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Review: Gluten Related Disorders and Novel Approaches in Gluten-Free Pasta Making

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Abstract

A gluten-free (GF) diet is a must for a healthy lifestyle and it is very important for those who suffer from diseases related to eating gluten, whether autoimmune diseases that occur in genetically susceptible individuals by eating gluten from wheat, rye, barley, and other related grains or not autoimmune disease or caused by an allergy to wheat or wheat gluten in particular. The replacement of gluten presents a significant technological challenge, since the absence of gluten can lead to technological limitations in forming good quality of food structures and unformulating high-quality baked goods. The objective of this paper is to review some basics about the diseases associated with gluten, and the recent advances in the preparation of high-quality pasta and noodles using GF flours, additives and technologies.

Keywords: Gluten related disorders, gluten-free flours, Biofermintation, Enzyme technology, Transgenesis and pasta

1. Introduction

Food allergy is a growing health problem which emerged as the “second wave” of the allergy epidemic, lagging decades behind the ‘first wave’ of asthma, allergic rhinitis and inhalant sensitization. Wheat is one of the five most common foods that trigger allergic reactions in children (induced by gluten and other wheat components), wheat consumption is also related with a variety of diseases, including auto-immune responses and nonceliac wheat sensitivity (NCWS, also called non-coeliac gluten sensitivity, NCGS) and some wheat protein components were studied such as glutenins with low and high molecular weight (LMW-glutenins and HMW-glutenins); alpha, beta, gamma and delta gliadins, as well as non-specific lipid transport protein Tri-a14 for the diagnosis of wheat allergy (WA). However, none proved to have high specificity and sensitivity [40].

Gluten free foods have also become popular because of the media attention brought on websites, that suggest that elimination of gluten improves a variety of autoimmune conditions, helps in losing excess weight, and enhances a healthy lifestyle. This has led to the welcome of gluten-free products and the conduct of many researches looking for alternative sources of grains closely related to the disease and moved gluten-free (GF) foods from a small niche product into mainstream grocery stores and onto chain restaurant menus and a quest to improve the quality of the product, as poor-quality, expensive products were the norm [57].

Regular wheat pasta, traditionally made of durum wheat (Triticum durum) semolina, is one of the simplest wheat products in terms of ingredients, it is considered as most popular due to easy cooking, sensorial and nutritional attributes, affordable price, versatility as well as better storage stability, traditionally obtained after three main processing steps: water hydration of semolina and mixing to form crumbly dough, extrusion, and finally drying. Recent dietary trends and increasing consumers awareness towards free gluten nutritional foods has led researchers to incorporation of several different raw material, functional additives and using different technological approaches to improve GF pasta quality. Presently, gluten free products are being developed through the incorporation of rice, amaranth, maize, soya, taro, unripe banana, legumes, millets and brown rice etc.

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Moreno et al, (2014) [93] reported that cereals (rice, corn and sorghum), minor cereals (fonio, teff, millet and job's tears) or pseudo cereals (amaranth, buckwheat, quinoa) can be used for the formulation of gluten free pasta. *Sakre et al, (2016)* [128] has developed gluten free pasta using amaranth, oat and rice with better sensory attributes. The paper focuses on some basics about disease, techniques and alternative sources of closely related grains and gluten alternatives, and how to improve GF products.

Definition of gluten and its role in bakery products

Gluten is the main structural protein in wheat and other cereals (such as barley, rye and spelt) and is the viscoelastic protein that remains after washing dough with water or dilute salt solution to remove most of the starch and soluble material**,** this remaining material is called rubber and consists of about 75 – 80% protein on a dry matter basis depending on how well the material is washed, composed of alcohol-soluble gliadin and alcohol-insoluble glutenins, its components gliadins and glutenins create a 3D network when flours are mixed with water, giving dough elasticity and viscosity allow to impart a light and extensible texture to food making it highly favored in the food industry, the storage proteins of these cereals are in the endosperm and are classified as two major groups: the ethanol soluble fraction (termed prolamins) and ethanol insoluble (termed glutenins). Prolamins from wheat, rye, barley, and oats are termed gliadin, secalin, hordeins, and avenins respectively. Gliadins are single chained, extremely sticky when hydrated. They are rich in proline and glutamine and have a low level of charged amino acids. The amino acid compositions of glutenin are very similar to those of gliadins, with high levels of glutamine and proline and low levels of charged amino acids, modern wheat gluten arises from a hexaploid genome, making it heterogeneous and more genetically complex than the human genome [143, 147].

