Innovations in Gluten-Free Cookie Production: A Review of Flour Substitutes and Market Trends

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Abstract : Individuals with celiac disease, gluten sensitivity, and those who prioritize health are increasingly seeking gluten-free baked products. Chemically leavened gluten-free products such as cakes, muffins, crackers, cookies, and biscuits are becoming popular due to their convenience and unique flavor and texture, in addition to bread items. The objective of this study was to perform a comprehensive and critical examination of the literature regarding alternatives to wheat flour in cookie recipes, evaluating the potential of these ingredients in terms of the product's technological, nutritional, and sensory attributes. Rice flour is the most prevalent substitute for wheat flour in cookies, yielding cookies with increased protein, fiber, and carbohydrate levels, as well as a lighter hue. When combined with additional elements, it is frequently acknowledged in sensory evaluations. The extent to which it renders cookies less crumbly and hard than conventional cookies remains a subject of contention. Amaranth, quinoa, sorghum, and banana flours serve as effective alternatives to wheat flour in cookie recipes. The review's concluding point addresses the identification of current market trends and prospective opportunities for innovation within the gluten-free cookie sector.

Keywords: Gluten-free baking. Wheat flour alternatives. Gluten-free cookies. Functional properties

1. Introduction

Interest among consumers in meals devoid of wheat (Triticum aestivum) has been steadily increasing in recent years as a means to mitigate the risk of celiac disease (CD), a rather obscure condition (Lovis 2003). The gluten-induced entropy responsible for celiac disease in predisposed individuals is characterized by the gliadin component of wheat inflicting damage to the mucosa of the small intestine (Murry 1999; Fasano and Catassi 2001; Farrell and Kelly 2002). These studies indicate that reducing gluten intake can aid in the management of celiac disease. Approximately 1% of the global population is

estimated to be afflicted with celiac disease, with this figure progressively increasing, partly attributable to enhanced clinical testing and improved diagnostic methodologies, predominantly in North America, Europe, and Australia (Lebwohl, Ludvigsson, & Green, 2015; Mahadov & Green, 2011; Rubio–Tapia et al., 2009). The exclusive treatment for individuals with celiac disease has been adherence to a gluten-free (GF) diet, which necessitates complete avoidance of gluten to facilitate gut healing and rectify nutritional deficiencies and other symptoms (Jnawali et al., 2016). Wheat-derived products, including gluten proteins, are essential sources of nutrition and energy for individuals. Cookies, a widely favored cereal-based confection, are unsuitable for individuals with gluten sensitivity due to the inclusion of ingredients such as soft wheat flour. Recent studies demonstrate that gluten-free cookies can be prepared using an array of gluten-free flours and starches, such as rice, sorghum, buckwheat, and cassava (Indrianingsih et al., 2024)[2].Foods believed to promote excellent health included those devoid of gluten. Nonetheless, considerable technological challenges exist in eliminating gluten from food ingredients, particularly in baked foods, resulting in worse texture, mouthfeel, and flavor.Reports indicate that most gluten-free replacements exhibit inferior texture, mouthfeel, and flavor quality (Adiamo et al., 2018; Ari Akin et al., 2022; de Oliveira et al., 2022), rendering them unappealing to consumers. Some gluten-free flour alternatives are recognized for their high nutritional value, including fiber, protein, and vitamin B complex.The gluten-free food landscape is complex and rapidly evolving due to the emergence of diverse food options catering to expanding consumer and patient populations seeking gluten-free meals. The genuine food sources of nutrients in the GFD remain inadequately explored, although prior evidence indicating the subpar dietary quality of packaged GF meals (Elliott, 2018; Jamieson, Weir & Gougeon, 2018; Kulai & Rashid, 2014).The medical needs of certain persons with celiac disease and the intentional choice of consumers to adopt a healthy diet have resulted in a significant increase in the demand for gluten-free products in recent years.Alternative methodologies to the GFD are being pursued for two principal reasons. The synthesis of starch and its common application as a food additive or component can lead to substantial gluten presence, posing challenges for individuals with celiac disease, as gluten proteins may be present in unforeseen sources such as meat, fish, or dairy products. Nonetheless, eliminating gluten presents considerable difficulties for bakers, and most gluten-free items available today are inferior, lacking in flavor and texture. This study will investigate the present condition of alternative grains with minimal to no immunogenic content that may be tolerated by people with celiac disease. This review was carried out to compile and examine recent research findings on gluten-free cookies with an emphasis on functional ingredients, processing methods, and commercial potential .

