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REVIEW ARTICLE

An overview on the incorporation of novel ingredients on nutritional, textural, and organoleptic properties of gluten-free cereal products

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Abstract

Background: Celiac disease is an autoimmune disorder launched by gluten ingestion in genetically susceptible persons. This component leads to an inflammation of the small intestine which causes malabsorption of some important nutrients including calcium, iron, folic acid, and liposoluble vitamins. A gluten-free diet, that is strictly followed by affected patients throughout their whole lives, constitutes the unique effective treatment for celiac disease. **Aims:** Several gluten-free cereals, pseudo-cereals, legumes, starches (rice, corn, sorghum, millets, buckwheat, quinoa, teff, chestnuts, chia, potato starch, peas, etc.), and various gluten substitutes (xanthan and gum guar) were utilized to maintain the physical and sensory properties of gluten-free cereal products. This review examined recent advances in the formulation of gluten-free cereal-based products using innovative gluten-free flours. **Conclusions:** Consequently, this review presents and summarizes recent findings in the improvement of the technological, nutritional, and sensory properties of gluten-free cereal products. However, the preparation of cereal-based gluten-free products still remains a difficult process. Therefore, the diet must be not only exempt from gluten but also healthy to avoid nutrient, vitamins, and minerals deficiencies. Thus, a great deal of this review focuses on studying novel and healthy gluten-free ingredients which should fulfill all quality requirements for bakery and pastry products as well as satisfy the needs of celiac consumers.

Keywords: gluten-free products, alternative flours, celiac disease.

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1 Introduction

Celiac disease (CD) is an autoimmune enteropathy induced by gluten ingestion, affecting about 1% of the world's population [1, 2]. CD is also frequent in developing countries, especially in Middle East and North Africa (MENA) region [1]. Gluten is responsible for the damage of the small intestine by causing pain and inflammation [3]. Prolamins, components of gluten, are responsible for this digestive disorder. Prolamins can be found in specific cereals: wheat, rye, barely, some cultivars of oats and their derivatives [4]. CD is not the unique disease related to gluten ingestion. In fact, gluten also causes other pathologies grouped under the term "gluten-related disorders" [5]. To date, the only cure for CD is strict adherence to a gluten-free (GF) diet. According to the Codex Alimentarius [6], gluten-free foods are dietetic foods that are made solely from one or more ingredients. These ingredients do not contain wheat, or manufactured only from one or more ingredients derived from wheat that has been especially treated to remove gluten and whose gluten content does not exceed 20 mg/kg in total. There are various challenges in the production of GF cereal products. First, gluten is responsible for the different functional characteristics of the dough [7]: it is difficult to find ingredients that can replace gluten to develop GF foods of acceptable sensory qualities. In addition, the nutritional value of GF products must be considered too in celiac patients. This category of patients is exposed to various nutrient deficiencies with high consumption of saturated fatty acids, simple carbohydrates and a deficit in certain nutrients such as dietary fiber, iron, minerals, and vitamins [8-9]. The objective of this review was to study different raw materials used to substitute flours containing gluten in order to offer fortified GF cereal products by focusing on innovative ingredients leading to the production of GF biscuits, bread, and pasta. The technological, nutritional and sensory constraints will also be addressed.

2 Alternative innovative flours used in the development of GF products

CD is characterized by an infiltration of intraepithelial lymphocytes in the near side of the small intestine. This can cause at the final stages of the disease, crypt hyperplasia and atrophy of villosities. In addition, CD patients produce highly disease-specific antibodies against deamidated gluten peptides and the enzyme tissue transglutaminase 2 (TG2) [10] (Figure 1). The unique treatment for CD is a complete eliminating gluten-containing foods from the diet. In recent years, there has been an increasing interest on GF foodstuffs. Several attempts have been undertaken to develop acceptable GF products using variety types of raw materials such as maize flour and starch, rice flour, buckwheat flour, sorghum, tubers such as potatoes and cassava. The selection of GF flours to produce GF bakery products is based on some considerations, such as accessibility, nutritional intake, and final product. However, the major attribute is consumer acceptability based on the organoleptic characteristics of the final product

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(Figure 2). It is well established that GF dietary products are low in minerals, vitamins, and fiber [8], as a result, their nutritional content is of increasing concern. Indeed, the common nutritional deficiencies in celiac subjects are B vitamins, vitamin D, iron, zinc, magnesium, and fiber [11]. Several innovative ingredients have recently been discovered to address this major nutrient gap in GF products and make them more acceptable to consumers. These ingredients are cereal, pseudo-cereal or legume flours (Table 1).