are restricted in distribution to the starchy endosperm cells of the grain, and have not been detected in any other tissues of the grain or plant, they are initially deposited in discrete protein bodies and fuse during the later stages of grain development to forma continuous matrix surrounding the starch granules (Figure 1A). This matrix forms a continuous protein network within the cell, which can be revealed when the starch is removed from a flour particle by enzyme digestion (Figure 1B) . Gluten proteins are not uniformly distributed in the starchy endosperm cells, but enriched in the outer 2 to 3 layers of cells (which are called the sub-aleurone cells). This is illustrated in Figure 1C, which shows a section of the starchy endosperm cells and outer layers from the lobe of the grain at a late stage of development stained with toluidine blue to show protein [134]**.**

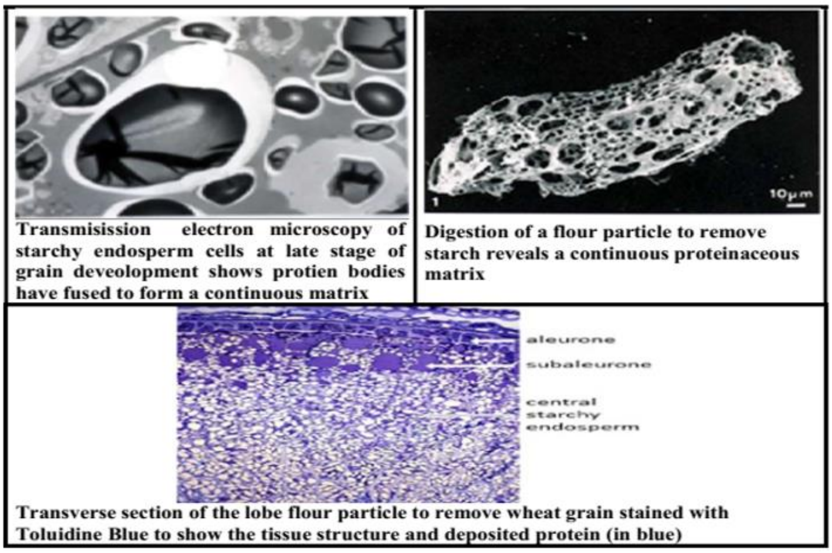

Figure 1. The origin of wheat gluten [134]

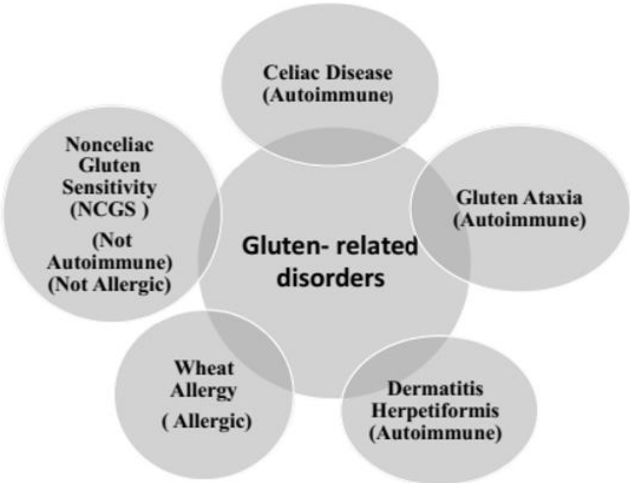

Figure 2. Classification of gluten related disorders

Gluten is known as "heart and soul" of bakery for providing the processing qualities familiar to both the home baker as well as the commercial food manufacturer. Gluten removal results in major problems for bakers, and currently, many gluten-free products available on the market are of low quality, where the absence of gluten often results in a liquid batter, and can result in baked bread with a crumbling texture, poor color and other quality defects post-baking and poor mouth feel and flavor [7]. This presents a major challenge to the cereal technologist and baker alike, and has led to the search for alternatives to gluten in the manufacture of gluten-free bakery products [115].

