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Formulation of Gluten-Free Baked Products for Coeliac Patients: A Review of Contemporary Methodologies and Quality Improving Factors

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Abstract: Coeliac disease (CD) is one of the common and under diagnosed food intolerance in the world. Recently, the only treatment of CD patients is complete evasion of food containing gluten, a wheat protein. This situation is increasing demand for gluten free foods. Food scientists are still trying their best to improve the quality of gluten free food products and formulate new food products with similar characteristics to the gluten containing foods. But, the quality of gluten free baked products is still not improved. Gluten is necessary for structure building of leavened baked products. Without gluten the baked products have low nutritional value, low volume, bad texture, bland flavor and lower shelf life. Hence, formulation of high quality gluten free baked products is technological task. This review focuses on most recent advances in research on gluten free baking which were designed to develop baked products with improving quality, high nutritional value and longer shelf life. However, widespread research is still needed by developing a nexus between food science, technology and nutrition to formulate gluten free baked products with good technological and nutritional properties and made more accessible to coeliac patients. This might be helpful for celiac patients to stick to gluten-free diet and improve the quality of their lives.

Key words: Gluten-free food · Food properties · Quality · Review

INTRODUCTION

Coeliac disease (CD) is a lifelong genetic disorder of small intestine. It is also known as “gluten intolerance”. Celiac patients when take ethanol soluble proteins like secalin (rye), hordein (barley) and specifically gliaden (wheat) it result in diarrhea, abdominal cramps and sickness. Till early 1990s celiac disease was considered as infrequent disorder because of lack of diagnostics facilities [1]. Latest epidemiological research studies have shown that celiac disease is one of the most common disorders [2]. Unfortunately, the only safe treatment of celiac disease is still gluten free diet. Gluten intake is so harmful for the CD patients that if gluten is reintroduced to their diet, disease relapse will occur [3]. It is difficult for the CD patients to maintain gluten free diet often due to unavailability of gluten free (GF) products widely and secondly GF foods usually have poor nutritional and organoleptic quality and are more expensive in comparison with gluten containing food products, especially bakery goods [4]. Furthermore, gluten free bakery products are usually formulated with rice or maize flours, which are low in fiber and protein. When CD patients consume food with low dietary fiber content, they suffer from constipation [5]. Recently, the main focus of food technologists is on development of GF bakery products with good nutritional quality and high fiber content to deal with the health problems. Gluten is essential for the proper structure of bakery products, especially yeast raised bakery products. Hence,

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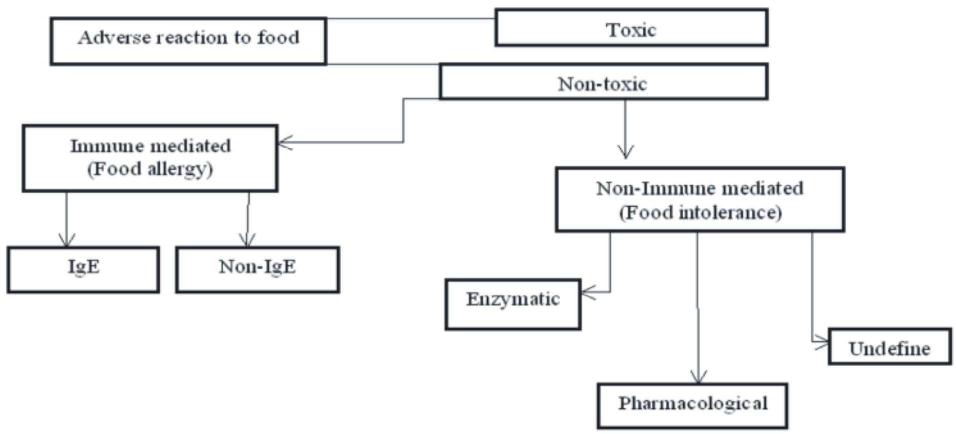

Fig. 1: Adversative reactions to food, redrawn from Ortolani *et al*. [7].

formulating high quality GF products is a challenge that needs the exploration of additives, ingredients and methods which may improve the baking performance and nutritional quality of gluten free flours. This review mainly focuses on current methodologies in gluten free baking which result in improved structure, texture, nutritive value and shelf life of GF products.

