, and network strength
Granule swelling power	High swelling; granules expand easily	Restricted swelling; more resistant to rupture	Low-amylose starch improves expansion and softness (snacks); high-amylose enhances firmness (pasta/noodles)
Gelatinisation temperature (To, Tp, Tc)	Lower (easier gelatinisation)	Higher (more heat required)	Adjust extrusion or cooking temperature to match starch type
Pasting behaviour (RVA profile)	High peak viscosity, high breakdown, low setback	Low peak viscosity, low breakdown, high setback	Low amylose → better expansion; High amylose → stronger structure after cooling
Retrogradation tendency	Slower; softer gels, longer freshness	Faster; firmer gels, higher syneresis	Control staling by balancing amylose fraction or adding hydrocolloids

Texture of gels / cooked product	Soft, elastic, cohesive	Firm, brittle, rigid	Low amylose for soft cookies/snacks; high amylose for firm pasta/analogues
Expansion in extrusion	Greater expansion; puffed, porous texture	Limited expansion; dense, compact structure	Blend types to modulate bulk density and mechanical strength
Water absorption & solubility (WAI, WSI)	High WAI and WSI (due to granule rupture)	Lower WAI and WSI	Influences cooking properties and soluble solid loss
Digestibility / Glycaemic index	Rapidly digestible; high glycaemic response	Slower digestion; higher resistant starch (RS)	High amylose improves nutritional profile (lower GI)
Shelf-life (retrogradation / staling)	Longer softness, less firming	Faster firming, more syneresis	Moderate amylose content balances texture retention
Extrusion torque / SME	Lower torque, easier processing	Higher torque, greater mechanical energy input required	Adjust screw speed, moisture, and temperature during extrusion
Cooking quality (pasta/noodles)	Short cooking time, higher mass increase, higher cooking loss	Longer cooking time, lower mass increase, lower cooking loss	Intermediate amylose ideal for balanced texture and integrity
Film-forming / gelling ability	Poor film formation, weaker gels	Strong film and gel formation	Important for structuring analogues and coatings
Freeze-thaw stability	Better freeze-thaw stability	Poorer (more syneresis upon thawing)	Low amylose preferred for frozen gluten-free foods
Sensory perception	Soft, smooth, sometimes sticky mouthfeel	Firm, dry, less sticky, more cohesive	Adjust blend for target consumer texture preference
Nutritional applications	Suitable for high-expansion, indulgent, or soft products	Suitable for high-fibre, slow-digesting, or functional foods	Enables design of diversified gluten-free product portfolio

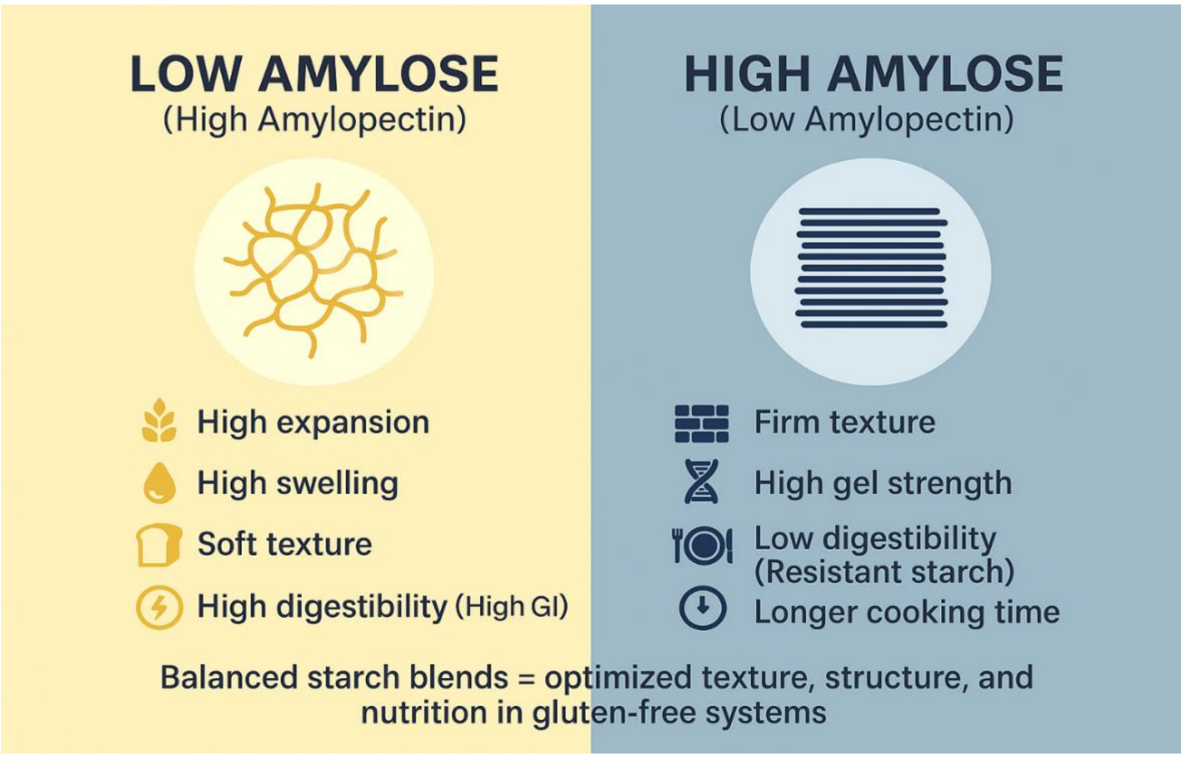


Figure 3: Summary of the main characteristics and functionalities of amylose and amylopectin.