The diseases associated with gluten

There is the overarching term proposed by an international, multidisciplinary task force, the Oslo group, to describe all gluten triggered diseases known as gluten related disorders (GRD). GRD include coeliac disease (CD), nonceliac gluten sensitivity (NCGS), dermatitis herpetiformis (DH), gluten ataxia and Wheat allergy [81] (Figure 2). Celiac disease (CD) is a chronic immune-mediated enteropathy precipitated by to dietary gluten in genetically predisposed individuals, common disease around the globe and is rising in prevalence in many populations.

Celiac disease (CD) was once thought to be quite rare but has recently been shown to be one of the most common immune-mediated disorders in Arab countries and Western countries.

Currently, the highest percent show among the general population (3.2%) in Saudi Arabia, and the lowest (0.1%) in Tunisia, recent screening studies indicate that CD in Cairo City, Egypt is one of the more frequent genetically based diseases, occurring in 1 in 187 in the general population, in children with failure to thrive (4.7%) and in children with type1 diabetes (6.4%), while western countries show an estimated prevalence of CD of approximately 1% of the population [2, 26, 39, 95].

Singh et al. (2018) [135] they found the prevalence of celiac disease based in worldwide on serologic test results is 1.4% and based on biopsy results is 0.7% and the prevalence of celiac disease varies with sex, age, and location. Where, Women demonstrated a higher prevalence of celiac disease relative to men [63]. Children with type 1 diabetes have a higher prevalence of CD (range from 5.5% to 20%), while the prevalence of CD in Down's syndrome patients was 1.1% and 10.7% in UAE and Saudi Arabia, respectively. Other autoimmune diseases associated with CD are thyroid disease and irritable bowel disease (IBS), an intestinal disorder that causes abdominal pain, bloating, diarrhea, constipation, and gut microbiota unbalance leading to misdiagnosis [39, 45, 52]. Besides gluten, IBS is also related to the intake of other nutrients or anti-nutritional factors (ANFs) such as lipopolysaccharides, amylase/trypsin inhibitors, wheat germ agglutinins (WGA), and fermentable oligo-, di-, and monosaccharides and polyols (FODMAPs) [27].

The clinical presentation includes gastrointestinal upset, chronic fatigue, deficient of nutrient, poor growth, and weight loss, symptoms of malabsorption known as classical CD.

These symptoms include diarrhea, steatorrhea, weight loss or failure to thrive [9, 81]. However, in recent times there has been an increasing recognition of nonclassical CD, where individuals present without signs and symptoms of malabsorption [81, 119]. Individuals may present with fatigue, headache, iron deficiency and osteoporosis, and this may in part explain why many individuals remain undiagnosed [77]. Celiac disease is one of the relatively frequent causes of chronic non–bloody diarrhea in adults Egyptian patients [90]. In addition to this, patients may present with other extraintestinal manifestations, such as dermatitis herpetiformis [21], infertility [24], neurological manifestations [156]. and abnormal liver function tests (LFTs) [11].

Extraintestinal manifestations are common in children, include short stature, anemia, delayed puberty, dental enamel hypoplasia, reduced bone density, oral ulcers, liver and biliary disease, and dermatitis herpetiformis. Poor growth and anemia tend to be the most common [98]. Insidious effects of undiagnosed CD in children include behavioral disturbances and reduced educational performance [136].