Coeliacdisease: Food Intolerance or Food Allergy: Coeliac disease and wheat sensitivity are two different conditions. Wheat (Triticum aestivum) has four types of proteins *viz.* gliadin, glutenin, globulin and albumin. Few people suffer from wheat allergy caused by albumin and globulin. This type of allergy is called wheat sensitivity and patients have an IgE-mediated response to these wheat proteins, however, wheat sensitivity is very uncommon [6]. Coeliac disease is caused by wheat gluten and also known as gluten-sensitive enteropathy. Coeliac disease is not IgE (immunoglobulin E)-mediated and hence not categorize as an allergy (Fig.1).

CD is triggered by a combination of three factors:

- Genetic tendency.
- Environmental factors i.e. lifestyle, eating habits etc.
- Immune based inflammation i.e. infection.

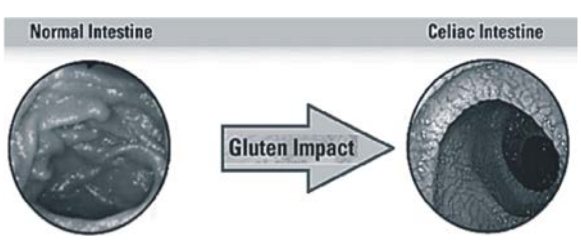

Fig. 2: Impact of gluten on the intestine of celiac patient.

The patients have harshly disrupted mucosal layer of small intestine (Fig. 2) with multiple symptoms *viz.* weight loss, diarrhea, abdominal cramps and tiredness. White *et al*. [8] stated that inflammation of small intestine adversely effects on the absorption of fat soluble vitamins and minerals (iron, magnesium, calcium and zinc). It is obligatory for coeliac disease patients to stick with gluten free diet supplemented with nutrients. In past, it was hard to detect CD and because of this reason many people died undiagnosed, but now emergence of new detecting techniques especially ELISA is very helpful in detection of coeliac disease [9].

Informing the Consumers: "The Codex Alimentarius"[10] in nexus with WHO and FAO redefined gluten free food as "A dietary food stuff made from one or more ingredients but which does not contain more than 20 ppm (20 mg / kg) in total gluten based on the food as sold or distributed to the consumer of ingredients from any member of the wheat (triticum) family, rye, barley or their cross breeds". In "Allergy Box" food processers are directed to mention gluten containing ingredients and their quantities.

Role of Gluten in Bakery: Gluten was first detected by a chemist called Beccari in 1728. It was defined as the "cohesive, visco-elastic proteinaceous material" which remains behind even after washing the wheat dough for the removal of water soluble compounds and starch [11]. Glutenhas the ability to entrap gas bubbles in wheat dough. The properties of gluten make it suitable for the production of food products especially baked. It is composed of gliaden and glutenin (namely prolamins), both of these frictions play an important role in dough

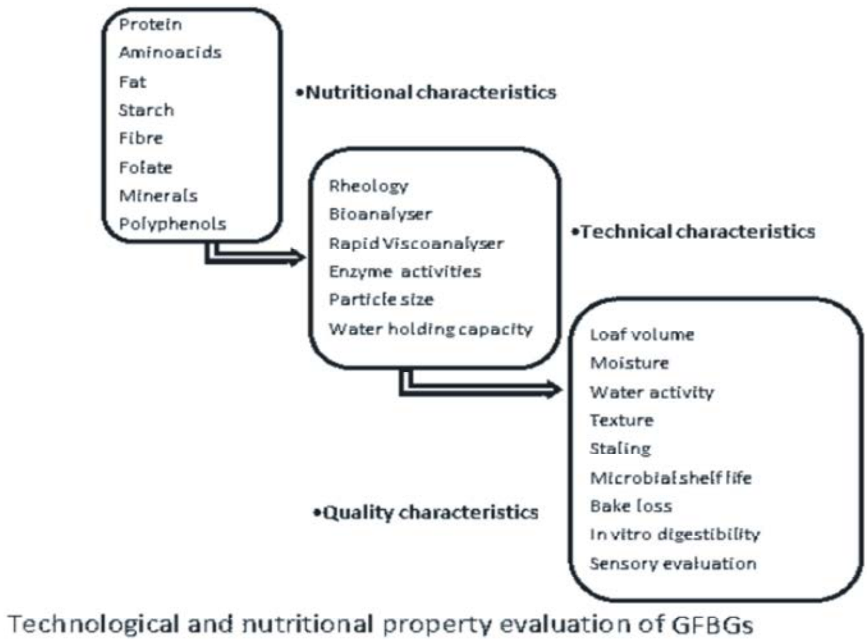

Fig. 3: Technological and nutritional property evaluation of GFBGs

elasticity and viscosity (Fig. 3) and give proper appearance and crumb structure to many yeast-raised leavened bakery goods. Glutemins, when are hydrated play a key role to elasticity and viscosity of dough. Gluten has the capability to form gas-encapsulating films, which helps the dough to extend properly and become softer, lighter and have good flavor. As gluten plays a key role in developing proper texture of dough it is very hard for bakers to remove it especially from breads and cakes [12].