TECHNOLOGICAL CHALLENGES

Role of Starch in Bread Making

Beyond gluten proteins, starch plays a complementary and indispensable role in bread structure and texture. During baking, starch granules absorb water and swell through gelatinization, forming a gel-like matrix that integrates with the gluten network (Delcour & Hoseney, 2020). This gelatinized starch contributes to crumb structure and softness by retaining moisture within the matrix. Furthermore, starch-gluten interactions stabilize the dough's viscoelastic properties, improving its elasticity and extensibility (Goesaert et al., 2021).

However, upon cooling and storage, starch retrogradation occurs as amylose and amylopectin molecules realign, leading to crumb firming and staling. Moisture retention by gelatinized starch can delay this process, maintaining bread freshness and sensory quality (Zhang et al., 2023). Altogether, the functionality of glutenin, gliadin, and starch defines the structural and sensory attributes of baked products. The balance between elasticity, extensibility, and moisture retention depends on the dynamic formation and rearrangement of protein and starch networks during mixing, fermentation, and baking. Understanding these molecular interactions is essential for improving dough quality, optimizing baking performance, and developing alternative formulations—particularly in gluten-free systems where these networks must be mimicked using hydrocolloids, proteins, and modified starches (Ronda & Caballero, 2022; Marco & Rosell, 2023).

Figure 1, presents a suggested scheme for a gluten network. Table 2 presents the main benefits of the most commercially available starches used in the formulation of different products.

Table 2: Benefits of Different Starch Sources

Starch Source	Benefits
Corn Starch	High gelatinization temperature and viscosity. - Provides a thick, smooth texture to sauces and soups. - Common in baking for its neutral flavor and texture.
Potato Starch	High water-binding capacity and low gelatinization temperature. - Contributes to a light, airy texture in baked goods. - Ideal for gluten-free recipes due to its fine texture and moisture retention.
Tapioca Starch	Smooth texture and glossy appearance. - Adds chewiness to baked goods and thickens without cloudiness. - Excellent in sauces and puddings.
Rice Starch	Fine texture and mild flavor. - Suitable for hypoallergenic and gluten-free formulations.

Each starch source has unique properties that influence texture, viscosity, and stability in different food applications.

Role of Lipids in Bread Making

1. **Dough Lubrication**: Lipids reduce friction between gluten strands, enhancing dough extensibility and making it easier to knead.
2. **Structure and Softness**: Lipids interfere with gluten formation, leading to a more tender crumb structure. They coat the gluten network and starch granules, preventing excessive rigidity.
3. **Gas Retention**: Lipids help stabilize gas cells during fermentation, contributing to better loaf volume and a fine crumb texture.
4. **Shelf Life Extension**: Lipids delay staling by slowing down the retrogradation of starch, maintaining bread softness over time.

Parte Inferior Do Formulário

Use of Gums and Thickeners

To replace the functional properties of gluten and attempt to form a gluten-like network, ingredients such as thickeners (Carboxymethylcellulose – CMC), gums (xanthan, guar), modified starches, and fibers are used. These additives help improve structure and moisture retention, creating a more malleable and stable dough. Xanthan gum, for example, is widely used to improve the elasticity and cohesion of gluten-free doughs, mimicking the effect of gluten on the texture of the products.

Processing and Formulation

Processing gluten-free foods requires specific adjustments to the formulation and methodology. The amount of water must be carefully adjusted, as gluten-free flours absorb water differently. Furthermore, extrusion techniques and the combination of different protein sources (such as soy, pea, or chickpea) can be used to improve the nutritional quality and texture of the final products. Creating gluten-free dough is a technical and scientific challenge, as gluten—which is only present in wheat flour—is responsible for the elasticity, extensibility, and gas-holding capacity of wheat doughs. Gluten forms a three-dimensional network composed of proteins (gliadin and glutenin) that interact to create a cohesive matrix, providing structure and texture to baked goods. The challenge is to simulate this network using ingredients that allow the dough to develop.

Creating gluten-free Dough

To replace this gluten network, different strategies and ingredients are used, each contributing differently to the structure and texture of the dough. Here are the main mechanisms involved:

Polysaccharides and Hydrocolloids

- Function: Hydrocolloids such as xanthan gum, guar gum, locust bean gum, and carboxymethyl cellulose are commonly used to replace the function of gluten. They increase viscosity and water-holding capacity, forming gels that help stabilize the dough structure. - Mechanism: These hydrocolloids create a viscous network that traps starch and protein particles, mimicking the gluten network by providing cohesion and elasticity to the dough.

