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Celiac disease: Overview and considerations for development of gluten-free foods

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Abstract

Celiac disease is a genetically-determined chronic inflammatory intestinal disease induced by gluten in wheat, barley, rye etc. Celiac disease affects approximately one percent of people in the world and strict gluten-free diet (GFD) for a lifetime is the only available treatment. As gluten-free products available in the market are known to have low nutritional quality as well as are more expensive than gluten-containing food products, there is a strong need to develop gluten-free products that are nutritionally complete as well as economical. This review focuses on the special considerations during developing gluten-free products viz., finding an alternate non-gluten source, ensuring nutrition and sensory quality characteristics, compliance with the regulatory guidelines, economics and product.

Keywords: Celiac disease; Gluten; Gluten-free diet; Functional foods; Sensory properties

1. Introduction

A rapid change in the dietary lifestyle has been observed since few years along with urbanization, globalization and economic development leading to increase in the number of people suffering from poor health, which is reflected by increased incidence of diseases such as obesity, diabetes, cardiovascular disease, stroke, hypertension, and some types of cancer [1]. Recently a rapid increase in consumer awareness and interest about the health-enhancing roles of specific foods or physiologically active food components has been observed [2]. Beside satisfying of hunger and providing the nutrients for humans, food should also prevent nutrition-related diseases and improve physical and mental well-being of the consumers [3,4]. This has led to the development of new concepts in the area of food and nutrition such as the development of health foods. There is no specific definition for health foods but generally used for all the foods that provide health benefit beyond nutrition. Health food is thus, used as an umbrella term encompassing functional foods, nutraceuticals, designer foods, along with all natural foods, organic foods, whole foods and sometimes even dietary supplements [5].

Health food plays an important role in health improvement in celiac disease in which the only treatment includes nutritional therapy [6]. As in this disease, people are allergic to gluten (a protein found in grains like wheat, rye, barley and oats) and thus require avoiding all such type of foods [7]. Therefore, specific considerations are important when designing such health food products. Various factors should be kept in mind such as health problems, current demand, cost and acceptability. The design of health foods should focus on the special age groups such as elders, youths and infants. Therefore, an attempt has been made to review all the considerations which play an important role in the development of health foods for celiac patients.

Celiac disease occurs in 1% of the population in Europe and the United States, induced by an environmental precipitant, gluten in genetically susceptible person [8]. It develops in genetically predisposed subjects as a consequence of abnor-

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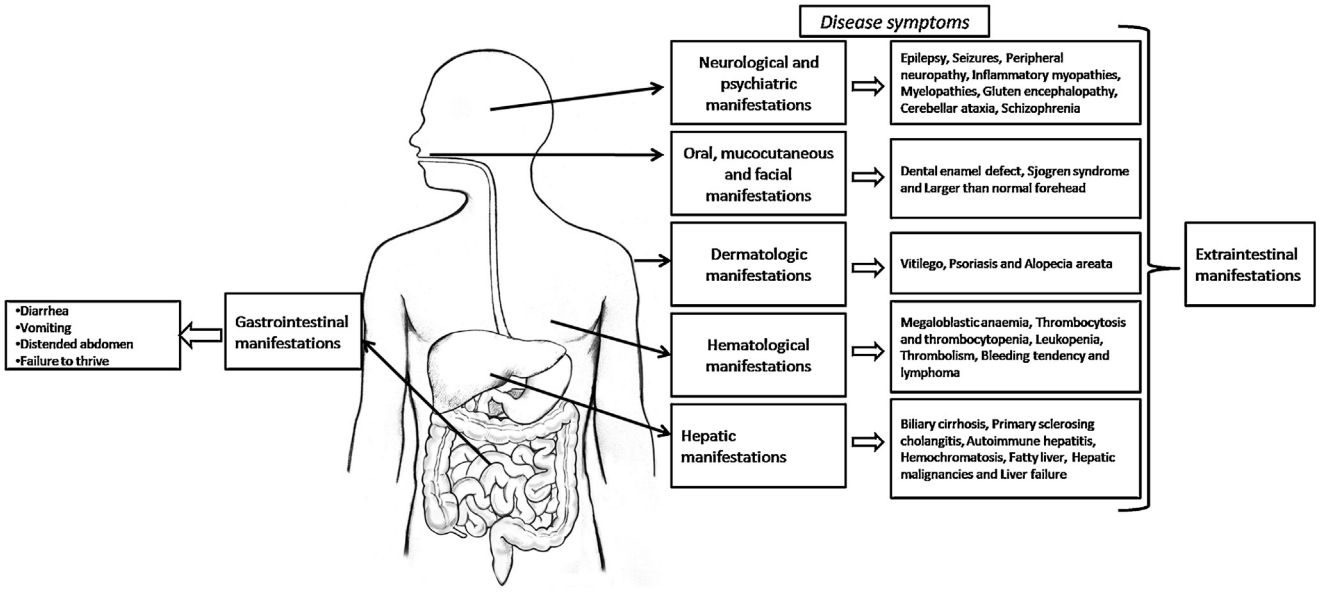