Quality Evaluation Parameters of Gluten Free Baked Products: Gluten free baked products usually have high caloric value and glycemic index, hence development of healthy and balanced diet for coeliac patients is still a challenge. Numerous studies have been conducted to search for healthy flours and ingredients and to develop new generation of gluten free baked products. Quality of bakery products can be evaluated on the basis of nutritional, technical and quality parameters of final product (Fig. 3).

Gluten Free Flours: The choice of flours other than wheat to formulate gluten free bakery items relies on upon numerous components i.e. accessibility, nutritive value and the end product, but most important attribute among these all is consumer’s acceptability based on organoleptic characteristics of product. Different types of flours have different organoleptic attributes (Table 1), hence choice of flour is very important component to formulate an acceptable gluten free bakery product.

Table 1: Flavors and colors imparted to GFBGs by different types of flours.

Flour type	Flavor	Color
Buckwheat (Fagopyrum esculentum)	Strong	Medium brown
Chestnut (*Fagus* castanea)	Strong	Pale brown
Chickpea (Cicer arietinum)	Strong	Tang
Corn (*Zea mays*)	Mild	Yellow
Quiona (*Chenopodium quinoa*)	Mild	Beige
Rice (*Oryza sativa*)	Mild	Beige
Sorghum (*Sorghum bicolor*)	Mild	Beige
Amaranth (Amaranthus cruentus)	Mild	Pale yellow
Teff (*Eragrostis tef*)	Earthly	Medium brown
Tapioca (Manihot esculenta)	Mild	White

Source: Adapted from the Artisan Bread Machine, Judith Fertig (Robert Rose)

This part of review focuses specifically on the use of conventional flours along with exploring new ingredients and flours with good nutritional and baking qualities in the gluten free bakery, use of some of them is discussed below;

Benefits and Limitations of Different Gluten Free Flours: Various gluten free formulations were developed using different flours including rice, maize, potato, cassava etc. Type of flour used effects greatly on the quality of gluten free bakery products [13,14].

Rice (*Oryza sativa* L.) Flour: Fortification of rice flour in gluten free baking products makes it nutritional and healthy. It is liked by bakers because of its sweet taste, white color, digestibility and hypoallergenic properties. However, besides these benefits rice flour exhibits poor baking properties because proteins in rice are hydrophobic. They don't give the elasticity to dough, which is necessary to entrap CO_2 during baking and final product has lower specific volume and harder and denser structure. Hence additives like hydrocolloids, emulsifiers, enzymes and proteins are added to improve the functional, baking and organoleptic properties of rice based GF baked foods.

Maize (*Zea mays*) Flour: Flour derived from maize contains starch, protein, lipids, fiber and sugars. Maize based GF bakery products exhibit yellow color, firm crumb and are dense [15]. However, gluten free foods prepared from rice and maize have a high glycemic index and if are consumed daily they increases the threat of metabolic syndrome, diabetes, obesity and cardiovascular diseases in celiac patients.

Chickpea (*Cicer arientum* L) Flour: Chickpea flour is a good source of protein, carbohydrates, starch and dietary fiber. It is also a rich source of vitamins and minerals. It has good binding and water holding properties and hence it is used widely in GF yeast based leavened products [16]. Though, it gives poor texture to baked products.

Cheshtnut (*Fagus* castanea) Flour: Cheshtnut flour is considered as potential feasible flour in the formulation of gluten-free products. It is rich in vitamins E and B, iron, folate, essential fatty acids and dietary fiber [17].

Chia (*Salvia hispanica*) Flour: Chia flour is rich in essential fatty acids, protein and fiber [18] found that chia flour increased the stability of chia dough. They further elaborated that addition of guar gum and hydroxypropyl methylcellulose further improved the rheological characteristics of dough.

Tigernut (*Cyperus esculentus*) Flour: Tigernut (*Cyperus esculentus*) is a superb source of vitamins (vitamins E and C), fatty acids, minerals (phosphorus, potassium, iron and calcium and 22.3% dietary fiber. High fiber content of tigernut enhances the water holding capacity of dough. Tigernut contains high amounts of fat which have a plasticizing effect on the sensory and proofing attributes of dough, which may improve crumb structure and volume of bread. It is also concluded from various studies that starch properties are also affected by tigernut flour. The starch is not being completely hydrated because of the composition of tigernut. Hence, tigernut flour is liked in baking of gluten free products [19].