Genetics play an important role in celiac disease, and HLA is the genetic system with the strongest disease association [18]. Everyone inherits human leucocyte antigen (HLA)-DQ genes from their parents and there are many different forms of HLA-DQ genes, including HLA-DQ7, HLA-DQ2, HLA-DQ8, HLA-DQ9, and HLA-DQ1. Of all these variants of HLA-DQ genes, two are called "celiac disease genes": HLA-DQ2 and the less common HLA-DQ8. Most people who develop celiac disease have HLA-DQ2, while a much smaller percentage have HLA-DQ8, these two genes seem to account for about 90- 99.7 of everyone with celiac disease (Figure 3) [82, 88, 121].

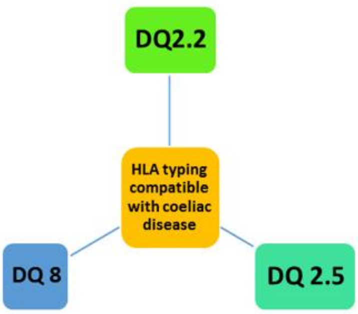

Figure 3. HLA typing compatible with coeliac disease

A recent study highlighted that for the detection of celiac disease, it is the most important guidelines for a clinician to follow: HLA testing with understand that in the absence of both DQ2 and DQ8, celiac disease can be ruled out, whereas the presence of DQ2 and/or DQ8 only infers risk, but cannot be used by itself to make a diagnosis of celiac disease [18]. Current diagnosis is based on demonstrating the enteropathy in small intestinal biopsies where histologic examination shows villous atrophy, crypt hyperplasia and intraepithelial lymphocytosis, and the presence of circulating CD-specific antibodies to tissue transglutaminase, deamidated gliadin peptides, and endomysium [61]. Key steps in CD pathogenesis as shown in figure 4. where Gluten peptides containing T-cell epitopes resist gastrointestinal degradation. Tissue transglutaminase (tTG) catalyses the deamidation of gluten peptides, which can then bind more efficiently to the disease-relevant HLA-DQ molecules on antigen-presenting cells (APCs). Activated gluten-specific T helper cells (CD4+ T) secrete a variety of pro-inflammatory cytokines such as interferon-gamma (IFN- ɣ) and interleukin 21 (IL-21) that contribute to the intestinal lesion and promote activation of intraepithelial lymphocytes (IELs) and stimulate B-cell responses. Activated IELs transform into cytolytic natural killer (NK) like cells that mediate destruction of enterocytes expressing stress signals. Interleukin 15 (IL-15) renders effector T cells resistant to the suppressive effects of regulatory T cells (Tregs) and, in the lamina propria, endows mucosal dendritic cells (DCs) with inflammatory properties promoting pro-inflammatory responses and preventing T reg differentiation.

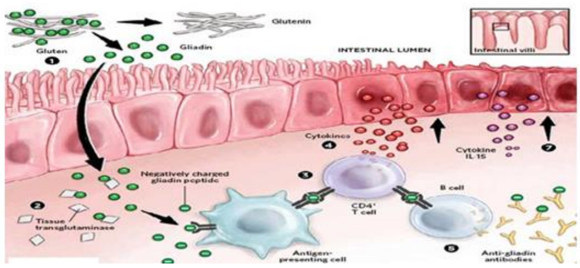

Figure 4. Key steps in celiac disease pathogenesis

Gluten ataxia (GA) is one of the commonest neurological manifestations of GRD, it was defined as otherwise idiopathic sporadic ataxia in the presence of circulating antigliadin antibodies of IgA and/or IgG type, it usually presents with gait and lower limb ataxia. Up to 60% of patients with GA have evidence of cerebellar atrophy on magnetic Resonance (MR) imaging, but all patients have spectroscopic abnormalities primarily affecting vermis cerebelli. Only a proportion (40%) of patients presenting with neurological dysfunction associated with gluten sensitivity will also have histological evidence of enteropathy on duodenal biopsy. The remaining patients have no histological evidence of small bowel involvement but have serological markers (serum antigliadin antibodies) in keeping with gluten sensitivity, GA has a prevalence of 15% amongst all ataxias and 40% of all idiopathic sporadic ataxias. GA is of insidious onset with a mean age at onset of 53 years [55, 56]. Most patients will stabilize or improve with strict adherence to gluten-free diet depending on the duration of the ataxia prior to the treatment, The advantage of early diagnosis and treatment (mean age 42 years in patients presenting with gastrointestinal symptoms vs. 53 years in patients presenting with ataxia) may protect the first group from the development and/or progression of neurological dysfunction [56].