Modified Starches

- Function: Starches such as corn, cassava, and potato are chemically or physically modified to improve their functional properties.
- Mechanism: During the gelatinization process, these starches absorb water and expand, creating a gelatinous structure that contributes to the cohesion and stability of the dough.

Alternative Proteins

- Function: Proteins from legumes (such as peas, soybeans, and chickpeas), rice, or quinoa are used to improve the protein structure.
- Mechanism: These proteins interact with each other and with the polysaccharides present in the formulation, forming a protein network that is less extensible than gluten but sufficient to provide stability to the dough. The addition of proteolytic enzymes can modify these proteins, improving their gelling and emulsification properties.

Emulsifiers

- Function: Emulsifiers such as lecithin and mono- and diglycerides help with the stability and homogeneous distribution of ingredients. - Mechanism: They facilitate air incorporation and gas retention during fermentation, improving the product's structure and final texture.

Starch-Protein Interactions

- Mechanism: The formation of a structural matrix in gluten-free doughs depends on the interaction between vegetable proteins and starches, where gelatinized starches and proteins form a cohesive network. This matrix is reinforced by the use of hydrocolloids and emulsifiers, which help stabilize the structure and retain moisture.

Challenges and Considerations

- Gas Retention: The lack of an effective gluten network makes it difficult to retain gases produced during fermentation, resulting in reduced dough expansion and reduced final product volume. Hydrocolloids partially help with this function, but they do not completely replace the effect of gluten.
- Texture and Sensory: The texture of gluten-free products can be denser and less elastic. Formulation optimization is necessary to improve sensory characteristics, which may involve blends of different types of starches, proteins, and emulsifiers. Consequently, the formulation of gluten-free products requires a multifactorial approach to replace the gluten protein network, combining polysaccharides, proteins and starches with the strategic use of emulsifiers and enzymes to develop a dough that has functional properties similar to those obtained with wheat.

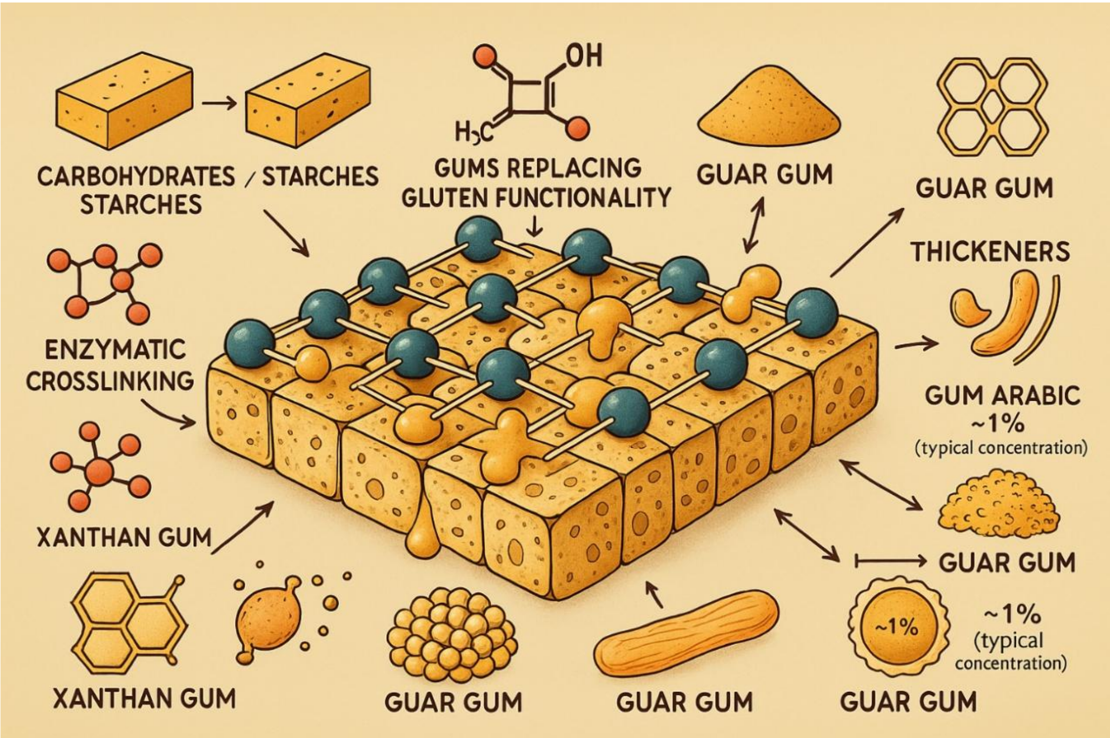


Figure 4: Representative as a tentative diagram of the interaction of gums, starches, and polysaccharides in the formation of the network in baking with gluten-free raw materials.

