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Chapter 20

Market and Nutrition Issues of Gluten-Free Foodstuff

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Abstract

Nutritional therapy is currently the unique treatment for gluten intolerance. However, food technologists have been developing gluten free foods without having in mind both the nutritional status and nutrients' needs. It is important to consider that gluten intolerant patients do not have the same requirements when diagnosed than when they are fulfilling a long-life gluten free diet. Their needs are different at each stage, because of that diet might respond to their nutritional demands and be adapted. This chapter gives an overview of the nutritional pattern of gluten free intolerants at diagnosis, their requirements and how the currently marketed gluten free products meets those needs. In addition, this chapter reviews the tools that food technologist have for enriching the gluten free products, particularly bakery products, in macro- and micronutrients giving response to the consumers. It is also highlighted the role that nutritionist must play in this picture giving proper advice to consumers.

Keywords

Nutrition, gluten free, food, bread, bakery products, market, enrichment, micronutrients.

1. Introduction

Gluten free foodstuff development has attracted in the last decade great attention due to better diagnoses of celiac disease and common chatters about the relationship of gluten free products with healthiness. A few years ago, gluten-free products were virtually unheard of except in specialty health food stores. Whatever is the real motivation to consume gluten free foodstuff, nowadays a rising demand for gluten-free products is observed in the market trends. The market for gluten-free foods and beverages has continued to grow even faster than anticipated. ‘Gluten-free’ has become an identity for the tens of millions of Americans who have reduced or eliminated their consumption of wheat, barley, rye, and oats. While growth rates will be moderate over the next five years in the wake of market expansion, Packaged Facts projects that U.S. sales of gluten-free foods and beverages will exceed $6.6 billion by 2017 (Packaged Facts, 2011). Trend data shows the gluten-free target audience to be 44 million strong. North America is the largest market for gluten-free products accounting nearly 59% of the market share in 2012. Major demand in the market is anticipated to come from countries such as U.K., Italy, U.S., Spain, Germany, Australia, Brazil, Canada, India, etc. (http://www.marketsandmarkets.com). The increasing interest has promoted the launching of hundredth of gluten free foodstuff, being a niche market with steady growing shares.

Those trends have been accomplished by numerous research studies on the topic of developing gluten free breads, as recent reviews pointed out. Very recently, even a breeding strategy has shown very successful results obtaining reduced gliadin wheat breads with 97% lower gliadin content than wheat breads[1]. It has been estimated that celiac patients could safely consume 67 grams of low-gliadin bread per day.

Additionally, analytical methods for gluten detection have been an active area of debate pertaining immunochemical and non-immunochemical assays developed for gluten quantification, their sensitivity, specificity, cross-reaction and their feasibility for testing gluten-free food consumed by patients with celiac disease[2,3].

Previous reviews showed that much research has been conducted on gluten free foods from different angles to obtain good quality gluten free foods. Nevertheless, nutrition quality of those products has been of interest only recently. In the last couple of years, the driven force of the gluten free research has been the nutrition quality. Very recently, Matos and Rosell[4] reviewed the different available strategies for improving the nutritional quality of gluten free breads.

This chapter will be focused primarily on presenting nutritional status of gluten intolerant population to define their nutritional requirements, and secondly on the nutritional quality of the existing gluten free food at scientific and commercial levels. Only by knowing the real needs of consumers it would be possible to design tailored made gluten free products for improving health status of gluten intolerant individuals.

2. Motivation to Consume Gluten Free Foodstuff

Increasing diagnoses of celiac disease and food allergies; growing awareness of these ailments among patients, healthcare practitioners, and the general public; the availability of more products, and better ones; and a trend that has friends and family members eating gluten-free to support loved ones are among the factors stimulating continuing expansion in this market (http://thegluten-freeagency.com/gluten-free-market-trends/). In recent years, an increasing number of individuals are suffering from celiac disease (CD). CD not only affects the gut, but is a systemic disease that may cause injury to the skin, liver, joints, brain, heart, and other organs. It is a complex genetic disorder, and human leukocyte antigen (HLA) status appears to be the strongest genetic determinant of risk for celiac autoimmunity[5].

Recently, Worosz & Wilson[6] described different types of consumers of gluten-free products, which are: persons who claim a gluten sensitivity or CD medical diagnostic, persons with perceived gluten-sensitivity, and consumers who do not have CD but who express interest in gluten-free products as a lifestyle. Additionally, these authors defined two types of gluten-free consumerism: Ethical Consumerism describes consumption driven by the ways in which a product is perceived to fit into an individual's overall lifestyle, to benefit the environment, and /or to meet social goals; and Non-CD Health Consciousness are those who are "motivated to improve and/or maintain their health and quality of life". Consumers who do not have CD may express interest in gluten-free products as a lifestyle choice because it evokes a cultural-ecological-, civic-, historical-, ethical-, or health-based interest or quality[6]. Gluten-free has been described by consumers as: "a mainstream sensation, embraced by both out of necessity and as a personal choice toward achieving a healthier way to live".

3. Special Nutritional Requirements of the Celiac Patients

In CD patients, ingestion of gluten leads to inflammation and mucosal damage of the small intestine. The typical lesion in the small intestinal epithelium is villous atrophy with crypt hyperplasia, leading to malabsorption of most nutrients including iron, folic acid, calcium, and fat-soluble vitamins[7]. This can lead to associated diseases such as osteoporosis, anemia and type I diabetes and skin disorders. Individuals with celiac disease are more susceptible to pancreatic insufficiencies, dysbiosis, lactase insufficiencies, and folic acid, vitamin B12, iron, and vitamin D deficiencies, besides accelerated bone loss[8].

CD patients might show an alteration in lipid metabolism, for instance low serum total and high-density lipoprotein-cholesterol derived from lipid malabsorption and decreased intake[9]. Moreover, the exclusion of wheat, rye and barley, important vitamin and mineral sources, from the diet might provoke deficiencies in iron, vitamin B and dietary fiber. In fact, common nutrient deficiencies in celiac subjects at diagnosis are calorie/protein, fiber, iron, calcium, magnesium, vitamin D, zinc, folate, niacin, vitamin B12 and riboflavin[10].