2. **Functional ingredients:**

To reproduce the structure, texture, and sensory characteristics gluten typically contributes while at the same time enhancing their nutritional content, gluten-free cookies need to include functional ingredients. One of the primary ingredients is using other flours such as rice flour, millet flour, chickpea flour, almond flour, and certified gluten-free oat flour. These flours provide essential nutrients such as fiber, protein, and healthy fats alongside the necessary foundation. Gluten substitute binding agents including xanthan gum, guar gum, psyllium husk, and flaxseed or chia seed gels are often used to compensate for gluten's lack. These reduce crumbliness in the final product, enhance elasticity, and maintain the integrity of dough. .In some gluten-free products, the ingredients used were: legumes (soybean, pea, chickpea, lentil), pseudo-cereals (buckwheat, quinoa, amaranth), lesser cereals (teff, millet), nuts (almonds, hazelnuts, chestnuts, walnut, cashew nut), and root vegetables (arrowroot, tapioca, jicama, taro, potato, and Xu et al., 2020, Bashir et al., 2020; Xu et al., 2020). Legumes and pseudocereals are increasingly being used in foods nowadays to provide additional protein. Along with this, some fruits—such as chokeberries, rosehips, and blueberries—are included to boost the antioxidant properties of GFP.One example is a functional cookie that was created with highly acceptable flavonoids, protein, dietary fiber, antioxidants, polyunsaturated fatty acids, minerals, and polyphenols.

2.1 Alternative Flours of gluten-free cookies

Cookies generally refer to a category of baked goods formed from soft wheat flour with a low final water content, and they are defined by a formula high in sugar and shortening (i.e., solid fat at room temperature) (Delcour & Hoseney, 2010). Typically, they are offered as snacks. Using flour, sugar, fat, and water, cookies are formed into tiny, crispy, sweet pastries. The popular sugar-snap cookie is distinguished by its high sugar, high fat, and low moisture level.

2.1.1 Rice based cookies

Rice flour's mild flavor, colorlessness, hypoallergenic qualities, and readily digestible carbohydrates make it the ideal ingredient for gluten-free recipes .These days, rice flour is widely used in baking due to its accessibility and affordability. Dietary fiber, lipids, amino acids, vitamin E, phytosterols, phenolic compounds, gamma-aminobutyric acid (GABA), minerals, and other nutrients and bioactive substances are all present in brown rice (Cho and Lim, 2015).On the other hand, a substantial portion of the nutritious value of white rice is eliminated during the milling process[10].GF biscuits are already made with a lot of rice flour (Oriza sativa). The nutritional qualities of GF items can also be improved by using rice

by-products. Co-products from agro-industrial processing were used in the creation of GF biscuits by Tavares et al. (2016). They added soybean okara, broken rice flour, and roasted rice bran to make biscuits. In comparison to the commercially available examples, the biscuits had a smaller specific volume, internal and external diameters, a lighter hue, and a lower water activity. Compared to commercial samples, experimental biscuits remained stable throughout time. Brown rice flour (70 parts), soy flour (10 parts), maize (10 parts), and potato starch (10 parts) were used by Schober et al..(2003) to create a gluten-free flour blend that produced a good-quality dough and biscuits that were on par with wheat biscuits. Mixtures containing 50 parts brown rice flour, 30 parts potato starch, 10 parts buckwheat flour, and 10 parts millet flakes produced less favorable results than mixtures containing 25 parts brown rice flour, 25 parts maize starch, 25 parts potato starch, 25 parts soy flour, and 25 parts millet flakes.