Fig. 1. Manifestations of celiac disease.

mal response of body's immune system to wheat gluten and related prolamines of rye and barley [9], resulting in inflammation and damage to the lining of the small intestine and reduced absorption of nutrients such as iron, calcium, vitamins A, D, E, K and folate [10]. Gluten, certain genes and immune system are the main factors causing this disease [11] and resulting in gastrointestinal and extra intestinal symptoms in the patients (Fig. 1).

2. Importance of developing gluten-free products

Till date the only treatment of people suffering from celiac disease is to follow a gluten-free diet [6]. Complete avoidance of gluten enables the intestine to heal, and the nutritional deficiencies and other symptoms to resolve [12]. A strict adherence to gluten-free diet also reduces the risk of developing many of the serious long-term complications related to untreated celiac disease [10]. However, following a gluten-free diet might sound simple but it is not easy, as it not only involves eliminating gluten-containing grains and all products that contain them, which requires constant vigilance, but there is also a sense of social isolation and pressure that accompanies the process [13]. Since most of the breads, biscuits, pasta, cakes, cookies, breakfast cereals, bagels, soups are made of wheat, avoidance of all these indicates a complete change in life style which might not be feasible for all. Due to all these reasons, the demand for gluten-free products is now on rise.

3. Specific considerations in the development of gluten-free products for celiac patients

Preparation of gluten-free products is a big challenge to the manufacturers with the main challenge of finding suitable alternatives for gluten [14]. The main protein fractions of gluten; glutenin, and gliadin, play a key role in baking quality characteristics, being responsible for water absorption capacity, cohesivity, viscosity, and elasticity of dough [15]. Hence, gluten removal results in major problems especially for bakers in terms of quality [14]. Apart from this, other challenges faced by the developers are safety of the product, its acceptability and affordability and being in line with the guidelines approved by FDA (Food and Drug Administration).

So, keeping all these points in mind, several considerations needs to be followed by the manufacturers when developing any gluten-free products (Fig. 2) and are reviewed here.

3.1. Avoidance of gluten-containing sources

The first consideration in the preparation of gluten-free product includes the exclusion of any food or food ingredient that contains gluten, as celiac disease is triggered by the ingestion of gluten or its protein fraction i.e. glaidin in wheat, horedins in barley, secalins in rye and avenins in oats [7]. Among these, according to European regulations oats have been included in the

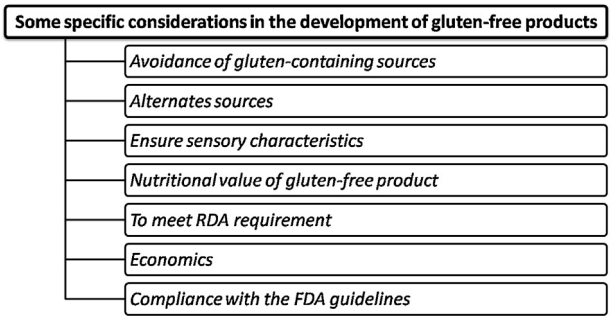

Fig. 2. Some specific considerations in the development of gluten-free products.

Table 1
Gluten content in different cereals.

Food grains	Total protein content (g/100 g)[a]	Glutenin (Glu) + Gliadin (Gln) content of total protein (mol %)[b]
Wheat	11.3	31.1
Rye	9.4	23.6
Barley	11.1	24.8
Oats	10.8	19.5
Rice	7.7	15.4
Millet	10.5	17.1
Corn	8.8	17.7

[a] Adapted from: Souci et al. [18]; Belitz et al. [19].
[b] Adapted from: Wieser et al. [20].

list of gluten-free ingredients; however their safety when consumed by celiac patients remains debatable [16]. Therefore, it would be wise to avoid oats for development of product. In case of wheat, all of its forms such as wheat starch, wheat bran, wheat germ, durum, emmer, einkorn, faro, farina, gliadin, semolina, spelt, matzo, cracked wheat and graham flour must be avoided [17]. List of gluten-containing cereals along with their gluten content are listed in Table 1.