Therefore, somewhat that might be surprising is that nutritional deficiencies are not only associated with poverty and developing countries, but also to population in developed countries who suffer from undiagnosed disease and those that must adhere to restricted diets like occurs with CD patients. Moreover, it has been identified the high frequency of underweight at diagnosis thus CD individuals might be in need of careful personalized nutritional management[11]. Health care counselors must be monitoring both growth and feeding patterns to identify unbalanced diets that may lead to nutritional deficiencies.

Recently, nutritional status of newly diagnosed adult CD-patients was analyzed in Netherlands[12]. Serum concentrations of folic acid, vitamin A, B6, B12, and D, zinc, haemoglobin and ferritin were determined and results showed that CD patients before gluten free diet compliance had at least one value below the lower limit of reference. The most frequent deficiencies were observed in zinc followed by iron, folic acid, vitamin B12, B6 and A.

4. Importance of Nutrition for Gluten Intolerant Patients

When following a gluten free diet does not respond to therapeutical counselling, nutritional unbalance might not be a problem. However, it is widely accepted that gluten intolerance therapy is restricted to gluten removal from the diet and uncertainty remains as to whether this gives a nutritionally balanced diet. In addition to that, it must be taken into account that individuals with CD may require additional nutritional supplementation to assist in regulation of several of these complications. Untreated CD individuals show reduced levels of iron, folate, vitamin B12, vitamin D, zinc, and magnesium; those deficiencies usually revert after gluten removal from the diet[13.] Nevertheless, folate and vitamin B12 deficiencies, and even vitamin D and calcium, may persist, being recommended the vitamin supplementation to meet healthy intake recommendations.

Lifelong adherence to gluten free diet as a treatment for gluten intolerant patients means complete exclusion of wheat and wheat containing products from the diet, which poses huge challenges in terms of compliance. Gluten free diet is very effective and greatly improves nutritional status, inducing an increase in fat and bone compartments, but does not completely normalize body composition, and it might be very difficult to maintain. It is paramount that health care providers have a deep understanding of CD and the gluten free diet in order to educate patients and their families.

Primarily, it was set up that treatment of patients with a gluten-free diet was enough to treat them and keep them healthy. That measure involved selecting appropriate foods by omitting gluten-containing products. In general, clinical studies were only focused on the recovery of intestinal mucosa after removing gluten from the diet but no long dietary studies were conducted. The intestine heals with removal of gluten from the diet but the intolerance is permanent and the injury recurs if gluten is introduced again. Several evaluations of the dietary intake of CD individuals on gluten free diet have been reported to estimate the convenience of the nutrient intakes. In children with diagnosed CD and on gluten free diet similar pattern to healthy children were observed pertaining dietary intakes of energy and nutrients, differences were observed in the lower intake of vitamin D, riboflavin, niacin, thiamine, magnesium and selenium among CD children and their higher intake of iron and calcium[14]. In spite of caution is necessary when analyzing dietary registrations in teenagers, results suggested that adolescents on gluten free diet have higher intake of saturated fatty acids and sucrose and lower intake of dietary fiber than healthy adolescents on a gluten containing diet. In general, CD individuals have a tendency to compensate for the restrictions of a gluten-free diet by eating foods containing high levels of fat, sugar and calories, because of that they may show an excessive consumption of total fats and saturated fats. Mariani et al.[15] reported that diet of CD adolescent patients was hyperproteic and hyperlipidic and contained low amounts of carbohydrates, iron, calcium, and fiber.

A decade ago, Hallert et al.[16] investigated the vitamin status in celiac patients on a gluten-free diet for 10 years by using a 4-day food record. Results showed that the daily intakes of folate and vitamin B12 were significantly lower in celiac patients, which may have clinical implications considering the linkage between vitamin deficiency, elevated total plasma homocysteine levels and cardiovascular disease. Haapalahti et al.[17] reported that one third of screen-detected CD adolescent had lower median values of blood folic acid besides low iron status (transferrin receptor-ferritin index) and although no association was found between the nutritional status and the markers of mucosal injury (villous-crypt measures), the level of transglutaminase was associated with whole blood folic acid and with transferrin receptor-ferritin index.

Later on, Shepherd and Gibson[18] analyzed a seven-day prospective food intake in 55 patients adhered to gluten free diet for more than 2 years and concomitantly in 50 newly-diagnosed, revealing similar nutritional intake between groups. However, differences were observed in the macronutrients intake, for instance starch intake decreased after 12 months under the diet, and fiber intake was inadequate for all CD individuals except males with long term under the diet. Newly-diagnosed and experienced patients showed deficiencies in thiamin, folate, magnesium, calcium and iron (females) or zinc (males). According to these authors, dietary deficiencies after short-time adhered to gluten free diet were similar to those after long term adherence to this diet.

A study carried out in Germany with 1,000 patients by recording a prospective 7-day food diary and a questionnaire revealed that male celiac patients showed no significant difference for the intake of energy and macronutrients compared to healthy individuals, although lower fiber intake was detected[19]. Regarding female patients, they showed higher fat intake and lower carbohydrate consumption. Both genders evidenced deficiencies of vitamin B1, B2, B6, folic acid, magnesium and iron. Similarly, in Sweden a study was conducted among 13-year old diagnosed with CD in early childhood with those of a non-celiac to compare their energy and nutrient intakes[20]. Dietary intake was assessed using a food-frequency questionnaire during 4 weeks. Most adolescents recorded an intake above requirements for most nutrients, with the exception of vitamin C, and thiamine, but the later only in the CD boys. Regarding fatty acids, they showed a high intake of saturated fats and a low intake of unsaturated fats. Girls and boys in the CD-group had an overall lower nutrient density compared to the healthy group.

During the first few years of treatment it seems that celiac patients have a nutritionally adequate diet. But after several years of dietary compliance some deficiencies have been detected, that should force food processors and nutritionist to adequate food composition and diet, respectively, to prevent those deficiencies and in consequence the risk to suffer some ailments associated to them.