Dermatitis herpetiformis (DH), is a cutaneous manifestation of celiac disease, presenting with an intense itch and blistering symmetrical rash, typically on the elbows, knees, and buttocks, with gastrointestinal symptoms are rare, three fourths of patients with DH have villous atrophy in the small bowel, and the rest have celiac-type inflammatory changes, DH affects mostly adults and slightly more males than females at age about 50 years. DH diagnosis is confirmed by showing granular immunoglobulin A deposits in the papillary dermis. At present, the DH-to-celiac disease prevalence is 1:8. The incidence of DH is decreasing, whereas that of celiac disease is increasing, probably because of improved diagnostics [122].

Non-celiac gluten sensitivity (NCGS) is a condition that affects many of the population in which gastrointestinal and nongastrointestinal symptoms caused by wheat and/or gluten ingestion even though they do not have celiac disease (CD) or wheat allergy (WA), and test of CD serology is negative, duodenal histology is negative, and IgE-based assays (prick tests or serum specific IgE dosage) are negative [83]. Therefore, it is possible to speculate that wheat and/or gluten ingestion might also be responsible, at least in part, for some of NCGS patient symptoms. Other proteins including alpha-amylase/ trypsin inhibitors, some carbohydrates especially fructans and other fermentable oligo- and di-monosaccharides and polyols (FODMAPs) because they are poorly absorbed in the small intestine and quick fermentation by bacteria increase gas production This causes abdominal pain, diarrhea and or constipation, and bloating, which may also occur due to osmotic activity. high osmotic activity fosters water mobilization in the intestine, thus increasing the amount of fluids causing abdominal distension, [14, 48, 60, 67, 94, 96, 153]. FODMAPs include fructose in excess of glucose, lactose, fructans and galactooligosaccharides (GOS), sorbitol, mannitol, xylitol and maltitol [85, 130, 155].

NCGS is clinically characterized by symptoms occur after gluten ingestion, improving or disappearing (within hours or a few days) with gluten withdrawal from nutritional meals and relapsing following its reintroduction. Clinical presentation of NCGS is a combination of irritable bowel syndrome (IBS) like symptoms as bloating, abdominal pain, diarrhea and/or constipation, and systemic manifestations as foggy mind, headache, fatigue, depression, joint and muscle pain, leg or arm numbness, dermatitis, and anemia [83]. Unlike CD patients, NCGS patients do not seem to have autoimmune comorbidities. In a group of 78 NCGS patients, none had type 1 diabetes mellitus and only one (1.3%) had autoimmune thyroiditis, compared to 5%and 19%, respectively, of 80 CD patients [148].

Wheat allergy is triggered by an immunoglobulin E (IgE)-dependent mechanism; it the most common in children its prevalence varies according to the age and region, wheat can be responsible of several clinical manifestations: food-dependent exercise-induced anaphylaxis (FDEIA), It is a severe allergic reaction induced by the ingestion of a causative food and subsequent physical exercise ,occupational asthma (or Baker's asthma) and rhinitis, urticaria, angioedema, bronchial obstruction, nausea, abdominal pain [62, 123, 141]. where wheat contains many allergenic proteins, divided in four classes on the basis of extraction in a series of solvents. This classification was formalized by the American chemist *Osborne, T. B. in the 19th century (1924)* [104]. He described four wheat protein fractions: albumins (extracted in water), globulins (extracted in dilute saline), gliadins (extracted in alcohol/water Medicine mixtures), and glutenins (extracted in dilute acid). The latter two classes account for 85% of wheat proteins and are known as gluten or prolamin, because of their high proline content [97]. The glutenins are classified into high-molecular-weight (HMW) and low-molecular-weight (LMW) groups after separation by electrophoresis [141], many wheat-allergic individuals have been shown to be sensitized to α, β, γ, and/or ω- globulins and to high- and low-molecular-weight glutenins [8].