3.2. Alternate sources

Avoidance of gluten-containing cereals includes the exclusion of major food sources which are one of the major protein sources in the diet. The protein content in wheat is 10%–12% and eliminating wheat from diet completely for celiac patient would mean the exclusion of a very good protein source from the diet. Therefore, the protein content of the alternate source has to be considered. Some of the gluten-free and high protein containing cereals, pseudocereals, minor cereals in comparison to wheat, which can be used as gluten-free flour are listed in Table 2. Apart from these, other gluten-free sources that can be used for developing food products for celiac patients include nuts (almonds, hazelnuts, walnut, chestnut, cashew nut), seeds (flax seeds, chia seeds, pumpkin seeds) and tubers (arrowroot, tapioca, jicama, taro, potato etc.) [24].

Till date various researchers have made numerous attempts to design and develop gluten-free food for celiac patients using some of the cereals, pulses and nuts as tabulated in Table 3 .

3.3. Ensure sensory characteristics

Gluten is the main structure-forming protein in flour and is responsible for the elastic characteristics of dough and contributes to the desired appearance and crumb structure of many products especially the baked ones [14]. So, one of the main challenge during development of gluten-free product is to ensuring that the product has desired texture as well as mouth feel as the gluten-containing product. Technical difficulties such as dry, rough and crumbly texture of gluten-free bread as well as gluten-free pasta, have been described by many authors [39–42]. Ahlborn et al. [42] also reported that gluten-free bread has a high staling tendency as compared to the gluten-containing one. A proper substitute of gluten is thus required to ensure desired texture, mouth feel and colour of the product. Rotsch [43] reported that bread dough without gluten can only retain gas if another gel like substance replaces gluten. Various studies have been conducted to improve the textural qualities of gluten-free products

Table 2
Average value based on dry matter basis of some grains that can be used as alternate flour source for preparing gluten-free products.

Cereals		Protein (g/100 g)	Fat (g/100 g)	CHO (g/100 g)	Crude fiber (g/100 g)	Dietary fiber (g/100 g)	Minerals (g/100 g)
Cereals	Rice	7.70	2.20	73.70	1.63	2.20	1.20
	Corn	8.80	3.80	65	ND	2.20	1.30
	Sorghum	10.40	1.90	72.60	1.60	9.80	1.60
Minor cereals	Teff	9.60	2.00	73	3.00	ND	2.90
	Pearl millet	14.80	4.86	59.80	12.19	ND	1.64
	Proso millet	11.58	4.90	80.10	0.70	ND	ND
	Finger millet	8.20	1.80	83.30	3.50	ND	2.70
	Kodo millet	9.80	3.60	66.60	5.20	37	3.30
	Jungle rice	5.2	ND	ND	34.8	ND	12.4
	Job's tear	6.70	2.50	85.90	ND	15.10	ND
Pseudo cereals	Buckwheat	12.50	2.10	75.74	0.70	29.50	1.42
	Quinoa	16.50	5.20	69	2.30	14.20	2.70
	Amaranth	16.50	5.70	70.30	3.90	20.60	3.25
Other cereals		23.70	7.90	60.93	ND	7.30	2.30
Legumes	Chickpea	23.64	6.48	64.60	3.82	18-22	ND
	Lentil	22.7	0.70	20	ND	14.6	ND
	Soyabean	36	19	35	7.5	17	5
	Carob germ	6.30	1.99	75.92	7.30	ND	ND
	Pea	21.3	0.60	14	ND	18.4	5
	Wheat	10.5	0.9	71	ND	2.8-12.1	ND

Adapted from: Moreno et al. [7]; Alajaji et al. [21]; Arab et al. [22]; Tosh et al. [23].
ND: Not determined.

Table 3
Gluten-free product development using alternate flours.