The formation of the network in gluten-free bread dough, as illustrated in the schematic diagram, can be explained as follows (Figure 1):

1. Starch Gelatinization, when the dough is mixed with water and heated, the starch granules (from sources such as rice, corn, or potatoes) absorb water and swell. This process is called gelatinization. For function in the network, is necessary, during gelatinization, the starch granules rupture and release amylose and amylopectin molecules, which form a viscous matrix, contributing to the structure and viscosity of the dough.
2. Gum network, the gums such as xanthan gum and guar gum are added to mimic the function of gluten. They form a viscous, cohesive network when interacting with water and other components. This gum network provides elasticity and extensibility to the dough, helping to trap air bubbles and provide structural stability, similar to the role of gluten in traditional doughs.
3. Protein Interactions from legumes (such as peas, soybeans) or other plant sources are included to provide additional structural support. The network function, is related as proteins unfold and interact with each other and with starch and gums, forming bonds that contribute to the dough's cohesion. This protein network helps stabilize the structure and improves the texture of the final product.
4. Air Cell Formation, during mixing and fermentation, carbon dioxide produced by leavening agents (such as yeast) is trapped within the gum and starch network. The formed air bubbles are held by the cohesive starch-gum-protein matrix, allowing the dough to rise and expand. This results in a more airy and light crumb. Also, structure stabilization, as the dough is baked, the gelatinized starch network solidifies, and the interactions between proteins and gums become stronger. This stabilizes the dough structure, preventing the collapse of air cells and ensuring a final product with good texture and volume.

In this sense, the diagram visually represents how these components (starches, gums, and proteins) work together to create a stable network that mimics the properties of gluten. This network is crucial for the formation of a dough that can retain gases and expand during fermentation and baking, resulting in a final product of similar quality to traditional bread, but without the presence of gluten.

Wheat Alternatives

The search for alternatives to wheat in the production of gluten-free foods has intensified in recent decades, driven both by the need to meet the needs of individuals with celiac disease and by the growing demand from consumers who opt for gluten-free diets. Several flours and ingredients can be used alone or in combination to replace the functional and sensory properties of wheat, ensuring adequate texture, flavor, and nutritional value.

Among the most common options, rice flour stands out, widely used due to its neutral flavor and light texture. It is used in breads, cakes, cookies, and pasta, although it presents the challenge of producing more crumbly products, which often requires its association with other ingredients to improve the elasticity and cohesion of the dough. Almond flour, in turn, is rich in protein, healthy fats, and vitamin E, giving a mild and slightly sweet flavor to preparations. It is ideal for cakes, cookies, and pancakes, but tends to produce denser and more caloric foods, in addition to having a high cost compared to other flours.

Chickpea flour is another relevant alternative, characterized by its high protein and fiber content, as well as a more intense flavor and yellowish color. It is suitable for breads, pasta, and savory preparations, although its strong taste requires balance with other ingredients. Oat flour, rich in soluble fiber such as beta-glucan, contributes to improving the texture of products such as cakes, breads, and cookies. However, it is essential to ensure that the oats used are certified gluten-free, due to the risk of cross-contamination during processing.

Sorghum flour has a high protein and antioxidant content, with a mild, earthy flavor. It is used in breads and cakes, but can result in a sandy texture if not combined with other flours. Teff flour, traditionally used in Ethiopian cuisine, is rich in protein, fiber, and minerals such as iron and calcium. Although it is an excellent option for breads and cookies, its limited availability and high price may restrict its use. Quinoa flour also stands out for its high protein content and the presence of essential amino acids, giving a slightly nutty flavor to preparations. It is used in breads, pasta, and cakes, but its characteristic taste may not appeal to everyone, so mixing it with other flours is recommended for better texture. Additionally, starches such as corn and potato starch are used to give lightness and volume to doughs, improving the structure of the products, although they have low nutritional value.

Corn flour, traditional in preparations such as tortillas and polenta, is rich in fiber and has a strong flavor. It is used in breads, cakes, and pancakes, but can result in dry and crumbly products. Finally, buckwheat flour, despite its name, does not contain gluten and is recognized for its high protein and fiber content. Its intense flavor, however, limits its isolated use, and it is often combined with more neutral flours to balance the sensory profile. In summary, each wheat alternative presents specific advantages and limitations, requiring careful formulations and strategic combinations to achieve gluten-free products that maintain sensory quality and nutritional value compatible with consumer expectations.

Nutritional and Technological Considerations

To achieve results similar to wheat, combinations of different flours and the use of gums (such as xanthan and guar) are essential. These ingredients help give doughs structure and elasticity. From a nutritional standpoint, it is important to choose flours that offer a balanced nutritional profile, ensuring the presence of protein, fiber, vitamins, and minerals.