4.1. Nutritional Therapy Facing Daily Shopping

Commercial gluten free foods are available in all the countries but they are very expensive and sometimes difficult to find. In fact, a qualitative study carried out in 2007 with 15 households confirmed the additional domestic costs for households with a member suffering from celiac disease[21]. Later on, Singh and Whelan[22] confirmed the fact that cost and availability of gluten-free products might be the main cause of incomplete dietary compliance. Those authors investigated the availability and cost of 20 gluten-free foods (including branded gluten-free and cheapest gluten-free) across 30 different stores; results indicated limited availability of gluten-free foods (41% foods being available in a gluten-free version per store, and no gluten free products were present in convenience store) and gluten-free foods were more costly than their gluten containing counterparts. Increasing availability and affordability of gluten-free foods may improve diet compliance.

Other aspect is the quality of the marketed gluten free products perceived by consumers. In Latvia, a survey was conducted from December 2010 till the end of July 2011 to find the opinion about quality of gluten-free products in this country, showing that the quality of gluten-free flour, flour blends and pasta was acceptable but no the quality of bread and confectionery, which required considerable technological improvement[23,24].

In some countries that fact limits the accessibility to those products leading to celiac children being anorexic and malnourished. Those states will need high calorie and high protein diets.

On the other hand, up to a few years ago gluten free products were somewhat limited in the market, thus CD patients had limited choice of food products and they consumed excessively packaged gluten-free products, such as snacks and biscuits with a high intake of lipids[10].

4.2. A Unique Nutritional Therapy or Adapted to Age Range?

It is clear that each age range or special human states might have specific nutritional requirements thus a tailored meal plan would be advisable, which consider the likes and dislikes of the person, the socio-economic condition, and the life style to ensure adequate intake of all nutrients. Studies conducted in adults and children show that approximately 20%-38% of patients with CD have nutritional complications, such as calorie/protein imbalance, dietary fiber, mineral and vitamin deficiencies likely to be caused either by the poor nutritional quality of the gluten free products or the incorrect alimentary choices of CD patients.

Children should be aware that according to dietary reference intake values recommended distribution of daily calorie intake for a healthy and balanced diet should be 55% from complex and simple carbohydrates, 15% from dietary protein and 25%–30% or less from lipids[25]. The adequacy of the diet is of really significant importance in children, because it is the age of maximal energy and nutrient requirements for growth, development and activity.

Moreover, compliance with the gluten free diet becomes difficult for adolescents. In fact, Altobelli et al.[26] reported that at least one third interviewed teenagers reported feeling angry “always” or “most of the time” about having to follow the gluten free diet. Therefore, health professionals must take special care to identify adolescents with major disease-related problems.

Lately, a very interesting study was reported for confirming the adherence to a gluten free diet by measuring the exhaled breath of healthy individuals after being adhered to gluten free diet for four weeks[27]. Twelve volatile compounds were associated to gluten-free diet and only seven could be chemically identified as 2-butanol, octane, 2-propyl-1pentanol, nonanal, dihydro-4-methyl-2(3H)-furanone, nonanoic acid and dodecanal.

5. Nutritional Quality of Gluten Free Products

Medical nutrition therapy is defined as specially processed or formulated foods that are used for the dietary management of patients. Amongst the medical foods, low-protein/protein-free foods have improved the physical manifestation of metabolic disorders in patients with amino acid or protein-related diseases, such as Phenylketonuria, Tyrosinaemia type I, as well as celiac. Most of the cereal-based gluten free foods currently marketed are a blend of refined or chemically-based food ingredients with unpalatable, frequently artificial flavors. Despite the numerous advances in the development of gluten free products resembling the quality of their gluten containing counterparts, to date there is no one raw material or defined ingredient to effectively replaced gluten. Scientific papers reached the conclusion that the combination of modified or functional starches or flours, with hydrocolloids and supplemented with fibers, proteins and co-texturizers is the best alternative to obtain gluten free products[28].

The production of protein free cereal foods is a technological challenge. Studies on gluten free products, particularly bread, have been concentrated on improving technological parameters (volume, crumb hardness, and so on) besides sensorial perception. However, the nutritional concept of the gluten free baked goods has been scarcely addressed. Historically, nutrition counselling for celiac disease has focused on the foods to avoid gluten in the diet. But some bells of alarm sounded after[29] survey showing the nutrient intakes and food consumption patterns of adults with celiac disease who adhere to a strict gluten-free diet. These authors compiled the three-day estimated self-reported food records of forty-seven volunteers to assess daily intakes of calories, percent daily calories from carbohydrates, dietary fiber, iron, calcium and grain food servings. Recommended daily amounts of fiber, iron and calcium were met by 46, 44 and 31% of women and 88, 100 and 63% of men, respectively.

There is growing concern over the nutritional adequacy of the GF dietary pattern because it is often characterized by an excessive consumption of fats and reduced intake of complex carbohydrates, dietary fiber, vitamins and minerals[30,31].

Some nutritional aspects of selected commercial gluten-free products including breads have pointed out the nutritionally variability of gluten free products. Matos and Rosell[31] evaluate the nutritional pattern of gluten-free breads representative of the Spanish market for this type of products (Table 1). In general, authors found that the protein, fat and mineral content of the gluten-free breads showed great variation, ranging from 0.90 to 15.5 g/100g, 2.00 to 26.1 g/100g and 1.10 to 5.43 g/100g, respectively; and as consequence had very low contribution to the recommended daily protein intake, and a high contribution to the carbohydrate dietary reference intake. Additionally, dietary fiber content showed great variation (1.30 to 7.20 g/100 g). Mentioned authors suggested that gluten-free breads showed great variation in the nutrient composition, being starchy based foods low in proteins and high in fat content. Fat composition of gluten free products is of great concern because they contained trans fatty acids that may provoke metabolic imbalance when combined with inadequate intake of essential fatty acids[10]. A high intake of dietary lipids is a risk factor in the development of coronary heart disease and obesity[32].

Table 1. Proximate composition of different gluten free breads reported in the scientific literature.