2.1.2 Millet based cookies

Cereals with tiny kernels are classified as millets. They are classified as coarse cereals and are not members of a single species. Instead, they are grouped together based on small size. Pearl millet (Pennisetum glaucum L.), foxtail millet (Setaria italic L.), proso millet (Panicum milaceum L.), finger millet (Eleucine coracana L.), teff (Eragostis tef Trotter), and fonio(black fonio Digitaria iburua Stapf, white fonio Digitaria exilis Stapf) are the most significant species (Taylor & Kruger, 2016)[13].There are some observed variations in the macro and micronutrient makeup of millets, but not many (Taylor, 2017).The only significant component that varies significantly amongst millet species is lipids. The lipid content of pearl millet and foxtail millet is higher than that of the other major millets. The statistics are unclear because they depend on the type of grain (de-hulled or not) that was used for the investigation, but it appears that there are significant variations in the dietary fiber content of millets. Furthermore, the home-scale preprocessing methods frequently used on millets (such as soaking, germination, pearling, fermentation, hydrothermal treatments, and cooking treatments) might change the composition of nutrients and lower the amount of anti-nutrients. In terms of micronutrients, foxtail millet contains more calcium than any other cereal (343 mg/100 g) (Taylor & Kruger, 2016). Since millets don't contain gluten, they're safe for those with celiac disease. When combined with other ingredients, millet flours can be helpful in making gluten-free baked goods. Using local, fermented, and malted pearl millet flour, Adebiyi, Obadina, Adebo, and Kayitesi (2017) made biscuits made entirely of millet flour. The acceptance of the biscuits was unaffected by the pearl millet flour's lack of gluten. When compared to local flour, biscuits made using malted and fermented millet flour were significantly more popular with consumers. In contrast, fermented millet biscuits and native millet biscuits had an unpleasant smell and a somewhat bitter taste. Malted millet flour biscuits, on the other hand, had the best aroma, taste, and

overall similarity because they were sweeter and better flavored. Cookies' nutritional qualities were increased by fermentation and malting; the treated samples had higher levels of phenolic compounds, a better amino acid profile, and mineral bioavailability. Millet fermentation and malting enhance the flour's physico-chemical qualities and the resulting biscuit, according to Adebiyi, Obadina, Mulaba-Bafubiandi, Adebo, and Kayitesi (2016).To enhance the sensory appeal of GF biscuits, Sharma, Saxena, and Riar (2016) employed flour made from foxtail, barnyard, and kodo millet seeds that had germinated. Compared to raw flour blends, germinated flour blends had greater levels of protein, total phenolic content, and antioxidant activity. Pasting qualities were negatively impacted by germination, but functional qualities were much enhanced and the biscuits turned out to be aesthetically pleasing. The nutritional value of flour and baked gluten-free items is improved by using malted, fermented, and germinated millet. The classic Ethiopian pancake known as injera is made from teff, a common cereal. When compared to other cereals, teff has higher levels of calcium and protein quality, as well as more dietary fiber and iron (Taylor & Kruger, 2016).In their 2011 study, Kenney et al[19]. found that biscuits made with 25 and 50% teff flour were less tough and more brittle than control biscuits. There was no discernible difference between the control and teff flour biscuits in terms of flavor, taste, or appearance. The control and biscuits made with 25% teff flour were preferred by the panelists. Additionally, Coleman, Abaye, Barbeau, and Thomason (2013) investigated if teff flour could be used to make biscuits[20]. Increased amounts of teff flour instead of wheat flour result in biscuits that are the least palatable when compared to the control set of samples.In contrast to Kenney et al. (2011)'s findings on biscuit spread, teff flour did not have a good capacity for absorbing water because biscuit spread increased[21].This is most likely because additional components were utilized in conjunction with teff flour. The low protein level of biscuit flour is a common characteristic. Although teff flour has a high protein content, it does not degrade the quality of biscuits because it does not include gluten protein (Coleman et al., 2013)[22]. Teff flour may therefore be a suitable ingredient for making GF biscuits when combined with other GF flours.

2.1.3 Oat based cookies

While the majority of individuals with celiac disease perceive oat consumption as benign, the scientific community is currently examining this issue (Comino et al., 2015). Oats may get contaminated with gluten post-harvest due to cross-contamination from other cereals. Increased replacement levels or total substitution of oat bran for oat flour in cookie recipes negatively affect consumer acceptability (Duță & Culețu, 2015). Pîrvulescu et al. (2014) investigated the differences between conventional flours and those derived from germinated oats. The results demonstrate that flour produced from germinated oats contains

reduced glucose levels. This demonstrates that hypoglucidic diets can utilize germinated flours. Understanding this is essential, as most patients with celiac disease also have diabetes.

