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Celiac Disease Management through Gluten-Free Diets

Babatunde Olawoye, Oseni Kadiri,

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Abstract

In recent times, there had been an increase in the consumption of food products made from cereals other than wheat flour. This is partly due to the surge or rise in wheat importation thereby led to a high foreign exchange spending for countries with comparative disadvantage in the cultivation and production of wheat grain. Aside from this, there had been a major concern on the health challenges emanating as a result of the consumption of food made from wheat flour. This health challenge is called celiac disease; an immune-mediated disease arising from the inability of the consumer to ingest gluten-containing products. This book chapter intends to write on the management of celiac disease using gluten-free diets.

Keywords: immune-mediated disorder, gluten-free diets, celiac disease: human leukocyte antigen

1. Introduction

In the last decade, there had been a rapid change in the dietary lifestyle among the world populace owing to increased globalization, urbanization and rapid economic development [1]. The rapid changes had also resulted in a large number of people suffering from poor health conditions due to the food they consume. Owing to this, there had been an increase in people's awareness about the role in which foods play in the emergence of these diseases [2–4]. One of such diseases resulting from food consumption is celiac disease (CD). Celiac disease, an autoimmune disorder, triggers when a genetically pre-disposed person or individual is exposed to dietary gluten resulting in the inflammation or damage of the lining of the small intestine. Celiac disease had become a global health challenge in which its prevalence is approximately 1% of the total world population with variation among regions, age, and sex [5]. However, there had been an increase in the prevalence of celiac disease in the US; a reason which was unclear but attributed to environmental component of celiac disease such as changes in the pattern of feeding, quality of ingested gluten, the spectrum of gastrointestinal infestation as well as the colonization of the gut microbiota. Symptoms associated with individuals suffering from celiac disease include retardation of growth, malnutrition, anemia, diarrhea as well as fatigue [6]. Currently, the only proven remedy for the treatment of celiac disease is the strict elimination of gluten from diets.

Generally, gluten is the term used to describe the alcohol-soluble fraction of storage protein in grain wheat which made up of most diet in western countries [7]. The storage proteins include prolamins (glutenin and gliadins) found in

wheat grain, secalin found in rye, hordeins found in barley and avenins found in oats. These storage proteins had been found to contain glutamine and proline residues which are resistant to digestion in the gastrointestinal tract and encourage the deamination by tissue trans-glutaminase [8]. These proteins when ingested by a genetically susceptible person caused a toxic effect on the gastrointestinal mucosa. The proteins activate the response by cellular immune leading to the injury of the intestinal mucosa which ranges from villous atrophy to infiltration of the lymphocytes. Villous atrophy in human leukocyte antigen (HLA) pre-disposed patient resulted in malabsorption of micro and macronutrients such as fat-soluble vitamins (A, D, E, K), folate, B complex vitamin (Niacin, riboflavin and thiamine), calcium, and iron. To revolve the menace, individuals suffering from a celiac disease needs to strictly adhere to gluten-free diets.

Gluten-free (GF) diets/foods are defined by the U.S. Food and Drug Administration as a food completely devoid of gluten or does not contain a gluten-containing grain (wheat, barley, oat and rye), flours made from gluten-containing grain in which the gluten had been removed or not removed (wheat flour or starch) and finally, if any of the above-mentioned products contain at least 20 ppm of gluten in food [9]. However, the Commission Regulation of European Union defines a gluten-free diet as a foodstuff that contains a gluten level not exceeding 20 ppm for people who are intolerance to gluten. It was further regulated that food not exceeding 100 ppm in gluten content should be tagged as very low gluten. There is a wide range of palatable and attractive gluten-free diets specifically manufactured for individuals suffering from celiac disease and this include but not limited to GFD baked products, beverage drinks, wines, beers, sourdough etc. [10, 11]. These products are cereal-based food and had gained wide visibility in North and South America, Europe, North Africa and some part of Asia. Gluten-free products' marketability is estimated to increase in value from US\$ 4.18 billion in 2017 to US\$ 6.47 billion by 2023 in which gluten-free bread and cookie are estimated to be the most consumed cereal-based GF-food globally [9]. During the production of food products made from gluten, gluten present in the food products is responsible for the elasticity, extensivity and texture resistant if the dough [2, 12]. However, to improve the quality (texture and specific volume) of gluten-free diet/products, hydrocolloids such as hydroxypropylmethylcellulose, xanthan gum, pectin, carboxymethylcellulose are commonly used to improve the baking quality, imparting texture and appearance as well as stability in the gluten-free dough.