Reference	Raw material	Chemical composition (g/100g, dm)					Dietary fiber (g/100g, dm)		
		Protein	Fat	Minerals (Ash)	Fibers	Total carbohydrate (*)	TDF	SDF	IDF
Pagliarini et al.[33] (1)	Maize starch	2.3	5.4	3.9	7.4	81.0	nr	nr	nr
	Maize starch, rice flour	3.5	14.0	Nr	nr	81.1	nr	nr	nr
	Rice flour, rice starch, tapioca starch	4.2	11.4	1.9	4.9	77.6	nr	nr	nr
	Maize starch, rice flour	5.3	9.1	2.4	10.9	72.3	nr	nr	nr
	Maize starch, rice flour	6.0	9.1	Nr	nr	66.4	nr	nr	nr
	Maize starch, rice starch, rice flour	4.3	8.3	2.2	4.5	80.7	nr	nr	nr
Matos and Rosell[31] (2)	Maize starch; egg	3.16	8.51	2.12	nr	86.21	9.69	5.79	3.9
	Maize starch; egg	6.94	16.91	1.10	nr	75.05	5.00	3.08	1.92
	Maize starch; egg	7.31	16.56	1.66	nr	74.47	1.83	0.65	1.18
	Potato starch, maize starch; casein, soy protein	15.05	7.33	1.85	nr	75.76	6.72	1.14	5.58
	Maize starch; egg	5.13	10.64	2.01	nr	82.22	5.1	3.62	1.49
	Maize starch, rice flour; lupine protein	4.92	4.86	2.03	nr	88.18	5.32	3.09	2.22
	Maize starch; egg	3.96	8.28	4.53	nr	83.22	9.37	5.2	4.17
	Maize starch	1.01	2.00	4.03	nr	92.96	2.33	1.07	1.26
	Maize starch	0.91	2.03	5.43	nr	91.63	6.96	2.02	4.94
	Maize starch	1.91	26.10	3.57	nr	68.42	8.22	6.1	2.11
	Maize starch	2.08	18.32	3.98	nr	74.91	8.53	6.94	1.59

Reference	Raw material	Chemical composition (g/100g, dm)					Dietary fiber (g/100g, dm)		
		Protein	Fat	Minerals (Ash)	Fibers	Total carbohydrate (*)	TDF	SDF	IDF
Matos and Rosell[34]	Commercial gf blend	3.30	0.97	1.37	nr	94.36	nr	nr	nr
	Rice flour	7.57	3.40	1.13	nr	87.90	nr	nr	nr
	Rice flour	7.10	3.70	1.31	nr	87.89	nr	nr	nr
	Rice flour, maize starch, potato starch	14.97	0.20	1.47	nr	83.36	nr	nr	nr
	Rice flour, maize starch, potato starch	3.63	1.87	1.03	nr	93.47	nr	nr	nr
	Rice flour, maize starch, potato starch	12.33	9.57	1.46	nr	76.54	nr	nr	nr
	Rice flour, potato starch	7.43	4.77	1.41	nr	86.39	nr	nr	nr
Phimolsiripol et al.[35]	GF-wheat starch, rice flour (control)	5.54	nr	Nr	nr	nr	2.29	0.10	2.19
	GF-wheat starch, rice flour+ rice bran	6.08	nr	Nr	nr	nr	2.46	0.66	1.80
	GF-wheat starch, rice flour+ rice bran	7.58	nr	Nr	nr	nr	5.97	0.58	5.39
	GF-wheat starch, rice flour+ rice bran	6.87	nr	Nr	nr	nr	4.44	0.40	4.05
	GF-wheat starch, rice flour+ rice bran	6.73	nr	Nr	nr	nr	5.03	0.71	4.32
Krupa-Kozak et al.[36]	GF-blend	2.52	1.90	3.03	nr	nr	2.29	0.10	2.19
	GF-blend + calcium caseinate	14.23	1.37	3.52	nr	nr	2.46	0.66	1.80
	GF-blend+ sodium caseinate	14.68	0.67	3.12	nr	nr	5.97	0.58	5.39
	GF-blend + whey proteins hydrolyzate	13.65	1.38	3.28	nr	nr	4.44	0.40	4.05
	GF-blend + whey protein isolate	13.47	13.47	1.74	nr	nr	5.03	0.71	4.32

dm: dry matter; nr: not reported.
(*) Total Carbohydrate (d.b) by difference: 100 – (weight in grams [protein + fat + ash] in 100 g of food) (FAO, 2003).
(1) Nutritional value reported on label (Commercial gluten-free breads samples, according to suppliers' informations).
(2) Commercial gluten free samples.

5.1. Alternatives for Improving Nutritionally Gluten Free Breads

Lately, gluten free formulations are being set up considering the nutritional quality of the final gluten-free baked products. The most common strategy to increase the nutritional value of gluten-free breads is to include nutritionally valued raw flours. Although those flours are often presented as new crops and raw material, they have been used by local populations in traditional ways for many centuries. Consequently, their innovation is rather related to the ways in which old and new uses are being readdressed[37]. Non-traditional flours such as pseudocereals flours (amaranth, quinoa and buckwheat), root and tubers flours (such as potato, cassava, sweet potato and edible aroids: taro and yams), and leguminous flours (chickpeas, lentils, dry beans, peas, and soybean)[38] are gaining popularity in the production of gluten-free foodstuff with major nutritional quality (Table 2). Amaranth is rich in lipids, proteins, carbohydrates, and dietary fiber and other constituents, such as squalene, tocopherols, phenolic compounds, phytates, and vitamins[39].