2.1.4 legume based cookies

Legume flours may enhance the nutritional quality of gluten-free products. All varieties of legumes constitute a significant nutritional resource. Melini, Melini, Luziatelli, and Ruzzi (2017) assert that they are rich in proteins, complex carbs, fibers, minerals, and antioxidant compounds. Currently, as stated in paragraph 4, GF biscuits are produced using legume flours. Sparvoli et al. (2016) utilized various common beans with minimal anti-nutrient content to produce nutritionally enhanced biscuits. Moreover, gluten-free biscuits were formulated utilizing bean and maize flours. Increased proportions of bean flours diminish the sensory ratings of the final product, as indicated by the results. The incorporation of α-amylase inhibitors resulted in a reduced glycemic index for biscuits formulated using maize and bean flour. Giuberti et al. (2018) included alfalfa (Medicago sativa L.) seed flour into gluten-free rice-based biscuits to enhance their nutritional profile[28]. In general, the quality of the nutrients has improved. While biscuits were considered favorable regarding their sensory attributes, all rice biscuits got superior sensory ratings. Consequently, it seems that the incorporation of bean flour alongside other flours is consistently necessary. The production of biscuits just using bean flours yields disappointing results. The research conducted by Maghaydah, Abdul-hussain, Ajo, Tawalbeh, and Elsahoryi (2013) confirmed that utilizing solely bean flours for the production of gluten-free biscuits is impractical. They evaluated the feasibility of use lupine flour as the principal gluten-free flour in biscuits. The findings indicated that utilizing alone lupine flour would not generate satisfactory biscuits; however, combining lupine flour with either maize flour, maize starch, rice flour, or maize flour supplemented with xanthan gum and carrageenan resulted in excellent biscuits. Legume proteins, already incorporated in several Italian cookies, may serve as a substitute for legume flours in the recipe to improve the quality of gluten-free biscuits (Table 3). Mancebo, Rodriguez, and Gómez (2016) substituted pea protein for a portion of the rice flour in their biscuits[30]. Proteins enhanced the dough's consistency without adversely affecting its sensory attributes.

2.1.5 **Buckwheat based cookies**

Buckwheat, also known as Fagopyrum esculentum Moench, is one of the most researched pseudocereals for GF biscuit composition. A distinct concentration of phytochemicals, especially rutin, is what distinguishes it. Following thermal treatments, buckwheat flour can retain its antioxidant capacity (Sakac & Hadnadev, 2011). When compared to a control group of biscuit samples made solely of rice flour, a

replacement study of rice flour with buckwheat flour (10, 20, and 30% proportion) showed increased rutin content, phenolic level, antioxidant potential (DPPH), and high mineral availability(Sakačetal.,2015. Additionally, Torbica, Hadnadev, and Dapčević Hadnadev (2012) noted that GF (Gluten Free) cereal-based goods could successfully combine rice and buckwheat flour combinations. Their biscuits' shape, cross section structure, rupture, and top and bottom surface look all demonstrated a satisfactory technological quality and a pleasing flavor. Two additional studies support the substantial antioxidant content of buckwheat-based bakery products: Molinari et al. (2018) discovered that biscuits enhanced with common buckwheat flour and combinations had a higher antioxidant content than control crackers made with wheat flour, and Sedej et al. (2011) produced GF crackers made with buckwheat flour.Amaranth and oat composite may be useful ingredients to enhance nutritional quality of GF biscuits in terms of antioxidant compounds and minerals.

2.1.5 Inulin based cookies

A member of the fructans group of indigestible carbohydrates, inulin is typically used to substitute fat or sugar un food items. It is also used as a source of fiber and for its prebiotic properties. Consuming inulin may provide a variety of advantages, such as improving the absorption of minerals (Shoaib et al., 2016). To create a product that might help celiacs absorb calcium, rice flour was substituted with varying percentages of oligofructose-enriched inulin in chocolate biscuits. Due to their slight grittiness, reduced fracturability, and diminished intensity of flavor, aroma, and texture, biscuits with a 25% substitution of rice flour were well received, whereas those with a higher substitution had lower like scores (de Silva & Conti-Silva, 2018). According to Drabińska et al. (2016), inulin-type fructans have the potential to enhance baked goods' technological qualities and sensory appeal. Another helpful component to lower the GI of gluten-free biscuits is inulin.