Gluten-free product developed	Alternate flour used	References
Tarhana	• Rice and corn flours	[25]
	• Rice and buckwheat flour	[26]
Cookies	• Quinoa and deffated Chiean hazelnuts	[27]
	• Quinoa flakes and flour	[28]
	• Shorgum flour	[29]
	• Rice-maize-pearl millet-sorghum flour blend	[30]
	• Coconut	[12]
Bread and cookies	• Raw and popped amaranth flour	[31]
	• Rice and corn flour	[32]
	• Corn starch, cassava starch, sodium caseinate	[33]
Pasta	• Sorghum-rice-corn flour mixture	[34]
	• Rice and white seeded low phytic acid and lectin free bean	[35]
Tagliatelle	• Teff flour and bean flour	[36]
Cake	• Lupin and buckwheat flour	[37]
Spaghetti	• Plantain-chickpea-maize • flour	[38]

Table 4
Components used for enhancing the texture in gluten-free products.

Gluten-free product	Ingredient used	Remarks	Reference
Bread	Rice starch (3%–9%)	• Less yellow crumb appearance • Reduced crumb hardness • Reduced rate of staling	[47]
	Guar gum Locust bean gum	• Crumb structure with even cell size distribution • Increased bread height • Retarded staling	[48]
Rice flour bread with added con and cassava starch	Soy flour (0.5%)	• Enhanced crumb characteristics	[41]
Rice flour bread with added potato starch	Fish surimi (10% of the starch weight)	• Softer crumb and crust • Higher loaf volume	[49]
Rice flour corn flour bread	Gum Arabic (3%) Methylcellulose (2%–4%) Egg albumin	• Comparable to wheat bread • rapid staling	[44]
Flat bread/biscuits cassava, pumpkin powder	Extruted soy protein (2.5%, 5%, 7.5%, 10%)	• hardness and cohesiveness increased with increasing ESP concentration	[50]
Coconut cookies	Guar gum	• Texture less harder than of control	[12]

using gluten alternate components such as starch, plant proteins [41], animal proteins [44], hydrocolloids such as gums, pectins, hydroxymethylcellulose [45], xanthan gums [46] etc. as listed in Table 4 .

3.4. Nutritional value of gluten-free product

Studies have shown that patient following a strict gluten-free diet often suffer from various nutrient deficiencies. Hallert et al. [51] reported signs of vitamin deficiency in celiac patients adhering to gluten-free diet. Ciacci et al. [52] showed that adults with celiac disease following a strict gluten-free diet have significantly lower weight, body mass index, fat and lean body mass than control subjects. It was further reported that the diet of these patients was unbalanced and had a higher percentage of calories from fat and less from carbohydrates. The authors attributed the inadequacy of the gluten-free diet to dietary habits and food products. Strict adherence to a gluten-free diet also reduces the fiber consumption in celiac patients [53,54]. Since gluten-free cereal foods are made using refined gluten-free flour or starch not enriched or fortified, so they are found to be rich in carbohydrates and fats only [7]. Also, mechanical and sensory challenges have to be solved in preparing such products, since dough without gluten has a weak structure, is technologically hard to work and often has a low mouth feel [55]. To ensure the good sensory properties, a large number of flours and starches as well as

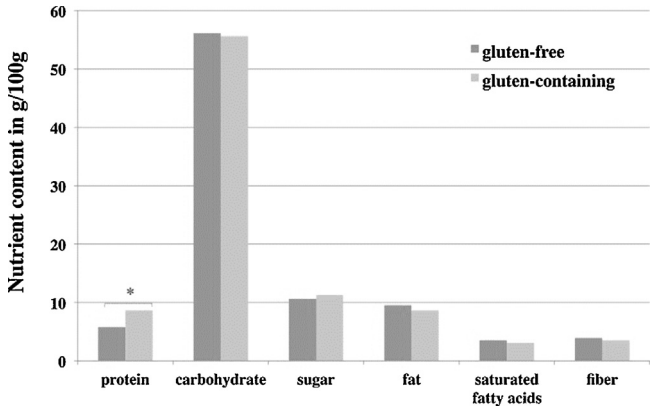

Fig. 3. Nutrient content in g/100 g between gluten-containing and gluten-free foods across seven categories in 12 different Austrian supermarkets [68].