2. Nutritional properties of gluten-free diet

Though gluten-free products are ideal for consumption by patients living with the celiac disease, it is however low in protein due to the utilization of flour and starches with higher starch to protein content. When flours from pulses are blended with gluten-free cereals, it results in a meal with the complementary amino acid profiles and likewise provides high-quality proteins for bakery purposes. Certain species of pseudocereals have been reported to have significant nutritional constituents such as micronutrients, polyphenols, proteins, and dietary fibers when compared with flour produced from cereals [13]. Significant higher mineral content has been reported in gluten-free foods produced from quinoa, millet, oat, amaranth, and buckwheat when compared with those made from rice, maize, and potato starch [13].

Some method which had been reported to improve nutritional values and bioavailability of gluten-free bakery goods includes malting and sprouting as these processes help in activating enzymes responsible for the starch, proteins, and lipids

breakdown [14, 15]. It has been suggested that gluten-free bakery products should be incorporated with pulses and pseudocereals rather than the use of starches and gluten-free cereals only.

2.1 Sensory properties of gluten-free diet

A major challenge in the production of gluten-free bakery products is in achieving sensory attributes that are desirable and acceptable by consumers. Gluten-free bakery products are known for their distinct color, texture, appearance, taste, and aroma when compared to those made from wheat flour. Due to complex formulation, gluten-free bakery products tend to appear darker. Regarding wheat products, gluten-free bakery products have lower volumes and harder textures. The acceptability of some gluten-free bakery products has been reported to improve in terms of texture when some proteins were added. In a study by Matos *et al.* [16], gluten-free muffins were more acceptable by consumers when soy protein isolate was incorporated. In a related study, the acceptability of millet muffins improved in terms of texture when chicken protein isolate and transglutaminase were combined [17]. Future research should focus on how enzymes, proteins, hydrocolloids, and other ingredients can improve the sensory acceptability of gluten-free bakery and pasta products.

2.2 Gluten-free products/diets used in managing celiac disease

A very good way of managing celiac disease in immune-mediated patients is the total exclusion of gluten from their diet and diet substitution using gluten-free products. The underlisted products are gluten-free products commonly used in the treatment and management of celiac disease.

2.2.1 GF-dough/sourdough

GF-dough is a thick, malleable mixture of flour (usually cereal - wheat, barley, and rye) and liquid (water) used in the production of bakery products void of gluten. Total removal of gluten from these products enhance safety consumption for celiac disease patients. However, this comes with several difficulties such as poor dough rheological properties, reduced nutritional qualities, off flavor, poor mouth-feel/taste, and more expensive GF-baked product compared with conventional gluten baked products [18–20].

In research for remedy, food products have been developed from GF-dough made from GF-flour (such as rice, sorghum, buckwheat, amaranth, quinoa, and maize) [19, 21], dairy products [22], dietary fibers [3, 23], and starches [2–4]. Advantages of these alternatives are low glycemic index, antihypertensive, and antihyperlipidemia [2–4].

Recently, researches have also focused on the production of food products from sourdough rather than from gluten flour [24–26]. Sourdough is described as a product of a biotechnological process that involves the mixture of flour (cereal) and water, fermented by lactic acid bacteria thereby causing a pleasant sour-tasting dough/product [27]. Sourdough is used to produce several varieties of baked products such as bread, biscuits (crackers) and cakes. Before production, sourdough is characterized by increase dough leavening which promotes GF-end product attractiveness, improved texture and palatability, increase mineral bioavailability, slow down the rate of starch digestion (low glycemic index), antihypertensive potential and extended shelf-life GF-products [19, 26, 28]. Sourdough applications also include the production of novel bioactive compounds which can be used as pre-bioactive starter cultures [28–30].