2.1.6 Quinoa based cookies

Quinoa (Chenopodium quinoa Wild.) is a very nutrient-dense food that contains a variety of minerals and vitamins, as well as high-quality protein that contains all the essential amino acids. Depending on the varietal, quinoa's protein composition can vary from 13.81 to 21.9%. Despite the great nutritional value of these grains, very few goods are produced due to the lack of gluten (Thejasri et al., 2017.

2.1.7 Hemp based cookies

Hemp has been rediscovered recently. Oil, flour, or herb tea are made from seeds and leaves. Proteins, minerals, and unsaturated fatty acids are abundant in hemp seeds. The nutritional value of biscuits can be increased by adding hemp flour to the recipe Hrušková, M., & Švec, I. (2015).

2.1.8 Hydrocolloids (Ingredients)

Among the most crucial components in GF formulations that enhance product texture and appearance are gums and hydrocolloids (Mariotti, Lucisano, Pagani, & Ng, 2009). Polysaccharides make up the majority of dietary gums and hydrocolloids. Their thickening, water-holding capacity, network and film creation, and deformation are some of their characteristics. These final two samples demonstrated that adding little components like hydrocolloids could be essential to raising the quality of GF biscuits. When added, nutritionally enriched biscuits that would normally have low sensory scores may handle and be more palatable.

3. Challenges in gluten free formulation

Substituting gluten in food products is challenging because to various issues, including nutritional deficiencies and textural inconsistencies. Literature indicates that preparing doughs with gluten-free flours is more challenging due to their inadequate cohesiveness, flexibility, and baking properties (Singh and Whelan, 2011). Gluten-free products often exhibit low fiber and high glucose levels, a limited shelf life, or textural problems such as coarser crumbs. Multiple combinations of gluten-free flours and their supplementary constituents have been examined to develop gluten-free goods with qualities akin to those of wheat-based alternatives [43]. The primary challenge confronting producers in the development of gluten-free products is identifying suitable gluten alternatives. The principal gluten proteins, glutenin and gliadin, are crucial for baking quality since they confer the dough with water absorption capacity, cohesion, viscosity, and elasticity. Consequently, the removal of gluten results in significant quality challenges, especially for bakers. Moreover, the product's safety, acceptability, cost, and adherence to FDA (Food and Drug Administration) regulations provide further challenges for the inventors. Health concerns, current demand, expenses, and acceptance are but a few of the factors that must be taken into account. The primary focus of health food design should be the elderly, youth, and infants. Gluten-free consumers face growing challenges in fulfilling their strict dietary requirements (Dimassi et al., 2020). Individuals with gluten-related disorders have gained from the increasing accessibility and marketing of gluten-free products with nutritional benefits. E-commerce platforms exhibited constrained supply. The health literature often identifies the elevated cost of gluten-free alternative products compared to

gluten-containing options as a major obstacle to celiac patients' full compliance with the gluten-free diet (Whitaker et al., 2009).

3.1 Acceptance of Gluten-Free Cookies by Consumers

The increasing awareness of celiac disease, gluten sensitivity, and the prevalent perception that gluten-free diets are healthier has led to a significant rise in the demand for gluten-free (GF) products in recent years. Gluten-free cookies have emerged as a popular and convenient snack option. Several parameters, including flavor, texture, visual appeal, nutritional content, and price, substantially affect consumer acceptability of gluten-free cookies. Research has shown that gluten-free baked products often struggle to mimic the sensory characteristics of their gluten-containing counterparts. For instance, due to gluten's role in providing elasticity and structure to dough, gluten-free cookies may exhibit a crumbly texture or a less complex flavor (Matos & Rosell, 2015). Food technologists frequently employ hydrocolloids, starches, and protein isolates to enhance mouthfeel and texture, hence augmenting consumer acceptance (Sivam et al., 2010). Consumer panels assert that whereas certain gluten-free cookies remain inferior to conventional cookies in flavor and appearance, others do not (Aprodu & Banu, 2015). Labeling and health perception can influence consumers' purchasing intentions; numerous consumers erroneously assume that "gluten-free" items are healthier, although lacking genuine nutritional benefits (Watson, 2016). Not with standing sensory constraints, the gluten-free cookie market continues to grow due to innovative formulations and a rising number of health-conscious consumers. Future initiatives should prioritize enhancing sensory attributes while preserving nutritional integrity to guarantee wider market appeal.