Nutritional Challenges

1. Nutritional Deficiencies: Eliminating gluten often results in a reduction in fiber, B vitamins (such as thiamine and folate), and minerals (iron, zinc, and magnesium) in the diet. This is because whole wheat flours are rich in nutrients, while many gluten-free flours, such as white rice and cornstarch, are refined and low in nutrients.
2. Enrichment and Fortification: To improve the nutritional profile of gluten-free foods, manufacturers are adding fiber, protein, and vitamins to their products. The use of ingredients such as quinoa, amaranth, chia, and teff, which are naturally rich in

nutrients, helps increase the nutritional value of gluten-free foods. Fortification with vitamins and minerals is also a common practice.

Thermoplastic Extrusion in Whole Grain Processing

Extrusion of gluten-free whole grains can facilitate the formulation of gluten-free foods by allowing flours with varying degrees of gelatinization to be obtained, increasing the versatility of these ingredients in the food industry. When whole grains such as rice, sorghum, millet, quinoa, or amaranth are processed by extrusion, they undergo a thermomechanical treatment that alters their physicochemical properties. This process causes the destructuring of starch granules and partial or complete gelatinization, resulting in precooked flours with greater water absorption capacity and improved solubility (Chuqui-Paulino, et al., 2025; Fernandes et al., 2025; Comettant-Rabanal, et al., 2023).

This structural modification is crucial for the formulation of gluten-free foods, as the absence of gluten requires the creation of an alternative structural network that provides texture, elasticity, and stability to the final products. Extruded flours, with different levels of gelatinization, can interact more efficiently with other ingredients, such as gums (xanthan and guar), vegetable proteins (such as pea and soy), and fiber, contributing to the formation of more homogeneous and less crumbly doughs. This characteristic is especially important in the production of gluten-free breads, pastas, and cakes, where structure and texture are determining factors in the sensory acceptance of the products.

Furthermore, extrusion improves grain digestibility and nutrient bioavailability, as heat and pressure destroy antinutritional factors such as phytates and tannins, present in many whole grains. This makes gluten-free products not only more palatable but also nutritionally rich. For example, extruded rice flour can be used in bread and cake mixes, providing a softer texture and a more airy structure, while extruded sorghum or millet flours can add higher fiber and mineral content, meeting consumers' nutritional needs.

Therefore, gluten-free whole grain extrusion is a powerful tool for developing gluten-free foods with improved sensory and nutritional quality, facilitating the creation of products that meet consumer expectations in terms of taste, texture, and health.

Desafios Sensoriais e Aceitabilidade

1. Texture and Flavor: The absence of gluten can result in products with a dry, crumbly texture and less elasticity. Flavor can also be affected by the use of flours with different flavor profiles, such as the earthy flavor of sorghum or the sweet flavor of rice. Improvements in formulation and the use of emulsifiers and stabilizers can help achieve a more acceptable texture and flavor.
2. Consumer Acceptability: Studies show that consumer acceptance remains a challenge for many gluten-free products. Consumer expectations for products that mimic the taste and texture of traditional products are high. Despite technological advances, many gluten-free products are still perceived as having inferior sensory quality.

Products Available on the Market

1. Pasta: Gluten-free pastas made from rice, corn, or quinoa are widely available. These pastas, however, tend to be more fragile and less elastic than those made with wheat.
2. Breads: Gluten-free breads are often made with a blend of different flours and starches to improve texture. Ready-made breads and bread mixes are common options.
3. Cookies and Cakes: Because these products are less dependent on the structure of gluten, they tend to have better sensory acceptance. The use of ingredients such as almonds and coconut flour helps improve texture and flavor.
4. Snacks: Snacks such as cereal bars, cookies, and crackers are popular in the gluten-free market, often enriched with seeds and whole grains to increase nutritional value.

GLUTEN-FREE FOOD CONSUMPTION AROUND THE WORLD AND IN BRAZIL

The demand for gluten-free foods has grown globally (Table 3), with the United States and Europe leading the market. In Brazil, demand has also increased, with an estimated annual growth of around 20% in the consumption of gluten-free products. A 2019 study indicated that approximately 1% of the Brazilian population suffers from celiac disease, while gluten sensitivity can affect up to 10% of the population (Cancer Foundation, 2019).

Table 3: Gluten-Free Food Consumption, by Region

Region	**Percentage of Gluten-Free Food Consumption**
North America	30%
Europe	25%
Asia	15%
Latin America	20%
Brazil	10%
Source: Mordor Intelligence, 2024	

Market

The gluten-free food market in Brazil is expanding and has seen significant growth in recent years. By 2024, the Brazilian gluten-free food and beverage market is estimated to grow at a compound annual growth rate (CAGR) of 10.70% over the forecast period from 2024 to 2029 (Mordor Intelligence). This growth reflects growing demand not only from consumers with celiac disease, but also from those seeking a healthier diet, associating gluten-free products with overall health benefits.