Lupin(*Lupinus albus* L.) Seed Flour: Lupin seed flour when debittered, is very rich source of protein, it contains about 38.71% protein. It also contains calcium and manganese [20]. They formulated GF cake with lupin seed flour which was debittered and compared its quality with buckwheat cake. They found that cakes developed with lupin flour had more protein, calcium and magnesium.

Recent Advancements in the Formulation of GFBP Ingredients to Improve the Quality of GFBGs: Wheat is a rich source of nutrients and GF bakery products lack all these beneficial components. Hence, coeliac patients consume died deficient in vitamins, iron, zinc, magnesium and fiber. Furthermore, these patients also face a major risk to develop obesity and metabolic syndrome. Therefore, these nutrients are added from different sources. Proteins are added from whey concentrate, soy flour, pea [21] oils from fish and flux seed [22] and dietary fibers from rice and wheat bran [23], minerals and vitamins from vegetable and fruit sources [24]. Cream powder and microencapsulated dairy powders improve the taste and flavor of GF baked foods [25] the effects of fortification of fruits and vegetable ingredients to GF bakery goods for example kiwi fruit puree [26], raisin extract [27], defatted blackcurrant and strawberry seeds [28], orange [29] and banana flour [30]. Moreira *et al*. [31] evaluated the effects of two types of shortenings; olive oil and sun flower oil as a dough improver of chestnut flour. It was observed that addition of these two shortenings decreased the water absorption, viscosity and storage module of dough and has health benefits.

CD patients are deficient in essential nutrients and suffer from different diseases, for example osteoporosis, it is a disorder which is associated with celiac disease. Food scientists are now trying to formulate GF food products fortified with calcium substitutes [32]. Iron is also not absorbed in CD patients, so they usually suffer from anemia. Unfortunately, the diets which they use are generally not fortified with iron. Few scientist worked on this issue, In GF bread Kiskini *et al*., [33] fortified and studied the effects of five sources of iron, viz. elemental iron, sodium iron EDTA, $FeSO_4$ ferric pyrophosphate and ferric pyrophosphate. They found that among all the treatments firm crumb texture and palatable taste was found for bread formulated with sodium iron EDTA and ferric pyrophosphate. To reduce the LDL-cholesterol and postprandial glycemic response γ–tocopherol is very helpful. Sedej *et al*., [34] developed buckwheat crackers fortified with flax and sesame seeds. They observed that because of these two ingredients γ –tocopherol increased to desirable levels.

In gluten free bakery industry starches, gums and hydrocolloids are frequently used to improve textural and baking qualities. Many researchers conducted studies to explore the magical role of starches, gums and hydrocolloids in improving the quality of GFBGs. It was found that, while using the starches, wheat starch should be avoided because it is documented that CD patients usually also have allergies towards wheat starch. Lohiniemi *et al*. [35] studied the properties of dough fortified with rice starch. They found that rice starch is low in sodium and is good source of carbohydrates, but several essential complex carbohydrates were missing. Moreira *et al*. [31] studied the effects of various hydrocollides on dough made up of chestnut flour. The hydrocollides used were; guar gum, CMC, hydroxypropyl methylcellulose (HPMC), agar gum and xanthan gum. Among all the hydrocollideshydroxypropyl methylcellulose gave the best results. They elaborated further that HPMC when added at a 1.5% reduced the pasting temperatures and increased the dough consistency. Kang *et al*., [36] investigated the effect of various gums originated from vegetables on the quality of gluten free bakery products. They choose HPMC, guar gum, xanthan gum, locust bean, agar and carageegan. They concluded that HPMC and xanthan gum gave satisfactory results. Demaite *et al*. [37] used cassava starch to develop GF biscuits and bread and obtained good results. Summary of flours and ingredients used in gluten free bakery products are showm in Fig. 4.