Vitali et al.[43] compared the nutrient composition of eleven raw materials (carob, soy flour, amaranth, orange sweet potato, red sweet potato, red quinoa, buckwheat, maize, rice flour and chickpea) (Table 2) apt to be used in gluten free diet. Those authors reported that fat content ranged from 0.53 g/100 g dry mater (d.m.) in red sweet potato up to 24.19 g/100 g dm in soy flour, being specially high in red quinoa, amaranth, and chickpea (6.39, 6.28, and 5.84 g/100 g dm, respectively). Protein content of the flours ranged from 5.38 g/100 g dm in carob up to 41.47 g/100 g dm in soy flour. Regarding carbohydrate content, flours could be clustered in three groups comprising low carbohydrate content (soy flour –10.64 g/100 g dm), moderate carbohydrate content ranging from 48.12 g/100 g dm to 68.56 g/100 g dm (wheat flour, carob, amaranth, buckwheat, maize, rice, and chickpea), and very high carbohydrate content ($>$ 80g/100 g dm) observed in sweet potato flours and red quinoa. Essential mineral and dietary fiber contents were significantly higher than those in wheat flour[43]. Additionally, chickpea, rice flour, maize, quinoa, and different types of sweet potato flour are sources of resistant starch and carob, soy, buckwheat, and sweet potato contain antioxidants that have been related to numerous health benefits in humans. Established the different proximate composition of those flours, Hager et al.[41] compared the nutritional quality of commercial gluten free flours made from teff, sorghum, maize, quinoa, buckwheat, oat and rice, showing that maize and rice flour are poor regarding their nutritional value (low protein, fibre, folate contents), whereas teff and pseudocereals like quinoa and buckwheat based flours presented favorable fatty acid composition and are high in protein and folate. Quinoa and teff gluten free based blends had the additional benefit of having high fiber and mineral (calcium, magnesium and iron) content.

Table 2. Nutritional composition of different gluten free breads reported in the scientific literature.

Reference	Raw material	Chemical composition (g/100g, dm)				
		Protein	Fat	Minerals (Ash)	Fibers	Total carbohydrate
	Wheat flour	9.00-13.00	1.00-1.05	0.5	0.40-1.20	
	Corn flour	6.90-13.00	4	1.00-1.40	3.00-4.00	65.00-80.00
	Rice flour	6.14-7.30	0.45-2.44	0.40-0.60	0.70-0.80	68.00-90.00
Vitali et al.[40]	Carob	5.38	0.56		43.45	
	Soy flour	41.47	24.19		26.07	10.45
	Amaranth	12	6.28		17.08	55.83
	Red quinoa	14.32	6.39		18.26	83.38
	Buckwheat	11.6	2.25		23.42	57.5
	Orange sweet potato	12.25	1.1		21.89	
	Red sweet potato	7.79	0.53		19.8	
Hager et al.[41]	Oat	6.91	6.74	0.82	4.05	
	Quinoa	13.48	8.59	2.43	7.14	
	Buckwheat	12.19	4.21	1.65	2.18	
	Sorghum	4.68	3.50	0.97	4.51	
	Teff	12.84	4.39	2.15	4.54	
Rai et al.[42]	Sorghum flour	13.34	4.56	2.51	2.62	79.59
	Pearl millet	13.11	5.13	1.76	1.37	80.00

Particularly, pseudocereal flours such as buckwheat[41,44-48], amaranth[49], and quinoa[41,50] have been used in several formulations. Pseudocereals like amaranth, quinoa and buckwheat have been used as healthy ingredients for improving the nutritional quality of gluten-free breads, leading to high levels of protein, fat, fiber and minerals[51]. In order to have a better picture about the nutritional quality of the numerous bread formulations proposed in the scientific literature a comparison table is included Table 1.

Cabrera-Chavez et al.[52] obtained a significant increase in protein, fat, minerals and dietary fiber content when rice based pasta was enriched with amaranth flour (Table 3). Gluten free cookies made with blends of the following alternate flours, rice, maize, sorghum and pearl millet had higher nutritional value than the ones obtained with wheat[42].

Table 3. Nutritional composition of other gluten free products reported in the scientific literature.

Reference	GF products	Raw materials	Chemical composition (g/100g, dm)					
			Protein	Fat	Ash	Fiber	Available carbohydrate	Total carbohydrates (*)
Gularte et al.[53]	Layer cake (control)	Rice flour	6.2	13.0	1.7	1.51	54.3	nr
	Layer cake+ fiber	Rice flour+ oat fiber+ guar gum	5.4	13.5	1.7	7.90	48.1	nr
	Layer cake+ fiber	Rice flour + oat fiber+ inulin	5.5	13.6	1.8	7.90	48.0	nr
	Layer cake+ fiber	Rice flour + oat fiber	5.5	13.2	1.8	8.60	47.6	nr
	Layer cake+ fiber	Rice flour + inulin	5.4	12.8	1.4	2.50	54.5	nr
Gularte et al.[54]	Layer cake + chickpea	Rice flour+ chickpea flour	9.3	14.3	2.2	1.4	45.6	
	Layer cake + pea	Rice flour+ pea flour	8.7	13.7	2.0	2.3	46.2	
	Layer cake + lentil	Rice flour+ lentil flour	9.1	13.8	2.0	2.8	46.0	

Reference	GF products	Raw materials	Chemical composition (g/100g, dm)					
			Protein	Fat	Ash	Fiber	Available carbohydrate	Total carbohydrates (*)
	Layer cake + bean	Rice flour+ bean flour	9.4	13.5	2.2	2.5	45.5	
Cabrera-Chávez et al.[52]	Pasta (control)	Rice flour, amataranth flour	12.9	2.9	1.3	5.5	nr	82.9
	Pasta (flour treatment)	Rice flour, amataranth flour	12.9	3.0	1.3	5.9	nr	82.7
	Pasta (flour treatment)	Rice flour, amataranth flour	12.6	2.9	1.3	5.9	nr	83.1
	Pasta	Rice flour	10.7	0.4	0.9	3.2	nr	87.9
	Pasta	Rice flour	10.0	0.4	1.0	3.0	nr	88.7

dm: dry matter; nr: not reported.
(*)Total Carbohydrate (d.m) by difference: 100 – (weight in grams [protein + fat + ash] in 100 g of food) (FAO, 2003).

Amaranth has been used for producing other convenience gluten free foods like snack bars[55]. Those bars have been also enriched with fructans like inulin and oligofructose for being considered prebiotic ingredients. Amaranth based bars had very good acceptance besides the nutritional advantages of caloric reduction and higher levels of dietary fiber as compared to commercial cereal bars.