Major players in the Brazilian market include companies such as Bob's Red Mill, Dr. Schar, General Mills, and Brazi Bites. The previously niche market is now consolidating as a broader category, with products ranging from bread and pasta to dairy and cookies (Mordor Intelligence). In the global context, the gluten-free prepared food market is also showing robust growth, with a CAGR of 5.80% expected between 2024 and 2029. This indicates a positive trend in the acceptance of gluten-free products worldwide, with North America standing out, leading the global market due to the high number of consumers who have adopted gluten-free diets, even without a diagnosis of celiac disease (Mordor Intelligence).

This expansion in the gluten-free food market reflects a growing consumer interest in products that contribute to a healthy lifestyle, as well as increased awareness of food intolerances and allergies.

Nutritional Implications of Using Cereals, Tubers, and Gums in Gluten-Free Food Formulations

Context: Why Ingredient Choice Matters in Gluten-Free Formulations

Gluten-free diets (GFDs) are essential for celiac disease management, yet long-term adherence can be associated with dietary imbalances, particularly when the diet relies heavily on commercial gluten-free products rather than naturally gluten-free foods (e.g., legumes, nuts, fruits, vegetables, and minimally processed grains). This risk is repeatedly linked to the frequent use of refined starches, limited whole-grain content, and product reformulation strategies that prioritize texture and shelf-life over nutrient density. Clinical and narrative reviews highlight that GFD adherence can coexist with suboptimal fiber intake and micronutrient gaps, reinforcing the need for nutritionally intentional formulation (Baptista, et al., 2024). A recent systematic review and meta-analysis focusing on micronutrient deficiencies in gluten-related disorders reports that even after treatment and dietary adherence, deficiencies in vitamins and minerals may persist or emerge, emphasizing the need for monitoring and improved dietary quality (including better formulated gluten-free staples), Di Rosa, C., et al. (2023).

Cereals and Pseudo-Cereals: Strengths, Limitations, and Key Risks

Rice and maize remain dominant bases in gluten-free foods due to neutral flavor, availability, and functionality. However, refined cereal flours and isolated starches often provide high glycemic load, lower protein quality, and lower intrinsic micronutrient density compared with fortified wheat-based equivalents in many markets. Reviews of gluten-free product quality consistently note that many gluten-free staples are more reliant on starch, and may be nutritionally inferior unless fortified or enriched with fiber/protein sources, (Ma, et al., 2025). A clinically relevant concern is that gluten-free packaged foods are frequently classified as ultra-processed, and therefore may increase dietary exposure to high sodium, added sugars, and low micronutrient density if used as daily staples. This does not mean gluten-free foods must be nutritionally poor—rather, it highlights that formulation decisions (ingredient selection and enrichment) are decisive (Xiong, et al., 2021). Pseudo-cereals (e.g., quinoa, amaranth, buckwheat) and whole grains (e.g., sorghum, millet, teff) typically increase protein, minerals, and fiber relative to refined starch bases and can meaningfully raise nutrient density. From a formulation standpoint, their inclusion should be evaluated not only for macronutrients but also for bioaccessibility (e.g., phytate–mineral interactions), and the need for processing strategies that reduce antinutritional factors (fermentation, germination, enzymatic strategies).

Tubers and Roots: Energy-Dense Bases with Variable Micronutrient Opportunity

Cassava/tapioca, potato, and other tuber-derived starches are widely used in gluten-free bread, biscuits, and pasta due to expansion, viscosity, and soft texture. Nutritionally, these ingredients often contribute primarily rapidly digestible carbohydrates, which can elevate predicted glycemic index if not counterbalanced with fiber, protein, lipids, and/or resistant starch strategies. This is one reason gluten-free products can produce sharper postprandial glucose responses, depending on structure and formulation (Giuntini, et al., 2022). However, "tubers" are not nutritionally uniform. Incorporation of whole tuber flours (rather than purified starch) can add fiber and phytochemicals (e.g., carotenoids in orange-fleshed sweet potato), improving micronutrient density and antioxidant potential—provided sensory and technological challenges are addressed through process and hydrocolloid design (Jebo, & Urga, 2024).

Hydrocolloids (Gums): Nutritional Effects Beyond Structure

Hydrocolloids (xanthan, guar, gellan, locust bean gum, psyllium, etc.) are used to replace gluten's structure by increasing viscosity, stabilizing gas cells, improving moisture retention, and reducing crumbliness. Beyond texture, hydrocolloids can affect physiological responses by altering bolus viscosity, gastric emptying, and nutrient diffusion. An overview focused on soluble dietary fibers emphasizes that viscous fibers can reduce postprandial glycemic response via increased chyme viscosity and altered carbohydrate bioaccessibility, and also via fermentation-derived metabolites that influence incretin signalling, (Giuntini, et al, 2022; Mazzola, et al., 2024) (e.g., GLP-1, intestinal hormone released after food intake, stimulates insulin secretion, reduces glucagon secretion, and slows gastric emptying, helps control postprandial (after meal) blood glucose levels. And PYY, Peptide YY, hormone secreted in the intestine after a meal. Acts by reducing appetite and slowing intestinal transit, contributes to the regulation of satiety and energy metabolism).