Water Addition: There is lack of studies evaluating the quality of gluten free bread produced by using mixture of different capacities. Moreover, there is no portrayal of the changes in the physical properties of bread brought on by an extensive quantity of included water. Gomez *et al.* [38] prepared gluten-free bread with different levels of water addition, supplemented with hydroxypropylmethylcellulose. Lazaridou *et al.* [39] studied the effect of combination of hydrocolloids with two levels of water on gluten free bread. Hager and Arendt [40] studied the influence of hydroxypropylmethylcellulose (HPMC), xanthan gum and

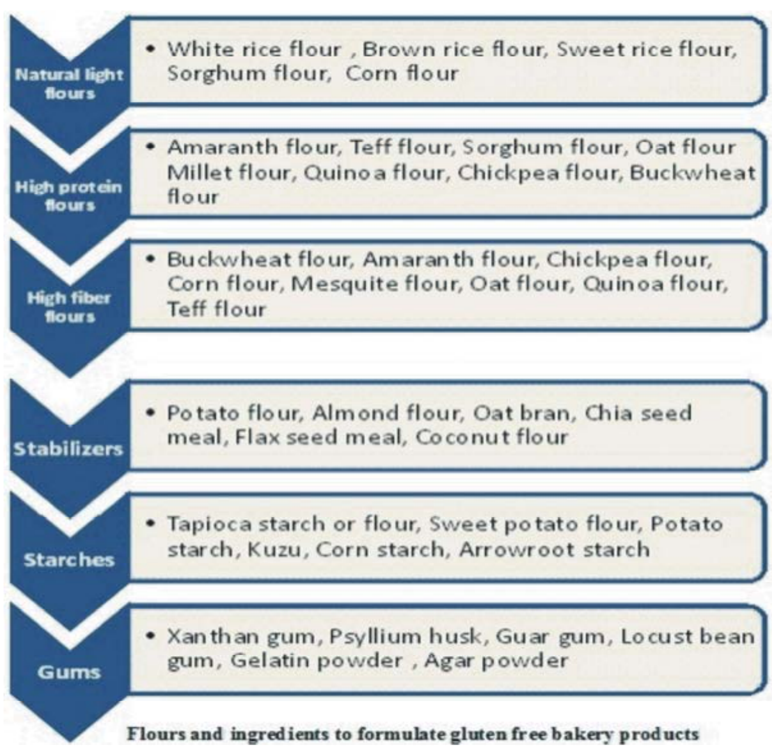

Fig. 4: Summery of flours and ingredients to formulate gluten free bakery products

their integration with water addition. It was found that gluten-free bread produced with 10% increase of water addition was found to be the best. De la Hera *et al.* [41] and Gomez *et al.* [38] evaluated the effect of two different levels of water addition to develop gluten-free bread supplemented with hydroxypropylmethylcellulose. Renata *et al*. [42] suggested for the first time a description of the changes in the physical properties of gluten-free bread produced with different amounts of water (80 to 120% of flour weight basis).With a water addition of 90%, these bread types maintained the best quality. Schoenlechner *et al.*, [43], studied bread made with amaranth flour, noticed that water amounts caused significant changes in bread volume. In the literature, there are no research studies which focus on the subjective changes of different sorts of gluten free bread affected by expanding levels of water expansion. It is clear from the literature reviewed that the changes in bread texture were greatly dependent on the type of the additive used [39].

Processing Conditions: It is found that many other factors also contribute to the texture and quality of gluten free baked products (GFBP), for example; size of particles of these flours influence greatly on the dough quality of GF foods, maize flour with granular particles are found to be the most suitable for making GF baked goods. De *et al*. [14] used maize of different particle sizes (<80 μm, 80 to 106 μm, 106 to 150 μm, 150 to 180 μm and >180 μm). It was found that the lower particle size developed poor structure and hence smaller volume of bread. Gomez *et al*. [38] studied the effects of proofing time, mixing speed and mixing attachment on chickpea flour dough. They found that longer mixing time had constructive effect on CO_2 production rate. They suggested that longer mixing time encourages greater oxygenation, which helps the reproduction of yeast under aerobic conditions and it also permits amylose to produce maltose. For yeast maltose is reserved food after the consumption of sucrose during the process of “proofing”.

Eradication of Gluten Immune Toxicity from Wheat Flour: To remove/reduce the “immune toxicity” gluten many studies have been conducted. Endopeptidase of bacterial source was used by Rizzello *et al*., [44] to degrade the gluten in wheat flour dough. By this process they completely eliminated those gluten peptides which are most lethal for coeliac patients. However, this treatment adversely affected the viscoelasticity of dough and hence it was concluded that detoxified wheat flour should be used in integration with other flours, emulsifiers or hydrocolloids. Gianfrani *et al*., [45] studied the effects of detoxification of wheat gluten by specific transdamidation of lethal epitopes via “tissue transglutaminase” of *Streptomyces mobaraensis.* They found that by using this method wheat dough did not lose its elasticity. Furthermore, this method was safe. The researchers are trying to find out more methods and ways to detoxify wheat gluten for coeliac patients but more specific research is needed.