Ricci et al, (*2019)* [123] indicated that the main wheat allergens that can be responsible for WA: Profilin, Lipid Transfer Proteins, alpha-Amylase Inhibitors, Agglutinins, ω-5 gliadins, γ-gliadins, α-β- gliadins, Thioredoxin, Glutenins, Thiol Reductase, Triosephosphate Isomerases, Peroxiredoxines, Trypsin Inhibitors, Glyceraldehyde-3-phosphate dehydrogenases, Dehydrins and Thionins, exposure to it is either through ingestion or inhalation**.** WA clinical manifestations can be different depending on the route of allergen exposure. Wheat ingestion is usually responsible for typical IgE-mediated reactions, with the development of symptoms within 2 h after the ingestion.

New therapeutic approaches for gluten related disorders (GRD)

Although sticking to a gluten-free diet is the only proven treatment for CD, it is for many patients complicated, onerous, and expensive especially when it is necessary to commit to it for life, Commission Implementing Regulation (EU) No 828/2014 [120] and FDA, 2019 [41] law set the limit to define gluten free products to 20 ppm. This limit is also applied to ingredients and food where a gluten-containing grain or flour is used. The challenge in maintaining adequately strict gluten exclusion and persistent disease activity is a major driver for research into new therapeutic approaches. Novel therapeutics development and a range of pharmaceuticals are currently being assessed aim to quantitatively reduce the load of gluten available to trigger the immune response and qualitative approaches that aim to induce gluten tolerance such as endopeptidase enzymes (glutenases) derived from plants, bacteria or fungi that have a gluten degrading effect, such as latiglutenase (An-PEP and ALV003) [73, 139, 142], used Tight junction modulators e.g., larazotide acetate (AT-1001) for reduce paracellular passage of gluten across mucosa, Transglutaminase inhibitors e.g., ZED 1227 for inhibit conversion of gluten to more immunogenic form, Gluten binding agents e.g., BL-7010 for Sequester gluten in the intestinal lumen, HLA-DQ2 blockers for prevent activation of gluten-specific T cells, Non-toxic gluten for modified or selectively bred cereals devoid of toxicit, Inhibition of inflammatory proteases e.g., elafin for anti-inflammatory effects and improved barrier function, Peptide-based therapeutic vaccine (Nexvax2) for epitope-specific targeting of gluten-specific CD4+ T cells and nanoparticle therapy (TIMP-GLIA) for nanoparticle encapsulating gliadin delivered intravenously [143]. In addition to, immunomodulators (e.g., budesonide, azathioprine), biologics (e.g., anti-IL-15, anti-CD52), and chemotherapy (e.g., cladribine) used to treat refractory CD [72].

Also, Gluten ataxia, dermatitis herpetiformis, NCGS and wheat allergy responds to a strict gluten-free diet while in DH, most patients also need additional dapsone to rapidly control the rash and itching. Dapsone can be stopped after a mean of 2 years. [54, 103, 122, 127] and some researchers suggested to supplement vitamins, proand prebiotics when switching to the low FODMAPs diet which play a key role in NCGS development. People resigning from products that are the source of FODMAP are at risk of vitamin and antioxidants deficiency [28, 113], where proven that FOS and GOS, compounds belonging to FODMAPS, alike prebiotic, favor proper colonization of intestines with Bifidobacteria and Lactobacilli bacteria and limit the proliferation of Bacteroides spp., Clostridium spp. and Escherichia coli, there is evidence that short-chain fatty acids (SCFA) the product of FODMAP fermentation have protective properties against colorectal cancer. FODMAPs are believed to have a positive effect on lipid metabolism by lowering serum cholesterol, triglycerides and phospholipids [10, 113]. In addition, this diet leads to calcium absorption disorders, lowering its serum levels, so It should be emphasized that a diet poor in FODMAPs should not be used without medical indications. Nowadays, oral immunotherapy has been proposed for wheat allergy with promising results [123].