2.2.2 GF-baked products

Understanding the functionality of gluten is very important in the baking process of convectional product made from wheat. This gives an insight into the most suitable ingredients that can be considered as gluten replacement. Gluten-free bread has been produced from several types of gluten-free flour such as pseudocereals (e.g., Buckwheat, quinoa, amaranth) [31, 32], cereals (e.g., sorghum, maize, rice) [33, 34], and potato flour [35]. A gluten substitute in bread-making is hydrocolloid. Some commonly reported hydrocolloids include; hydroxypropylmethylcellulose [36]; xanthan gum [32], carboxymethylcellulose, and apple pectic [35]. The application of buckwheat in the production of gluten-free bakery products such as noodle, pasta, cookie, and bread has been reviewed by Giménez-Bastida *et al.* [37]. The sensory acceptability and present technological limitations of gluten-free pasta and bread were reviewed by Padalino *et al.* [4]. Strategies for enhancing the quality of gluten-free noodles, pasta, and bread were likewise reviewed by Collar [38], Elgeti *et al.* [39], and Naqash *et al.* [40]. Aside from the formulation of gluten-free baked products from cereals and pseudocereals, there had also been a report of the production of GF-baked products such as bread, pastries and cookies from starch isolated from root and tuber crops, banana, cereals and legumes [2–4, 12, 41].

2.2.3 Gluten-free noodles

A diet which is free of gluten is the most effective therapy for ailment such as celiac disease. Aside from its beneficial roles in patients with celiac disease, it also has some perceived health benefits such as the regulation weight loss regulation and prevention of gastrointestinal disease. The gluten-free industry was reported to experience a growth of 136% between 2013 and 2015 [42]. Aside from the conventional production of noodles from wheat, noodles are also produced from other uncommon sources such as starches derived from corn, cassava, potatoes, mung beans, and konjac. Grains of rice, oats, and buckwheat are other unconventional sources.

Several grain varieties were also used in the production of gluten-free noodles with good nutritional and health values. Gluten-free noodles are most suitable for consumption by patients with intolerance to gluten as found in patients with celiac disease. This type of noodles is mostly recommended for anyone who needs to avoid the health challenges posed by the consumption of gluten foods.

Noodles made from rice grains are the second most common products after cooked rice grains. Noodles are mostly produced from Indica rice variety and very common in Asia countries like the Philippines, Sri Lanka, Vietnam, Thailand, and Sri Lanka. Fu [43] classified rice noodles into instant, frozen, dried products of shapes and thickness of differing types. With an amylose content of over 22%, Indica rice is most suitable for noodles production. The starch properties determine the structural characteristics of rice noodles as its constituent protein does not play any role in the formation of a stable network structure [44].

Rice noodles are not prone to breaking apart when pan-fried. They also have an elastic and flexible texture when pan-fried. Majority of consumers preferred rice noodles which are boiled, pan-fried or soup with several ingredients as this noodle products have a smooth taste when eaten and improved eating qualities. Aside from its amylose which is viewed as a possible reason for its suitability in rice noodles production, the exact mechanism is not understood fully.

Oat grain is a herb plant grown annually. The consumer market for this plant is small. The two major types of oats are *Avena nuda* L. (naked oats) and *Avena sativa* L. (*Avena sativa*). *Avena nuda* L. is the most commonly cultivated oat in the

Gansu, Hebei, Jilin, and Inner Mongolia Provinces in China. Oats are highly nutritious, high-energy and low-sugar food. Oats are usually referred to as healthy foods because of their ability to regulate the metabolism of cholesterol, thereby impeding the onset of certain ailment such as cardiovascular disease, aside its other health benefits [45].