Staling of Gluten Free Bakery Goods: GFBG have high amounts of starch which leads to swift staling rate and high economic losses. Different scientists suggested different solutions of this problem; Sciarini *et al*. [46] suggested that storing the partially baked GFBG if stored at low temperature it delayed staling. However, it decreased the quality of GFBG (crumb quality and volume). They found that if hydrocolloids are added this problem could be solved. Another well documented solution of this problem is “bioprocessing” or “sourdough fermentation method”. Basically, sourdough is blend of gluten free flour, water and other ingredients used in baked goods, fermented by LAB and yeast. Leavened baked products fermented with LAB exhibits good texture, flavor, nutritional value and shelf life [25].

Addition of Lactic Acid Bacteria: Addition of LAB is associated with various multifaceted metabolic activities including exopolysaccharides production, acidification, proteolytic, amylolytic/ phytase activity and production of bacteriosins [12]. Various LABacterial strains produce exopolysaccharides (which are sugar polymers) from sucrose during fermentation process. Exopolysaccharides act as hydrocollides and prebiotics [47, 48] developed GF sourdough with composite flour (buckwheat, amaranth, chickpea and quinoa flour) fermented by LAB. They found that LAB produced γ -aminobutyric acid. Calasso *et al*. [49] observed that LAB decreased pH which degenerate phytic acid (an antinutritional factor) and controls the microbial growth and increase the shelf life of product. It is also found that gluten free foods having sourdough have improved flavor [21]. Type of flour used, dough yield, cell count and sucrose concentration are the main fermentation factors. Ruhmkorf *et al*. 50] studied the effects of fermentation factors on the effectiveness of starter cultures used in sourdough of GFBGs. They concluded that it is vert important to select the starter culture which fits well with the flour type used. They found that *L. curvatus* would govern good results when incorporated with rice/buckwheat.

High Pressure Treatment: Huttner *et al*. [51] applied high pressure treatment to oat dough for 10 minutes at 200, 350 and 500 MPa he integrated the treated and untreated oat dough in different ratios; (10:90), (20:80), (40:60) in GF bread recipe. They observed that by adding 10% oat dough treated at 200 MPa improved the structure and appearance and increased the shelf life. However, high pressure treatment above 350 MPa decreased the quality of bread. All the previous studies concluded that high pressure treatment is very effective technology that improved the characteristics of GF bread and delayed staling. Still there is a need of conducting studies to evaluate the rate of high pressure treatment on different types of GF dough and flours in order to get required results regarding to structure, volume, consumer acceptability and shelf life.

Packaging: Gutierrez *et al*. [52] suggested that if modified atmospheric packaging (MAP) is used in integration with antimicrobial active packaging it deals divinely with the problem of staling. It is environment friendly and economical method [51]. Gutierrez *et al*. [52] studied the effects of active packaging and modified atmosphere packaging (60% CO_2 and 40% N_2) on the quality characteristics of GFBGs. They concluded that active packaging increased the shelf life of GF product by retarding the growth of microorganisms and also retained its organoleptic properties. Further studies are still required to search about each and every aspect of these technologies so that these methods could be used on commercial gluten free products.

CONCLUSIONS

Celiac disease is a typical deep rooted intestinal disorder which has no treatment with the exception of avoiding food which contains gluten. On the other hand, gluten is a noteworthy part of wheat, barley and rye and its complete substitution in bakery items remains a critical innovative errand because it imparts viscoelastic properties to dough. Furthermore, wheat flour contains important nutrients and fiber. The replacement of wheat flour from baked products and formulating high quality GFB products with fine texture and good organoleptic properties is still a key task for the food technologists. Gut of coeliac patients can't absorb nutrients and they also can't consume wheat flour, hence they usually suffer from different problems for example, nutrition deficiency, high glycemic index, obesity etc. Starches, gums and hydrocolloids are the most favorite ingredients which are being utilized to supplant gluten and maintaining the structure of gluten free bakery items. Novel systems including stronghold of fibers, other protein sources and added substances which enhance the gluten free bakery items wholesome quality are likewise encouraging. However, in spite of several research studies, it is still not become possible to provide coeliac patients with nutritious, healthy and palatable naturally gluten free food stuff with low price and easy availability. Further studies are needed to meet these challenges.

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