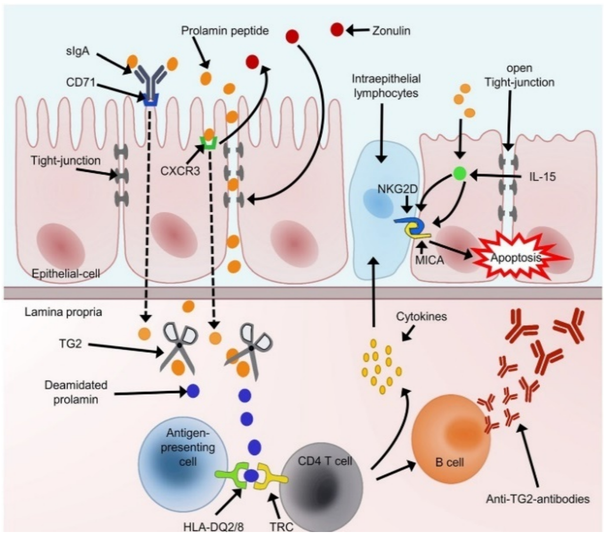

Figure 1: Adapted simplified pathogenesis of celiac disease [12, 13]

Table 1: Gluten-free (GF) products developed with alternative flours

GF Products	Alternative flours used	References
Cookies	Quinoa flour with the addition of pea protein powder, pumpkin seed protein powder, coconut flour, aronia powder, carrot powder, tomatoes powder and ginger powder	14
	Quinoa flakes and flour	15
	Sorghum flour and Turkish beans	16
	Rice-maize-pearl millet-sorghum flour blend	17
	Coconut and rice flours	18
Bread	Quinoa and amaranth flour	19
	Hydrothermal treated rice and corn flours	20
	Corn, potato and tapioca starches, rice flour	21
Pasta	Sorghum- rice- corn flour mixture	22
	Rice and white seeded low phytic acid and lectin free bean	23
Tagliatelle	Teff flour and bean flour	24
Cake	Fermented soy and lupin powders	25
Spaghetti	Plantain- chickpea- maize flour	26

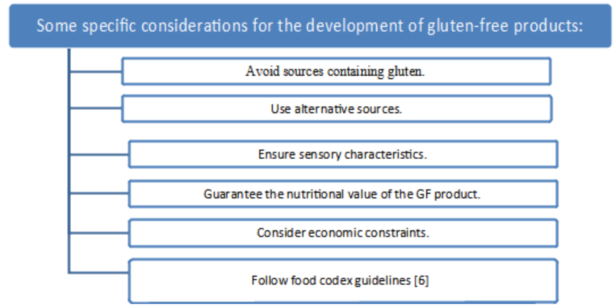

Figure 2: Some specific considerations for the development of gluten-free products [7]