Buckwheat flour has protein content within the range of 7–13%, which is significantly higher than the values present in wheat and rice flour. Buckwheat flour is also rich in linoleic and oleic acid with a fat content of about 3%. Rutin, a bioactive compound with hypertensive and hypolipidemic effects, is present in buckwheat flour. Buckwheat noodles are majorly produced in northeast China, Korea, and Japan. Buckwheat noodles processing can be either slit buckwheat noodles or extruded buckwheat noodles. Just like in wheat noodles production, buckwheat noodles are also produced manually or mechanically. In studies by Alamprese et al. [46], pasta product was developed from a combination of eggs, rice flour, and buckwheat flour. This study demonstrates the potential of buckwheat use for noodles production without incorporating wheat flour which is gluten carrying constituent.

Cassava noodles, potato noodles, konjac noodles, corn noodles, mung bean noodles etc. are some other types of noodles product which are gluten-free. These noodles are rich in nutritional and functional values [47–51]. **Figure 1** shows the flowchart for noodle processing.

2.2.4 GF-beverage/functional drinks based on cereal

GF-beverage is another GF-product made from GF-cereals such as teff, millet, tigernut, acha, fonio, sorghum among others, consume for prevention/management of celiac disease. Some also play an additional role in the body beyond basic nutritional needs and served as functional drinks. Teff is GF-grain suitable for wheat/barley replacement in production of GF-beverage. Gebremariam et al. [52] reported on Ethiopia local functional drinks made from teff. It was observed that the GF-functional drink exhibits medicinal potential and is suitable for the management of malaria, anemia and diabetes. Badejo et al. [53] developed a GF-beverage from the combination of tigernut and acha varying the blending ratios at 25%. It was observed that the developed beverages contain an appreciable number of phenolic compounds such as gallic acid, rutin, quercetin, ellagic and caffeic acids which may be responsible for higher free radical scavenging abilities reported against DPPH* and ABTS*. Sharma et al. [54] developed prebiotic oligosaccharide rich GF-functional drink from sorghum. They highlighted that the GF-functional drink is suitable for celiac disease patient and contains high calories value, antioxidant capacity, and no changes in sensory properties compared with wheat/barley beverage. GF-beverage are relatively cheap and have extended shelf-life [55].

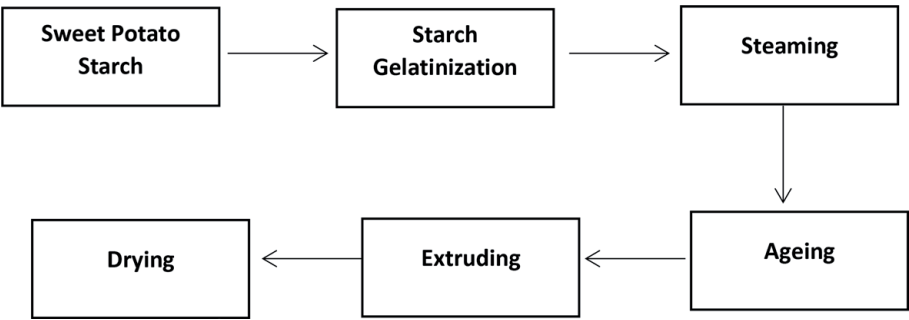


Figure 1.
Potato noodles processing flowchart.

2.2.5 Gluten-free beer

Beer is an alcoholic carbonated, and fermented beverage produced from malted cereal grain (such as wheat, barley, and rye). Consumption of beer is toxic to celiac patients and could result into this autoimmune disorder due to the presence of gliadin from wheat gluten, prolamines/hordeins from barley, and secalins from rye [19, 56]. Scientific research has shown that the successful long-term management of this autoimmune disorder is strict adherence to GF diets [57–59]. Hence, the needs for GF-beer. European Commission guidelines described GF-beer as pseudo-cereals/cereal malted beer devoid of gluten or beer technologically produced from brewing malt to reduced its gluten content to less than 20 mg/kg [60, 61]. However, controversy exists as US Food and Drug Administration (FDA) proclaim the latter product has the potential to exhibit celiac symptoms in some patients than the former [62, 63].

Pseudo-cereals malted beer produced from amaranth, buckwheat, and quinoa free of gluten is therefore recommended for celiac patient [56, 57, 64]. These malted beers contain adequate proteins and relatively high starch with sensory attributes slightly lower compared to beer produced from wheat and barley in respect to their taste, aroma, and mouthfeel when adequately mashed, fermented, and stabilized. However, the cost of technology to achieve the aforementioned may inflate the price of pseudo-cereal beer [56, 65].