Guar gum (including partially hydrolyzed forms) is repeatedly described as a soluble fiber ingredient with potential metabolic benefits, including improved glycemic response and lipid-related outcomes, depending on dose and matrix (Tahmouzi, et al., 2023).

A critical nuance for gluten-free applications is that gums can improve nutrition indirectly by enabling formulation shifts: if hydrocolloids stabilize structure, the developer can increase whole-grain fractions, legume flours, seed meals, and fiber concentrates without catastrophic loss of volume or palatability. A "clean label" gluten-free bread study illustrates how enrichment strategies (e.g., seed-derived ingredients) can be technologically feasible and can improve quality attributes—supporting a path toward more nutrient-dense gluten-free staples (Papagianni, et al., 2024).

Resistant Starch, Amylose Content, and Glycemic Modulation in Gluten-Free Foods

Because many gluten-free staples are starch-driven, starch digestibility engineering is central to nutritional improvement. Resistant starch (RS) functions physiologically as a fiber-like carbohydrate fraction that escapes small-intestinal digestion and is fermented in the colon, producing short-chain fatty acids (SCFAs) and influencing glycemic response, insulin sensitivity, and gut ecology (Simón, et al, 2023; Xiong, et al., 2021).

A systematic review and meta-analysis reports that resistant starch supplementation can reduce fasting plasma glucose and improve insulin resistance indices (e.g., HOMA-IR, an index that estimates insulin resistance based on fasting glucose and insulin. High values indicate a greater risk of diabetes and metabolic problems.), with stronger effects at higher doses and longer intervention durations (Baptista, et al., 2024).

A recent narrative review further emphasizes that RS benefits depend on RS type and that food processing (milling, heating, fermentation, cooling/storage) can substantially increase or decrease RS content—making RS a formulation-and-process variable rather than a fixed ingredient property (Di Rosa, et al., 2023).

In product terms, increasing amylose proportion (via high-amylose ingredients or RS-enriched strategies) may reduce glycemic impact but can increase firmness and alter staling kinetics; therefore, hydrocolloids and lipid/protein co-structuring often become essential to preserve sensory quality. Controlled human testing of high-amylose bakery items has shown lower glycemic index compared with controls, supporting the nutritional rationale for high-amylose/RS strategies in cereal-based products (Giuntini, et al., 2022).

Micronutrients: Fortification Gaps and "Hidden Deficiencies" in Gluten-Free Diets

Micronutrient adequacy is a recurring concern. Many wheat-based staples are fortified in numerous regions, whereas gluten-free replacements may not be equivalently fortified, creating a structural risk for lower intakes of iron, folate, B vitamins, and other nutrients depending on the food system. In parallel, gastrointestinal pathology and dietary restriction can compound risk in celiac disease and related conditions. A recent systematic review and meta-analysis concludes that risks of several micronutrient deficiencies are elevated in treated celiac disease and that evidence also suggests elevated risk in non-celiac wheat/gluten sensitivity populations adopting gluten-free diets, reinforcing the need for both clinical monitoring and better nutritional design of gluten-free staples (Russel, et al., 2025).

Practical Implications for Formulation: Nutrition-First Strategies

From a product development perspective, the evidence supports several consistent strategies:

- Replace part of refined starch with whole-grain gluten-free cereals/pseudo-cereals and legumes, using hydrocolloids to maintain structure (Mazzola, et al., 2024).
- Target glycemic quality by increasing viscous fiber (selected gums/soluble fibers), adding protein and lipids strategically, and using RS/high-amylose approaches (Di Rosa, et al., 2023).
- Design for micronutrient density, including consideration of fortification and bioavailability (and processing steps that reduce antinutritional constraints), (Simón et al., 2023).
- Avoid a "starch-only" architecture, as reviews consistently associate many commercial gluten-free staples with ultra-processed profiles and lower nutritional value unless enrichment is deliberate (Baptista, et al., 2024).

Sensory Challenges of Gluten-Free Foods

The sensory quality of gluten-free foods remains one of the main factors limiting consumer acceptance, particularly in countries such as Brazil, where wheat-based products are deeply embedded in culinary habits. Attributes such as texture, flavor, appearance, aroma, and shelf stability are strongly influenced by the absence of gluten, a structural protein that plays a central role in the technological and sensory performance of conventional bakery and pasta products.

Among these attributes, texture is widely recognized as the most critical challenge (Jebo, & Urga, 2024). Gluten is responsible for the viscoelastic network that confers extensibility, gas retention, and structural integrity to wheat-based doughs. In gluten-free formulations, the lack of this protein often results in products with a dry, crumbly, and dense texture, characteristics that contrast sharply with the softness and elasticity expected by consumers accustomed to traditional baked goods. As a consequence, gluten-free breads and cakes frequently show reduced volume and inferior mouthfeel, which negatively affects overall sensory acceptance (Almeida, Chang, & Steel, 2013).