3.4 Market Trends :

A heightened addiction to GFPs and an increased purchase intention are associated with a more favorable attitude. In their study, the Zarkadas team discovered that around 90% of individuals reported adhering to a gluten-free diet. In this study, 27.4% of respondents said that their gluten sensitivity was found incidentally during testing for other conditions, whereas 52.4% indicated that they received a diagnosis of gluten sensitivity subsequent to the emergence of symptoms and a focused medical assessment. Aside from 14% of respondents who eschew lactose-containing products, the remaining 65% of the population adopted a gluten-free diet in adulthood without any other dietary limitations. In 2013, "gluten-free food" ranked among the top five Google search keywords. Over the past five years, consumer interest in the term "gluten" has steadily risen. The subject had become a prominent topic of discourse in business journals and culinary magazines. Specialty items specifically marketed to consumers seeking

alternatives to wheat, barley, or rye-based products were termed gluten-free products. The market for gluten-free products was characterized by numerous competitors and a wide array of offerings. Various players excelled based on their core competencies. Even among individuals without gluten sensitivity, consumers perceive gluten-free cookies as healthier alternatives.

Many studies illustrated the impact of gluten-free labeling on consumer perception and purchasing intent. A further study investigated the utilization of defatted seed flours in cookie production and found that they preserved an exceptional texture while significantly enhancing fiber and mineral content. A study published in indicates that gluten-free labels and claims such as "rich in fiber" and "low sugar" garner increased attention and enhance the perceived value of a product. A cross-European study involving 7,296 gluten-free customers indicates that many individuals choose gluten-free cookies due to perceptions of enhanced naturalness, improved digestibility, and associated health benefits. Customers expressed greater satisfaction with products featuring clean ingredients and more comprehensible labels. Replacing gluten in food products is difficult due to several challenges, including nutritional inadequacies and textural difficulties. For example, as noted in the literature, creating doughs with gluten-free flours is difficult due to their insufficient cohesiveness, flexibility, and baking characteristics. Unexpectedly, gluten-free products frequently exhibit low fiber content, elevated glucose levels, reduced shelf life, or textural issues such as denser crumbs. Various combinations of gluten-free flours and their complementary additives have been studied to create gluten-free goods that possess characteristics akin to those of their wheat-based counterparts. It is essential to weigh the nutritional benefits of using bean flour against the diminished organoleptic qualities of the finished product. Although the market for these products has been steadily expanding, the existing options frequently fall short of gluten-containing items regarding flavor and nutritional quality.

4. Conclusion and Future Research

The gluten-free flours have been made from a variety of plant materials, legumes and pulses (soybean, chickpea, lupin, lentils, and pea), cereals (rice, maize, and sorghum), pseudocereals (buckwheat, amaranth, and quinoa), and composite flours. Gums, emulsifiers, and fibers are examples of common functional food additives that have been studied in gluten-free baking systems and have demonstrated some improvement in the qualities of dough and bakery goods, particularly with regard to the rheological and water hydration properties of dough or batter. The functional qualities, difficulties, and commercial demand for gluten-free baked goods are also covered.Using functional ingredients within formulations and technologies such as high pressure, improved aeration, sourdough fermentation, and extrusion enables minimization of technological weaknesses within gluten-free bread and corresponding products. Faturally

occurring faults are minimized by great reductions, with the provision of a higher-quality product to be received by those customers with a gluten intolerance.

To further develop commercialization and provide a better, more encompassing, and more reliable alternative in the marketplace for gluten-free cookies, there is an understanding that additional research is required to properly investigate formulation, shelf life, and optimization of manufacturing quality. In order to encourage the desired changes, break the repetitive patterns of development, and expand the growth and innovation of gluten-free products—especially cookies that are relevant due to their practical consumption and extended shelf life—many paths need to be explored and improved. Therefore, these developments encompass everything from the attainment of social, economic, and cultural freedom to enhancements in sensory, nutritional, and technological qualities.

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