Lee et al.[56] set up an alternative gluten free dietary pattern that replaced grains and starches in a 'standard' gluten-free dietary pattern defined from a retrospective review of diet history records of celiac patients. The proposed alternative diet contained oats, high fiber gluten-free bread and quinoa and by that way a significant increase in the protein content, iron, calcium and fiber, besides the B vitamin content (riboflavin, niacin and folate).

Other raw materials such as sorghum flour[41,57-59], carob germ flour[60], chestnut flour[61,62], tigernut flour[63] and teff flour[41,57] have also been used as innovative gluten-free raw materials; and generally, gluten-free breads of good quality have been obtained when optimized breadmaking recipe. The nutritional quality of flour made from pseudocereals or teff is better than that of wheat flour, but their breadmaking properties and sensory characteristic compromise their suitability for the production of gluten-free bread somewhat.

Gambus et al.[64] tested the nutritional effect of flaxseed (also known as linseed) meal, amaranth and/or buckwheat on the quality of gluten free confectionery products obtaining an increase in the protein content, although considering the amino acid composition amaranth would be the elected commodity. Those flours also gave gluten free products with higher dietary fiber and in the case of linseed meal also an enhancement in the alpha-linolenic acid. Besides the effect on the macronutrients content, products contained more microelements (potassium, phosphorus, magnesium, calcium, iron, manganese, zinc and copper). Gluten free rolls were also prepared containing 10% of ground flaxseed without affecting the technological quality of the rolls, but they significantly increased the content of proteins, fat (including alpha-linolenic acid), mineral compounds, dietary fiber and phytates[65].

Gluten-free cakes made of maize starch and rice flour (1:1) of acceptable sensory quality have been obtained when replaced by 30% debittered lupin flour with the additional benefit that lupin increases the protein, calcium, iron, manganese, phosphorus and zinc contents of the cakes[66]. Other alternative for making healthy gluten free products is the use of green banana, sub-product of low commercial value and little industrial use, which has been revealed as an innovative raw material with many benefits to the food industry and consumers who are on a gluten-free diet[67]. When gluten free pasta was made with green banana flour the resulting product was greatly accepted by CD consumers and this type of pasta had 98% less lipids[68]. In addition, some by-products from the agri-industry have been also used as nutrients sources. For instance cassava generates high volume of waste like cassava hull, which after being dehydrated and milled has been incorporated in the formulation of gluten free cakes replacing rice flour[69]. A progressive increasing amount of substitution up to 100% increased the contents of ash (3.1 to 4.8 g/100g), lipids (8.6 to 16.7 g/100g) and total (4.1 to 19.3 g/100g) and insoluble dietary fibers (3.5 to 17.3 g/100g). Even acceptable sensory cakes were obtained with 100% cassava peel flour.

Next to the use of new raw materials, protein enrichment has gained interest and with that aim soy protein isolates and also legume flours or legume protein isolates have been incorporated (Marco & Rosell, 2008a, b; Matos & Rosell, 2012b; Ziobro et. al., 2013a; Storck et al., 2013). Generally, the enrichment of gluten free bread in proteins leads to a decrease in both the specific volume and the crumb softness, but despite the detrimental effect on the instrumental quality parameters the nutritional impact was readily evident. For instance, gluten free cakes, when enriched with legume flours (rice flour/legume flour, 50:50) like chickpea, pea, lentil and bean increased their protein content in 30% (Table 3), and in less extension the fat, minerals and dietary fiber content, with except in the case of chickpeas[38].

Gluten free cracker snacks made of pulse fractions (chickpea, green and red lentil, yellow pea, pinto and navy bean flours and pea protein, starch and fiber isolates) giving similar physical characteristics and consumer acceptance to marketed products[70]. Interestingly, the nutritional composition of the crackers was also similar to the commercial cracker with the exception of the % daily values per serving of iron in the chickpea crackers that were 3-6 times higher.

Also protein enrichment has been carried out with proteins from animal sources, like dairy or eggs proteins. Krupa-Kozak et al.[36] tested the effect of different low-lactose dairy proteins (12%) on the quality of gluten free breads (Table 1). Those authors obtained gluten-free breads rich in proteins, and, regarding the energy value delivered by proteins, they could be considered as a source of proteins or high in proteins, because they provided around 15% of the energy. Considering the European Parliament regulation on nutrition and health claims made on foods, a claim that a food is a source of protein may only be applied to food product where at least 12% of the energy value of the food is provided by protein, thus those breads could be labeled as source of proteins.

In addition, gluten free foodstuff has not been immune to the new trends in baked products pertaining fiber enrichment. According to the American Dietetic Association the recommended fiber intakes for adults range from 25 to 30 g/day and the ratio of insoluble dietary fiber and soluble dietary fiber should be 3[71]. Physiological effects of soluble and insoluble fibers are different, while insoluble dietary fiber health benefits are related to intestinal regulation and water absorption, soluble dietary fiber benefits are associated with cholesterol lowering and improved diabetic control and to moderate postprandial glycaemic responses. Matos et al.[31] reported that the fiber content of commercial gluten free breads ranged from 1.30 to 7.20 g/100g, which indicates the great variability in nutritional composition of those products. Cereal fibers from wheat, maize, oat and barley have been used for enriching gluten-free bread formulation based on maize starch, rice flour and hydroxypropylmethylcellulose (HPMC)[72]. Adding those fibers at 3, 6 and 9 g/100 g level led to breads with higher fiber content. At the 9 g/100 g level of inclusion breads contained 7g/100 g dietary fiber, thus they can be labeled as rich in fiber, but acceptance decreased significantly due to their powdery taste. Even different fractions of rice bran, especially those with greater proportion of soluble dietary fiber, have been supplemented up to 10% to gluten free breads improving the quality, particularly darker color of crust, higher specific volume and softer crumb firmness was obtained[35] (Table 1). Similarly, gluten free layer cakes have been enriched with soluble and insoluble fibers like inulin and oat fiber, respectively (Table 3)[53]. Fibers significantly affected the *in vitro* hydrolysis of starch fractions, being the most pronounced effect the decrease in the slowly digestible starch. Overall, combination of oat fiber–inulin resulted in better gluten-free cakes.