Flavor also represents a significant challenge, largely due to the use of alternative raw materials such as rice, corn, sorghum, and other gluten-free cereals and pseudocereals. These ingredients possess distinct sensory profiles that differ markedly from wheat, and their flavors may be perceived as unfamiliar or undesirable by some consumers. In addition, certain additives incorporated to improve structure and texture can impart residual or bitter aftertastes, further compromising palatability and consumer satisfaction (Sá & Masson, 2019).

Visual appearance plays a decisive role in purchase intention and perception of quality. Gluten-free products, particularly breads and pasta, often exhibit lower loaf volume, irregular crumb structure, and paler coloration when compared with their wheat-based counterparts. The difficulty in achieving a golden crust in breads or a uniform and appealing appearance in pasta and cookies can generate negative consumer perceptions, even before tasting, thereby limiting market acceptance (Tingting, et al., 2021).

Aroma is another sensory dimension that differentiates gluten-free products from conventional ones. The characteristic aroma associated with wheat flour and gluten development during baking is frequently absent, which may reduce the perceived freshness and attractiveness of gluten-free foods. Although the incorporation of natural or artificial flavoring agents is commonly employed to compensate for this limitation, achieving aromatic equivalence with traditional products remains a technological challenge (Brasil et al., 2015).

Shelf stability further complicates the sensory performance of gluten-free products. Gluten contributes to moisture retention and structural cohesion, and its absence often leads to faster staling, particularly in breads. As a result, gluten-free bakery products tend to become dry and hard over a relatively short period, which negatively affects texture and consumer acceptance throughout storage.

To mitigate these technological and sensory shortcomings, hydrocolloids and gums such as xanthan and guar gum are frequently incorporated into gluten-free formulations to mimic the structural function of gluten. While these ingredients can improve dough handling and product cohesion, excessive or poorly balanced use may result in overly sticky, gummy, or viscous textures, which can be perceived negatively by consumers and compromise the overall sensory experience (Ribeiro et al., 2018).

Economic factors also influence the accessibility and acceptance of gluten-free foods. Production costs are generally higher due to the use of specialized ingredients and differentiated processing conditions, and these costs are typically transferred to the final consumer. Unlike wheat, which is a globally traded commodity with stable availability and pricing, alternative ingredients such as cassava, legumes, and specialty flours may exhibit greater price volatility and supply limitations, particularly in developing markets. This economic disparity can restrict access to gluten-free products for a significant portion of the population.

The Brazilian and Global Context

In Brazil, the gluten-free food market has expanded significantly in recent years, following a global trend driven by increased awareness of celiac disease, gluten sensitivity, and broader interest in health-oriented diets. This growing demand has stimulated product innovation and diversification, leading to gradual improvements in sensory quality and consumer acceptance. At the global level, the market for wheat alternatives continues to expand, supported not only by medical needs but also by changing dietary preferences and lifestyle trends.

Emerging Brands and Product Innovations

Within this context, several Brazilian initiatives highlight advances in gluten-free product development. Research conducted by Embrapa has resulted in the formulation of gluten-free products based on rice flour, millet flour, and legumes such as chickpeas and carioca beans. These ingredients have been successfully applied in whole-grain snacks and pita breads, which demonstrated satisfactory sensory acceptance alongside enhanced nutritional profiles, including protein contents reaching 12.8% in snacks and 10.5% in pita breads. These products target consumers seeking convenient, nutritious, and GMO- and gluten-free alternatives.

In the private sector, companies such as Vitalin have expanded their portfolios with innovative gluten-free snack products, such as the “Happies” line, offered in flavors like bacon and butter. These products are vegan, lactose-free, baked, and formulated to be low in sodium, fat, and sugar, reflecting the growing demand for convenient and sensorially appealing options within the healthy food market.

Similarly, Josapar, through its Tio João brand, has developed a diversified line of gluten-free bread and cake mixes based on rice flour, including formulations for homemade bread, multigrain bread, pizza dough, and brisée dough, thereby increasing product variety and consumer choice.

Trends and Opportunities

The expansion of the gluten-free market is driven not only by clinical conditions but also by lifestyle choices, in which gluten exclusion is often associated with perceived health benefits, such as reduced inflammation and mitigation of allergic responses. This scenario presents significant opportunities for technological innovation, particularly in improving sensory quality, nutritional balance, and cost-effectiveness, which are essential for broadening consumer acceptance and ensuring the long-term sustainability of gluten-free products.

CONCLUSION

Producing gluten-free foods that are nutritionally balanced and sensorially acceptable is an ongoing challenge. The use of gums, thickeners, and the selection of alternative flours are essential strategies for replacing gluten. The inclusion of nutrient-rich ingredients and innovation in processing will continue to be crucial to meeting consumer expectations for healthy and tasty gluten-free products. In recent years, the gluten-free food market in Brazil has grown significantly, with new brands and products being launched to meet the growing demand for healthier and safer options for people with gluten intolerance or who choose gluten-free diets.

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