2.1 Millet flour

Millets are indigenous African cereals that are well adapted to African semi-arid and sub-tropical agronomic conditions. Millet invokes nine different species cultivated around the world, and all of them are small-grained and annual cereal grasses [27]. Millet flour is a good source of nutrients, especially fiber, calcium, and other minerals. Adebiyi *et al.* [28] prepared 100% millet flour biscuits using native pearl, fermented and malted millet flour. The lack of gluten in pearl millet flour did not affect the acceptance of cookies by consumers. On the contrary, the sensory analysis of these biscuits, based on malted millet flour, revealed a better appreciation of the aroma, taste, and flavor. However, the use of fermented or native millet in biscuits generated a perceived unpleasant aroma and a relatively bitter taste. On the other hand, the fermentation and malting processes have improved the nutritional characteristics of the biscuits, promoting an improved amino acid profile, mineral bioavailability, and high phenolic compounds in the treated samples. Adebiyi *et al.* [29] also stated that the fermentation and malting of millet improves the physicochemical properties of the resulting flour and biscuit. Sharma *et al.* [30] used flour obtained from sprouted millet seeds to improve the sensory appeal of GF biscuits. Sprouted flour blends possess a higher protein, total phenolic content, and antioxidant activity than raw millet flour blends. Germination displayed a negative effect on the bonding characteristics while the functional properties were significantly improved.

2.2 Teff flour

Teff or tef, *Eragrostis tef*, is a monocotyledonous plant species that belongs to the *Poaceae* family. Teff flour exhibited high levels of carbohydrates (66.7%), fibers (9.8%) [31] and contain a complete set of essential amino acids [32]. Inglett *et al.* [33] developed blends of teff and oat flours (4:1) for the preparation of acceptable cookies in terms of color, flavor, and texture. Moreover, Minarovičová *et al.* [34] studied the effect of teff flour addition (25, 50, and 75%) to rice muffins on qualitative and sensory parameters. The inclusion of teff flour up to 50% provided satisfactory results. Substitution of higher teff flour levels (75%) had negative effects on qualitative and textural properties of muffins. Sensory evaluation showed that muffins incorporated with teff flour at level 25% were the most acceptable for consumers. Hager *et al.* [35] established formulations for the generating of egg pasta from oatmeal and teff flours. The composition analysis showed that regarding fiber and mineral contents, oat and teff flour samples are nutritionally higher in comparison with wheat flour samples.

2.3 Moringa flour

Moringa oleifera belongs to the *Moringaceae* family. This plant is universally called the "miracle plant" or "tree of life". *M. oleifera* leaves include important levels of vitamin A, C, and E, besides significant contents of total phenols, protein, calcium, potassium, magnesium, iron, manganese, and copper [36]. Besides the leaves, the flowers and fruits of *M. oleifera* contain significant amounts of carotenoids [37]. *M. olifera* seeds [38] or leaves [39] were utilized as a fortifying ingredient of the biscuit. Indeed, Kiranawati *et al.* [40] used a composite flour of potato starch and *Moringa* leaves flour to substitute wheat to produce GF and casein-free staple foods (cookies and snacks). These authors revealed that the best composite flour with similar properties to wheat flour is composed of a ratio potato starch/Moringa leaves flour of 94% / 6%. In addition, *moringa (M. oleifera)* seed flour was mixed with *acha* (*Digitaria exilis*) flour in different proportions of 5, 10, 15, 20, and 25%, to formulate biscuits [41]. It was found that a rate more than 10% of *moringa* seed flour caused a decrease in the appreciation of the biscuit. On the other hand, Bourekoua *et al.* [42] evaluated the effect of the addition of *Moringa oleifera* leaves powder on the physical, sensory, and antioxidant properties of GF bread. *Moringa* leaf powder (MLP) has been included at different proportions (2.5; 5; 7.5, and 10%) in the production of GF bread. The results showed a decrease in the specific volume of the bread with an addition of more than 2.5%. The hardness and chewiness of bread lightly decreased with 2.5 and 10% of MLP addition, whereas springiness was not affected. For sensory quality, consumers preferred control bread and bread with 2.5% of MLP. The lightness of crumb and crust decreased from 63.37 to 27.59 and from 52.40 to 33.49, respectively as the MLP rate increased. The total phenolic content of extracts increased from 0.88 to 2.12 GAE/g of dry weight, with the addition of 2.5% of MLP. Furthermore, the DPPH scavenging activity was enhanced with the inclusion of MLP. Findings exhibited that gluten-free bread with a level of 2.5% of *moringa* leaves powder had the highest hedonic score.