Production of gluten-free pasta with different raw materials

There are numerous studies that have utilised different types of flour in producing wheat-based pasta or gluten-free pasta (Table 1) where pasta is very popular and consumed worldwide due to its long shelf life, ease of storage and simple meal preparation [137]. Pasta is traditionally produced from durum wheat flour due to its high protein content (gluten) that responsible for creating the necessary characteristics of the dough, where plays a key role in protein coagulation and influences the texture of cooked pasta. Hence, therefore that produces a desirable and well accepted pasta product. A high-quality pasta exhibits overcooking tolerance, low cooking loss, high firmness, high adhesiveness, and no surface stickiness. According to USDA (A-A-20062F, 2015) [144], the required pasta characteristics are smooth surface with characteristic yellow color and does not break on cooking with firm texture. Around 0.3–0.6% of the world population, and up to 3–10% in most wheat-consuming populations, suffer from gluten-related disorders [64, 154]. Since these diseases are connected to genetic factors, there are no effective medical treatments to cure these diseases. Hence, a gluten-free diet is a must for these patients [58, 59, 64, 92, 114]. In 2017, the gluten-free pasta market valued $909.8 million globally and is projected to reach $1,289.2 million by 2025 For these reasons, there are numerous research projects to develop gluten-free pasta. This can be achieved by selecting appropriate raw materials and improving the technology process to meet standard quality and desirable pasta product.

The development of alternative raw materials for pasta making leads to the utilisation of non-gluten containing cereal, as a partial or whole substitution for those whose diet requires gluten-free foods (Table 1) and the challenge is to develop viscoelastic characteristics and good texture of pasta. Hence, the main efforts are directed towards improving the quality, functionality, nutritional properties, and sensory quality of gluten-free pasta. [46, 106, 151].

Recently, the use of fruit and vegetable powder in GF pasta has increased. banana flour was used as suitable alternative for producing gluten-free pasta not only for their widely availability, but also for physicochemical and nutritional properties where banana flour has a lower carbohydrate content (80-83%), higher protein content (3-5%), a variable fat content (0.1-3%), and much higher resistant starch and fibre content (31-46% and 7-15%, respectively) [23, 34, 71]. Banana flour has also been found to have a high total phenolic content (44-145 mg/100 g) and antioxidant activities (0.7-1 mg/g of DPPH, 2-7 μmoles/mg of ferric reducing/antioxidant power (FRAP) values) and low glycemic properties that made it a healthy food source [71]. The use of Banana flour (40-60%) with modified starch (7-27%) has been studied in gluten-free pasta formulation, it was observed that the pasta was nutritious, had prebiotic and differed from the commercial product for its soft and flexible texture and their overall preference score was at a moderate level of 7.02 [105, 146]. When banana flour has been used as a substitute for wheat flour in proportions of 10-40%, the viscoelastic properties increased, while tensile strength and elasticity decreased, RS content increased from 5.56 to 23.31% while reduced glycemic index from 77.05 to 62.62. and the modified noodles are classified as intermediate GI food [140] and when using 12.5% unripe banana flour in gluten-free pasta formulation based on maize (73.5-75%) and chickpea flour (12.5%) showed that a significant increase in dietary fibre and had medium glycemic index [GI] [3, 4, 109].

Garcia-Valle et al, (2020) [47] studied effect of incorporation of whole unripe plantain flour as dietary fiber in semolina-based pasta formulations .it was observed that the cooking quality and Texture attributes of the pasta was similar to samples made only with semolina and whole unripe plantain flour is a viable source of dietary fiber for improving the digestibility properties of semolina-based pastas. Also, the use of unripe banana flour has been studied as a single raw material had a greater sensory quality for produce Gluten-free pasta compared with wheat-based pasta, different types of banana cultivar have also been reported to give sensory acceptance. The best cultivars studied were Pisang Nipah flour for production brighter green banana pasta and Pisang Nangka flour for production of green banana pasta with firmer texture after cooked [31]. and when *Castelo-Branco et al, (2017)* [25] used 15% and 30% a green banana flour (GPF) for development pasta based on wheat flour showed that 15% of GBF provided pasta with good sensory acceptance and could represent an alternative functional ingredient for pasta. and found that addition banana flour led to higher content of resistant starch and dietary fibre in the gluten-free pasta as well led to improved iron and manganese content as well as increasing the total phenolic content compared to rice pasta control [116, 131]. Some researchers reported that when incorporation of 30% green banana flour in yellow alkaline noodle as an alternative to wheat flour significantly increased the total dietary fiber of noodles, the resistant starch, total starch and some essential minerals, including phosphorus, magnesium, potassium, and calcium [32].