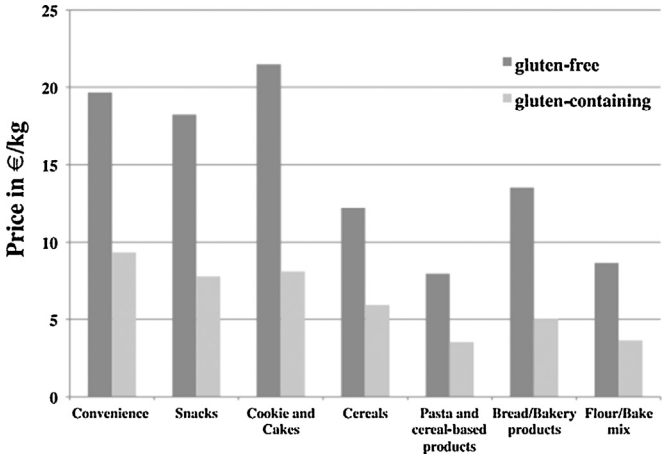

Fig. 4. Comparison between the price of gluten-containing and gluten-free products in 12 different Austrian supermarkets [68].

many ingredients (enzymes, proteins, hydrocolloids) are used to mimic the viscoelastic properties of gluten, improve the structural acceptability of gluten-free products [56] and enhance the nutritional composition of gluten-free foods [55].

A gluten-free product should not just be gluten-free but must be comparable with gluten-containing products in nutritional profile. Various researchers have attempted to develop gluten-free products with enhanced nutritional profile as shown in Table 5.

3.5. To meet recommended dietary allowances (RDA) requirement

RDA is defined as "the average daily dietary nutrient intake level sufficient to meet the nutrient requirement of nearly 97%–98% healthy individuals in a particular life age" [63]. Indian Council of Medical Research (ICMR) has provided the RDA for different nutrients for each age group of Indian population. Fulfilling the RDA helps to provide necessary nutrients to the body and helps to prevent adult-diet related chronic diseases, such as cardiovascular disease, cancer and osteoporosis [64]. It has been seen that gluten-free dietary therapy has often low content of vitamins and ions, such as vitamins B and D, calcium, iron, zinc, and magnesium, as well as fiber [51,65,66] which suggests that the RDA for individual nutrients is not being met. Miranda et al. [67] compared the nutritional composition of the 206 gluten-free rendered products which is mostly consumed in Spain, against the 289 equivalent gluten-containing food products and pointed out the differences in calorie, macronutrient, fiber, sodium, salt and cholesterol content between gluten-free and gluten-containing foodstuffs. They further reported that gluten-free products could cause a nutritional imbalance for celiac patients as well as for non-celiacs who follow a diet that includes many gluten-free rendered foodstuffs. A recent study conducted by Missbach et al. [68] in an Austrian supermarket showed that the gluten-free product was substantially lower in important nutrient like proteins but relatively higher in total fat and saturated fat as compared to its gluten-containing counterparts (Fig. 3). Thus, an important requirement when developing a gluten-free product is to ensure that while developing a gluten-free product, nutritional profile of the product should not be reduced to such a level which may affect RDA of the person.

3.6. Economics

Various studies and market surveys have shown that adherence to a gluten-free diet adds a lifelong economic burden to the patients, especially because the gluten-free products available in the market have prices much higher as compared to the non-gluten-free products [69–71] as well as have limited availability in the market [72]. In a comparative study of the price of gluten free and gluten containing food products conducted in Chile, an 89% increase in feeding cost of celiac patient was observed [71], whereas, in another study conducted in Atlantic Canada, it was observed that gluten-free products were 242% more expensive than regular products [70]. Nascimento et al. [73] evaluated the availability, prices, and nutritional composition of gluten-free products in retail stores of a Brazilian capital city and reported that availability and variety of gluten-free products was limited and prices were high. Missbach et al. [68] conducted a study in Austrian supermarket and showed that some of the gluten-free products were substantially low in important nutrients like proteins as compared to their gluten-containing counterparts, but their price was still higher than the later (Fig. 4). A recent study conducted by Lambert and Ficken [74] in Australia to determine the cost and affordability of a gluten-free healthy food basket for four reference families, reported that gluten-free healthy food basket was significantly more expensive as compared to a gluten-containing healthy food basket for all family types under study.

However, to avoid any economic burden on the patients, the cost of any gluten-free food product being developed must be considered.