2.4 Chia flour

The botanical name of chia is *Salvia hispanica* L. which belongs to the *Salvia* category of the *Labiatae* family. Chia seed is of great interest due to its nutritional and functional potentials either in food or pharmaceutical industries [43]. Mas *et al.* [44] studied the impact of chia flour to enhance the antioxidant quality of cookies. Cookies were made using various proportions of chia flour (5, 10, and 20%); the technological and sensory qualities of the cookies were evaluated. The addition of 10% of this flour increased polyphenols content and antioxidant capacity without reducing technological or sensory properties. So far, few studies have been conducted on the use of chia seeds in the development of GF bread. Moreira *et al.* [45] and Moreira *et al.* [46] incorporated 2.5% to 7.5% of whole chia seed flour into a GF chestnut paste. Authors evidenced that the addition of 7.5% chia seed flour improved the rheological properties of the dough, stability, viscosity, and elasticity. Steffolani *et al.* [47] found that replacing rice flour with 15% of chia flour darkened the GF cereal product, reduced its specific volume and increased its hardness, while it maintained the product's acceptability to consumers. Huerta *et al.* [48] substituted rice and soybean flours with 2.5; 5.0 and 7.5% of chia flour in order to replace the gum required in this type of bread; bread with 2.5% of chia flour replacement had no significant difference from the control in terms of specific volume, color, aroma, taste, texture, and appearance. Sandri *et al.* [49] optimized a GF bread recipe with potato starch, rice flour, and chia flour. They concluded that rice flour mixtures with 5%, 10%, and 14% of whole chia flour obtained the best sensory results. Furthermore, corn tortillas with 15% and 20% added chia flour have a reduced glycemic index with significantly higher levels of protein, fat and total dietary fiber [50]. Moreover, rice-based GF pasta has been optimized with chia flour and mucilage as a thickener and to increase their nutritional values [51]. Indeed, with a concentration of 10% of mucilage or chia flour, the resulting pasta was more nutritious compared to samples based on commercial GF ingredients. Similarly, chia flour has been used in the preparation of GF noodles based on rice and corn flours at different percentages (0, 10, 20, and 30%) with and without diacetyl esters of mono (and di) glycerides tartaric esters [52]. These studies showed that pasta was accepted by consumers with 20% of chia flour in association with diacetyl tartaric esters of mono (and di) glycerides.

2.5 Acorn flour

Acorns (*Quercus coccifera* L.) belong to the family of *Fagaceae.* Since ancient times, acorn fruits are considered as nutritionally rich products besides of their good medicinal properties. Despite their long culinary tradition, they have become under-appreciated. Due to their high starch content, acorns are especially used to produce flour considered as a good alternative for cereal flour in many food industry applications [53]. Torabi *et al.* [54] investigated the influence of acorn flour (substituted at levels of 0-30% with rice flour, corn flour, and starch) as a mixture design on chemical, nutritional, textural, and organoleptic properties of GF biscuits for celiac patients. The results indicated that moisture, ash, crude fiber, carbohydrate, antioxidant capacity, and total phenol of GF biscuits supplemented with acorn flour distinctly increased compared to the control. The increase of acorn flour decreased calorie value of GF biscuits; however, it increased the hardness and penetration energy of samples. Sensory evaluation showed that up to 20% of inclusion of acorn flour was acceptable. Korus *et al.* [55] studied the application of debittered acorn flour as a natural nutritional enrichment of GF bakery products and evaluated the effects on rheological properties of the dough, quality, and staling of the bread. They concluded the importance of debittered acorn flour's application in GF baking products. It enriched bread with protein, minerals, and dietary fiber, but also it had a beneficial impact due to its technological effects, including structure enhancement, and sensory improvement.