Pre-gelatinized flour made from cassava starch and cassava bagasse (70:30), cassava starch and amaranth flour have been blended in a proportion 10:60:30 respectively, to obtain fiber enriched gluten-free pasta containing 9.37 g/100 g dietary fiber[73].

Fiber sources such as rice bran (Phimolsiripol et al., 2012) and inulin (Krupa-Kozak et al., 2012; Phimolsiripol et al., 2013), have been considered in gluten-free breads development with the consequent improvement in the nutritional quality. Very recently, Psillium gum and sugar beet fibers have been added to gluten free breads (Cappa et al., 2013), and water adsorption must be adapted due to the fibers water binding ability. Those fibers improved the workability of the doughs, but mainly Psillium thanks to its film forming ability contributed to bread development and had more effective anti-staling result.

Nevertheless, although numerous scientific studies have reported the alternatives for improving nutritionally the gluten free products, industry has not really incorporated that new knowledge into marketed products. In fact, do Nascimento et al.[74] analyzed the labels of 324 products including gluten free products and their gluten containing counterparts. They confirmed the short variety of gluten free products, and that raw materials used were reduced to five types of flours: rice, cassava, maize, soy, and potato; but the presence of pseudocereals, suggested in scientific literature, was not evident.

5.2. Enrichment of Gluten Free Products with Minerals and Vitamins

The level of micronutrients in gluten free breads has been also a point of attention. Suliburska et al.[75] determined the content and release of minerals (Ca, Mg, Fe, Zn and Cu) from selected gluten-free products (bread, biscuits, pasta, maize porridge and peas puff) of the Poland market (Table 4). Results showed that the content of minerals varied considerably among the types of products, and it was relatively low. Among the analyzed products bread was characterized by a high content of calcium and zinc, and relative high content of magnesium. However, bread showed the lowest content of iron and copper. Moreover, the potential bioavailability of minerals from gluten-free products was in the range 10-70%, and it depended on the element and the composition of the analyzed product. Authors concluded that it should be consider the enrichment of gluten-free products in minerals.

Table 4. Content of minerals in gluten free food products formulations reported in the scientific literature.

Reference	GF products	Main raw material used	Content of minerals (mg/100g, md)				
			Ca	Mg	Fe	Zn	Cu
Krupa-Kozak et al.[76] (*)	GF Bread (control)	Maize starch, potato starch; inulin	15	nr	nr	nr	nr
	Calcium carbonate	Maize starch, potato starch; inulin + calcium carbonate	1.085	nr	nr	nr	nr
	Calcium chloride	Maize starch, potato starch; inulin + calcium chloride	1.052	nr	nr	nr	nr
	Calcium citrate	Maize starch, potato starch; inulin + calcium citrate	1.088	nr	nr	nr	nr
	Calcium lactate	Maize starch, potato starch; inulin + calcium lactate	1.121	nr	nr	nr	nr
Cabrera-Chávez et al.[52]	Pasta (control)	Rice flour, amaranth flour	29.6	nr	7.5	7.1	
	Pasta (flour treatment)	Rice flour, amaranth flour	29.9	nr	7.6	7.3	
	Pasta (flour treatment)	Rice flour, amaranth flour	28.8	nr	7.6	7.2	
	Pasta	Rice flour	3.6	nr	1.6	0.7	
	Pasta	Rice flour	3.6	nr	1.7	0.7	
Suliburska et al.[75] (*)	Bread	Maize starch	44.62	31.40	1.14	2.46	0.07
	Pasta	Maize starch, pea protein isolate	18.96	19.70	2.66	1.75	0.41
	Corn porridge	Maize porridge	3.43	33.10	1.29	1.63	0.09
	Peas puff	Maize starch, g-f wheat starch, egg	45.8	13.61	1.85	6.37	0.18
	Biscuits	Maize starch, potato starch, g-f wheat starch	25.70	15.73	1.40	0.83	0.08

dm: dry matter; nr: not reported.
(*) selected commercial gluten-free products.

In fact, that point has been addressed in several researches dealing with the supplementation of vitamins and minerals in gluten free breads. Kiskini et al.[77] studied the feasibility of produced gluten-free bread fortified with iron using selected iron compounds. The most acceptable products were those fortified with ferric pyrophosphate, which showed satisfactory sensory and nutritional characteristics. Buckwheat flour incorporation (10-40%) is also a way to enrich gluten free breads especially in copper and manganese[78]. A more recent research carried out by Krupa-Kozak et al.[76] was focused on the fortification of gluten-free bread containing inulin, with different organic and non-organic calcium sources (Table 4). All experimental breads were significantly richer in calcium compared to the control, confirming the fortification. Additionally, sensory evaluation of the calcium-fortified breads confirmed that calcium carbonate was the most recommended salt for obtaining calcium fortification of gluten-free breads.

It must be stressed that even folate enrichment should be strongly considered after being concluded in different studies that celiac patients adhering to gluten-free diet show low folate intake and suboptimal folate and vitamin B12, possibly due to low folate content in gluten-free products[79].

Good glycemic control is particularly important in celiac disease, as there appears to be a higher incidence of type I diabetes among CD patients[80]. However, limited studies have been focused on assessing the glycemic index (GI) of the gluten-free products[31,80,81]. Overall, pseudocereals such as quinoa and amaranth have shown some hypoglycaemic effects, and have been recommended as an alternative to traditional ingredients in the formulation of cereal-based gluten-free products with low GI[80] 2004; Alvarez-Jubete et al., 2010a). Contrarily, starch-based gluten-free breads have shown estimated glycaemic index values between 83.3 and 96.1, thus this type of breads could be considered as food with high glycaemic index[31]. Therefore, it is necessary to choose suitable materials when formulating gluten-free products to reduce their GI. For instance, fresh egg pasta when made of oat or teff decreased significantly the GI compared to that of wheat pasta, showing similar sensory properties, although taste of pasta made with teff required some additional improvement[82].