Alternatively, GF-beer can also be produced from GF-cereal such as sorghum, rice, and maize with several brewing conditions been altered such as mashing, sparging, boiling, fermentation temperatures, and pH [66, 67]. This adjustment relatively increases their disparities compared with wheat and barley beer. Comparing GF-sorghum beer with barley beer, the former is rather too viscous, slightly sweetish, and a little bit sour due to the formation of lactic acid [68]. Ceppi and Brenna [69] observed that rice GF-beer were acceptable by consumers but had lower enzymatic activity than barley. Zweytik and Berghofer [68] also reported that GF-maize beer is light yellow with good foam stability, but was relatively poor in taste compared with barley beer. However, they tend to have higher demands by the consumers due to their cheap price [66].

3. Market feasibility of GF diets/foods

Owing to increase in patients suffering from celiac disease as well as gluten intolerance, there had been a rise in consumer demand for gluten-free products as a result of the increase in the number of diagnosis as well as consumers who are making a conscious choice or effort to exclude gluten from their diets. The demand had made gluten-free products one of the fastest-growing market opportunity within the consumer wellness and global health market. For a patient who requires a gluten-free diet, the products must be the same in terms of texture and appearance as conventional gluten-containing products. A market survey of gluten-free food in the United State of America (USA) reveals that the market stood at \$2.3 billion in 2019 and it's estimated to reach \$4.5 billion by 2027 according to Gorgitano and Sodano [70]. The United Kingdom (UK) gluten-free products, however, was estimated to be £426 million in 2018 and it's expected to grow by 40% by 2030. The estimated increase in gluten-free products in the US and UK was due to the facts that gluten-free products are alternative to conventional and traditional grain-based food products such as bakery, pastries, pasta-products which can be made alternatively from other cereals such as maize, sorghum, millet as well as rice [71]. Although the market of gluten-free products had surged higher than the products

for other medically diagnosed gluten-related diseases, however, the demand is lower in comparison with gluten-containing products. This had been attributed to the perception of gluten-free products by the consumers as poor or lower quality products with poor appearance, flavor, and texture [1]. However, due to the adherence to gluten-free diets by patients suffering from celiac or gluten intolerance disease, there had been an additional economic burden on the patients due to higher cost price of the products when compared to conventional non-gluten-free products found in the market. In addition to the high selling price of the gluten-free diets, there had been a problem of its availability in the market [72]. A general survey on the market price of gluten-free foods over gluten-containing food products revealed that the price of gluten-free products was 242% more expensive than conventional gluten-containing products. The price was, however, found to be 89% more expensive than its regular products in Chile. The evaluation of the market price, availability and the nutritional composition of gluten-free products by Bagolin do Nascimento et al. [72] at the capital city of Brazil revealed the limitation in the availability of the products in the market coupled with high selling price in comparison with conventional products. Concerning market size among the different segment of gluten-free products, it was reported that gluten-free cookies had more sales and brought in more money compared to gluten-free bread, a reason which could be attributed to the convenience and the quality of the cookie [73]. Other reason could be the importance of gluten in the functional properties of the bread compared to cookie. Gluten gives desirable quality such as the loaf texture and volume to the bread. To make gluten-free foods or products available and avoidable to the patients, the price of the develop GF-foods needs to be considered.

4. Conclusion

An approximately 1% of the people living in the world today suffers from celiac disease. However, there had been an uprise in the prevalence of the disease due to the underestimation of the disease as it is often left undiagnosed. The only proven remedy to the treatment and management of the disease is the exclusion of wheat or gluten-containing products from their diet and through adherence to gluten-free products/foods. One constrains being perceived by patient suffering from celiac disease is the nutritional imbalance of the diets as a result of the exclusion of gluten and other major gluten-related protein from their diets. Owing to this, it is important that when developing gluten-free diets for patients suffering from celiac disease, the GF-food should be of high nutritional composition, available, and avoidable economically.

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