2.6 Chestnut flour

The chestnut fruit (*Castanea sativa* Mill.) is part of the *Fagaceae* family. Chestnut flour contains high-quality protein with essential amino acids (4-7 g/100g), a relatively high level of sugars (20-30 g/100g), starch (50-60 g/100g), dietary fiber (4-10 g/100g), and low-fat content (2-4 g/100g), mainly unsaturated[56]. Paciulli *et al.* [57] evaluated the impact of different proportions of chestnut flour (0, 500, 800, 1000 g/kg) in GF biscuits formulations. The incorporation of chestnut flour at high levels (0.8% and 1%) led to a significant hardness of the biscuits while a replacement of 0.5% of chestnut flour can be considered as the best compromise between quality and storage stability. On the other hand, Paciulli *et al.* [58] enriched two commercial GF mixtures with 20 g/100 g and 10 g/100 g of chestnut flour to produce technologically and nutritionally improved breads. The addition of chestnut flour led to color browning, lower bulk volume with larger crumb holes and faster staling. They concluded that only breads with 20 g/100 g of enrichment showed a significant increase in total, soluble and insoluble fibers. While Oniszczuk *et al.* [59] mixed different amounts of chestnut flour (10, 20, 30, 40, and 50%) with rice and bean flours to produce innovative GF pasta. In a sample containing 20% or more of chestnut flour, up to 13 amino acids were detected. In addition, the antioxidant activity, free phenolic acid content and total polyphenols were positively correlated with the addition of chestnut flour.

2.7 Tiger nut flour

The tiger nut (*Cyperus esculentus*) belongs to the *Cyperaceae* family. The tiger nut flour is characterized by brown color and mild flavor. It's rich in carbohydrates, lipids, fiber, some minerals (K, P, Ca), and vitamins E and C [60]. Ahmed *et al.* [61] investigated the functional properties of GF biscuits following the incorporation of tiger nut flour. Corn flour was substituted by 10, 20, and 30% of tiger nut flour. The addition of tiger nut flour resulted in a significant increase in fiber and ash content and a decrease in protein content. The spread ratio of biscuits increased substantially by increasing tiger nut flour content. The texture analysis of biscuits showed that the hardness and resilience values decreased when the tiger nut flour content in the biscuit formulation increased. Microscopic observation revealed that tiger nut biscuits were more porous with a mainly granular structure compared to the control sample which was compact. A proportion of 20% addition of tiger nut flour was considered as the better percentage to produce biscuits with a softer and more airy texture besides a nutty flavor.

2.8 Coconut flour

Coconut (*Cocos nucifera*) is a palm species of the *Arecaceae* family. Coconut flour, of unique taste and aroma, is a soft flour obtained from coconut pulp as a by-product during coconut milk processing. It is an excellent source of vitamins, minerals, healthy fats, and dietary fibers which might have potential application in baking products and human nutrition [62]. Paucean *et al.* [18] evaluated the addition of blends of rice and coconut flours in GF cookies formulation in terms of composition and acceptability. The mixture of coconut and rice flours in different proportions led to cookies with increased protein, ash, and fat content. Sensory analysis proved that mixtures of rice and coconut flours can be successfully introduced into the formulation of GF cookies, giving products with pleasant flavor and taste.

2.9 Carob flour

The carob tree (*Ceratonia siliqua* L.) belongs to the *Fabaceae* family. Carob flour is rich in pectin, high-quality soluble fiber, and sugars in addition to its thickening properties. This flour is a good alternative to produce viscoelastic dough and high-quality GF bread [63]. Berk *et al.* [64] studied the effect of the use of carob flour (10%, 20%, and 30%), and the inclusion of different types of protein (soy protein and whey protein) on the technological quality of GF cakes (specific volume, hardness). They showed that cakes prepared with 20% carob flour had the highest specific volume and the lowest hardness. Moreover, Gularte *et al.* [65] showed that substituting 15% of rice flour with carob flour produced GF bread with enhanced structure and color crumb than rice bread. However, crumbs were harder, and the specific volume was lower.