The inclusion of prebiotic inulin-type fructans has been reported as one alternative for decreasing the glycaemic index of gluten free breads, even one-third of these fructans is lost during baking[83]. The addition of 12% of these fructans give breads enriched with 8% dietary fiber (4 g of fructans per

50 g bread serving size), and with a glycaemic index and glycaemic load of 48 and 8, respectively, in front of 71 GI and 12 glycaemic load obtained in the absence of this prebiotic. Similarly, dietary fiber supplementation to gluten free layer cakes affected the *in vitro* hydrolysis of starch fractions (related to glycaemic index), inducing mainly a decrease in the slowly digestible starch[53].

Besides the recipes modification for controlling the glycaemic index, other researchers propose to control the raw materials particle size or in the case of the gluten free cereals to control the varieties[84]. In the case of rice flour, particle size heterogeneity is responsible of different pattern in starch enzymatic hydrolysis, and also this effect is grain type dependent. Flour from long grain rice undergoes lower enzymatic hydrolysis[84]. Even breadmaking process can effectively modulate the starch digestibility of the baked rice based gluten free breads[85]. Coarse rice flour united to low hydration during mixing was the most suitable combination to limit starch gelatinization and hindered the *in vitro* starch digestibility[85].

5.3. Other Alternatives for Nutritionally Improving Gluten Free Foods

Additionally to different ingredients and additives, an interesting way to improve the nutritional quality of gluten free foods is to use sourdoughs. This is an ancient practice in breadmaking of wheat based products, where sourdough has been used to help fermentation and also to improve texture, palatability, aroma, nutritional properties and shelf life. Sourdough fermentation promotes mainly acidification and proteolysis releasing multiple microbial metabolites, which are responsible of the bread quality improvement. Nevertheless, this practice is lately being extended to gluten free products because besides the before mentioned benefits, sourdoughs are natural products that can also increase the nutritional value. It is widely known the role of sourdough in acidification, production of exopolysaccharides, and activation of enzymes like proteases, amylases and phytases, as well as the production of antimicrobial substances like propionate. Other reported benefits include a decrease of the glycaemic response, increase the bioavailability of dietary fiber and phytochemicals, and the production of nutritionally active compounds, such as peptides and amino acid derivatives and potentially prebiotic exo-polysaccharides[86,87]. However, scarce information exists about the use of sourdough in gluten free baked goods[88]. Microbial fermentation by means of lactic acid bacteria and yeast is one of the most ecological/economical methods for improving the quality of gluten free foods with health-promoting characteristics[89].

Some attempts have been carried out with pseudocereals fermentation to obtain nutritionally improved gluten free products. For instance, quinoa fermentation in slurry was possible using Lactobacillus plantarum CRL 778, yielding greater lactic acid production than in wheat[90]. This type of fermentation stimulated flour protein hydrolysis by endogenous proteases, which proceeded faster in quinoa than in wheat (reaching 40-100 % in quinoa at 8 h of incubation vs only 0-20% in wheat). Protein hydrolysis was parallel to peptides and amino acids release, besides the synthesis of greater concentrations of the antifungal compounds (phenyllactic and hydroxyphenyllactic acids) synthesized from phenylalanine and tyrosine[90].

Also pseudocereals, although good sources of vitamins, minerals, fiber, can be improved nutritionally by germination. Those germinated seeds can be added for fortifying gluten free foods[91]. Germination of amaranth, buckwheat, maize, millet, rice, sorghum, and quinoa can reduce their anti-nutrients content. Their use to naturally fortify and enrich gluten-free foods has great potential. For instance, oat and quinoa malts (obtained after germination) were incorporated in rice and potato based gluten free bread obtaining better crumb due to the amylase activity, and protein hydrolysis[92].

A relatively new current is the detoxification of dietary gluten in those cereals containing gluten by enzymatic cleavage of gliadin fragment with the action of prolyl endopeptidases (PEPs) from different organisms, which can be used to produce gluten free foods from gluten containing cereals or they can be ingested as oral therapy[93]. In addition, the degradation of toxic peptides can be made by germinating cereal enzymes and by transamidation of cereal flours[94]. These treatments may lead to flours with baking and nutritional qualities of toxic cereals. Microbial transglutaminase modifies selectively the glutamine residues of gluten by transamidation with lysine methyl ester or crosslinking gluten peptide chains that can be removed by filtration leading to gluten detoxification[93].

Wheat flour digestion by fungal proteases and selected sourdough lactobacilli has been reported as an alternative to obtain safe foods for celiac patients[86]. The combination of sourdough lactic acid bacteria fermentation and fungal proteases has been applied in the manufacture of experimental gluten-free pasta by Curiel et al.[95]. Those authors formulated the gluten free pasta with pre-gelatinized rice flour: wheat flour (1:1), optimizing the protocol for hydrolyzing completely the wheat flour. Detoxified wheat flour led to pasta with better sensory properties, digestibility, and nutritional quality.

A study carried on in a mouse model to test the antigenicity of a germinated rye sourdough with extensive prolamin hydrolysis. The quantitation of gluten using competitive R5 ELISA confirmed extensive degradation of the gluten R5 epitope but hydrolysis of secalins in germinated rye sourdough remains incomplete, although this open new alternative for CD with diverse grade of intolerance[96].

6. Conclusion

Medical nutrition therapy is crucial for the dietary management of CD individuals. However, numerous studies have stated that although gluten removal is the solely effective measurement for ameliorating CD symptoms, nutritional deficiencies presents previously to diagnose are not completely mitigated and some others might appeared after long-term gluten free diet compliance.

On the other side, gluten free products are made of complex combinations of ingredients, which significantly differed from gluten containing foods in consequence, their composition is rather diverse. Therefore, the gluten free diet compliance might result in CD individuals with nutritional unbalance.

Overall, current marketed gluten free foods, although meet consumer's expectation regarding quality and availability, often their composition does not completely meet dietary requirements of CD consumers, which drives to reconsider the formulation of gluten free foods having in mind the target consumers and even their age range.

Currently, research is moving fast to answer CD individuals' needs and numerous gluten free foods are yearly launched. Strategies like cereal breeding, design of balanced and enriched formulations, food processing and gluten detoxification are among the most interesting alternatives. Extensive research has been carried out in CD and gluten free food technology but still there is no a near date for having high quality gluten free food products nutritionally equivalent to gluten containing products.

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