3.7. Compliance with the FDA guidelines

It is very important to comply with the standards and regulations set by various national and international bodies, when developing products targeting celiac patients. The Codex

Table 5
Incorporation of various nutrient rich components to enhance the nutritional value of gluten-free products.

Product prepared	Ingredients	Remarks on the nutritional quality (in comparison to control)	References
Biscuits	• Jerusalem • Artichoke flour • Corn flour	• Increase in protein, fiber, ash and minerals (Fe, Ca, Mg) with increase in the jeruselam artichoke concentration	[57]
	• Whole meal amaranthus flour	• Increased protein content (5.7%)	[58]
Bread	• Amaranth flour (as replacement for corn starch	• Increased protein and fiber content by 32% and 152% upon 10% replacement	[59]
	• Tartary buckwheat • Chia seed flour	• Increased α-linoleic acid content (12 times higher) • Increased antioxidant property (75% higher)	[60]
	• Rice flour • Potato starch (Supplementation with 10% fish surimi)	• Increased protein content • Enhanced texture (soft crumbs and crust)	[49]
	• Wheat starch supplementation with 8% inulin	• Increase in dietary fiber from 1.4% to 7.5%.	[14]
Cakes/biscuits	• Linseed meal • Amaranth • Buckwheat	• Increased protein • Increased fiber • Increased alfa linoleic acid (in incorporation of linseed meal)	[61]
	• Lupin • Buckwheat	• Increased protein, calcium, iron, manganese, phosphorus and zinc contents (for lupin) • Increased Pottassium and magnesium content (for buckwheat)	[37]
Cookies	• Rice • Maize • Sorghum • Pearl millet	• Increased fat, protein ash and calorific value for cookies from pearl millet and Sorghum flour	[30]
	• Coconut powder	• Increased protein, fiber, ash, fat, calorific value and decreased carbohydrate content.	[12]
Crackers	• Hemp seed flour • Decaffinated green tea leaves	• Increased fiber (39%–249%) • Lower carbohydrate (8.4%–42.3%) • Increased antioxidant property	[62]
Flat bread/biscuits	• Cassava • Extruded soy protein(ESP) • Pumpkin powder	• Increased protein, fiber, ash,fat content with increased ESP content • Increased β-carotene in the samples	[50]

Standard for gluten-free foods was adopted by the Codex Alimentarius Commission (CODEX) of the World Health Organization (WHO) and by the Food and Agricultural Organization (FAO) in 1976 [14,75,76]. The standards were revised in 1981 and again in 2000 which has described the gluten-free products as "gluten-free foods", which can be described as:

(a) Consisting of, or made only from ingredients which do not contain any prolamins from wheat or all Triticum species such as spelt, kamut or durum wheat, rye, barley, oats or their crossbred varieties with a gluten level not exceeding 20 ppm [14,75,76].
(b) Consisting of ingredients from wheat, rye, barley, oats, spelt or their crossbred varieties, which have been rendered gluten-free; with a gluten level not exceeding 200 ppm [14,75,76].
(c) Any mixture of two ingredients as in (a) and (b) mentioned with a level not exceeding 200 ppm [14,75,76].

In August 2013, the U.S. Food and Drug Administration (FDA) issued a regulation that defined the term "gluten-free" for food labelling. According to FDA Gluten-free foods may be labelled in a variety of ways:

- "Gluten-free"

- "Free of gluten"
- "No gluten"
- "Without gluten"

Labelling plays a key role in allowing consumers to make informed choices about foods with enhanced health attributes [77] and in case of celiac disease it helps to assure them that the product they are consuming is safe.

4. Conclusion

Celiac disease affects approximately 1% of the world and is significantly increasing due to the underestimation as the condition is often left undiagnosed. The only treatment for people with celiac problem is adherence to gluten-free foods for life time. However, sticking to gluten-free diet for life time can lead to nutritional imbalance in patients. This is because avoidance of gluten-containing foods from the diet means eliminating the major protein sources from the diet and sticking to a high carbohydrate diet. Therefore, there is an important need to develop gluten-free products that are highly nutritious and at the same time economical. However, several points have to be kept in mind and accordingly considerations have to be made before developing products for celiac patients. Some of the considerations include exclusion of all possible gluten-containing raw materials, selection of an alternate flour source, acceptable texture and colour of the product, enhancement of nutritional quality of the product, product safety and labelling. These considerations will help in developing nutritionally complete safe gluten-free health foods for people with celiac disease.

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