2.10 Lupine flour

Lupine (*Lupinus albus*) is a legume that can be grown in marginal agricultural conditions. Lupine flour has high amount of protein (~ 40%) and dietary fiber (~ 28%) [66]. Albuja-Vaca *et al.* [67] developed a GF pasta by substituting rice flour with lupin flour (10g/100g -30g/100g) using a mixture-process design. The best formulation was obtained with 20g/100g lupin flour compared to the control sample (100% rice flour). This formulation showed an increase in ash (37.5 g/100g), protein (63.15 g/100g), fat (112.12 g/100g), and fiber (126.66 g/100g). They concluded that partial substitution of rice flour by lupin flour could be a reliable alternative for GF products. Furthermore, Maghaydah *et al.* [68] were interested in producing GF cookies where lupine flour was employed as the major substitute to wheat flour. Eight flours blends for the preparation of GF cookies were made, consequently. The results of the sensory analysis indicated that the overall best quality of the cookies was obtained for preparations based on 50% lupin flour and 50% maize starch and those based on 20% lupin flour, 30% corn flour, 20% rice flour, and 30% corn starch, in comparison with wheat flour control.

2.11 Alfalfa flour

Alfalfa (*Medicago sativa* L.) is a plant of the *Fabaceae* family. When comparing alfalfa seeds to wheat seeds, they contain high levels of protein, fat, and raw fiber [69]. In an effort to strengthen nutritional value, GF cookies, using alfalfa seed flour at different proportions of rice flour substitution (0% as control, 15%, 30%, and 45%), were produced by Giuberti *et al.* [70]. The analyses revealed that the highest levels of alfalfa seed flour substitution (30 and 45%) contributed to formulate GF cookies with higher content of slow-digesting starch, total dietary fiber, crude proteins, and resistant starch than the control or the lower substitution levels (0 and 15%) without altering sensory, technological, and global attributes of the product.

2.12 Bee pollen flour

Bee pollen is a beekeeping product generally composed of pollen from flowers of different plant species. The main components of bee pollen are carbohydrates (13-55%), proteins (10-40%), crude fibers (0.3-20%), and lipids (1-10%). Conte *et al.* [71] explored the use of multi-flower bee pollen (1, 2, 3, 4, and 5%) as a natural and functional ingredient in GF bread making. They evaluated its impact on the physicochemical, technological, and sensory characteristics of the bread obtained. The increase in pollen supplementation levels (1% to 5%) significantly improved the technological properties of bread. Moreover, the overall acceptability of GF bread enriched with bee pollen between 3% and 5% was greater than the control. Similarly, Krystyjan *et al.* [72] worked on the optimization of GF cookies formulation with the addition of pollen. Although the supplementation of bee pollen did not affect fat content of the cookies, it induced a significant positive influence on the content of carbohydrates, proteins, ash, fibers, as well as polyphenolic composition and potential antioxidants. Besides nutritional benefits, cookies enhanced with bee pollen are marked by higher penetration and darker surface than the control. However, only up to 5% of pollen was needed to allow the taste of the cookies to be at the same level as the control.

2.13 Other fruits and vegetables flours

Recently, the use of fruit and vegetable powder in GF pasta was emerged as an innovative product. Banana flour, rich in indigestible carbohydrates, was utilized to provide GF pasta [73, 74]. The inclusion of 30% of pregelatinized green plantain flour or dried green banana flour gives GF spaghetti with satisfying cooking quality and high-resistant starch. Mirhosseini *et al.* [75] used pumpkin flour or durian seed flour to make GF pasta, where the inclusion of 25% pumpkin flour in the formulation improved the color, texture and sensory acceptability of GF pasta.

3 Conclusion

For years, the most alternative flours widely used for producing GF foods were rice and maize. Thus, avoiding foods containing gluten in the diet means eliminating the main sources of protein in the diet and sticking to a high-carbohydrate diet. To overcome this effect, in recent years, innovative flours such as GF cereal flours, pseudo-cereals, legumes and fruits are increasingly being used. Besides these flours and/or starches, additives such as hydrocolloids, fibers, proteins, and emulsifiers are used. They are introduced into GF formulations in order to mimic the effect of gluten and give highly nutritious GF products, satisfying textural and sensory constraints. Therefore, it is important to do more research on these ingredients, without neglecting economic constraints.

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