Campos & Almeida, (2021) [22] indicated the possibility of using taro flour for production of gluten-free pasta and to help the structure of the pasta it was necessary to incorporate a source of protein for retain the small starch granules the structure and avoiding the cooking loss, so researchers used egg whites as a source of protein, and the transglutaminase enzyme was used as a processing aid. It was noted that the egg whites contributed to increasing the chroma and hue angle, while transglutaminase only increased the chroma. Both egg white and transglutaminase showed a positive interaction effect for cooking time and increased weight of cooked pasta, and a negative interaction effect on firmness. However, these raw materials had no significant effect on the volume increase of the cooked pasta and cooking loss.

In comparison with wheat, used in traditional pasta, taro has a low protein content (2% dry basis while wheat contain 9 - 16%, in addition to presenting much smaller starch granules (taro = 0.25 - 0.5 µm x wheat = 1 - 45 µm) [13, 70, 76].

Cervini et al, (2021) [29] concluded that there is a possibility of using the annealed sorghum starch (annRS) as a value-added ingredient to produce GF pasta with high a resistant starch (RS) content and lower in vitro starch digestion with respect to 100% rice counterpart where replaced rice flour with 0, 5, 10, 15 g/100 g (w/w) of a resistant starch ingredient from annealed sorghum starch (annRS).The use of annRS positively influenced the optimal cooking time, the cooking loss, the firmness, and the stickiness of the cooked samples, with not remarkably change in color after cooking. The starch hydrolysis index values decreased as the level of annRS increased. Despite a significant decrease in the overall sensory with increasing levels of annRS, all samples were characterized by a value > 5, which is considered the limit of acceptability.

Scarton et al, (2021) [132] concluded that it is possible to use the biofortified sweet potato flour (BSPF) as a natural source yellow color, regional flavor, good sensory acceptance and increase of the protein and β-carotene content of rice flour-based gluten free pasta with hydrolyzed soy protein concentrate (HSPC) and carboxymethylcellulose gum, the results indicated that the concentrations of ingredients, nutritional value and sensory acceptance of gluten-free pasta improved by adding potato flour.

Jiao et al, (2020) [65] studied that the effect of pea starch on the properties of rice flour for production gluten-free noodle, pea starch played a positive role in improving the cooking qualities of rice noodles by significantly reducing their cooking loss. The results revealed the possibility of blending rice flour with pea starch up to 25 g/100 g to produce rice noodles of acceptable textural properties and cooking quality.

Albuja-Vaca et al, (2020) [6] developed Gluten-free pasta by substituting rice flour (RF) with lupin flour (LF) using a mixture-process design, LF was a significant factor due to its high protein and mineral content, the best formulation was obtained with 20g/100g LF, 30g/100g egg and 0.15g/100g guar gum. This study showed that lupine flour is the variable that most affects the weight gain due to its water absorption capacity. Pasta sensory characteristics such as color were influenced by the addition of lupine flour. Cooking of rice starch leads to gelatinisation which occurs at the same time as protein denaturation [19]. Furthermore, the combination of starch gelatinisation and protein denaturation builds a compact structure to increase the firmness of GF pasta.

Cai et al. (2016) [20] reported quality improvement of GF noodles formulated using hydrothermally treated polysaccharide mixtures (HTT-PSM) of glutinous rice flour and xanthan gum at different concentrations. They reported that HTT-PSM had high extensibility which enabled the dough to make GF noodles with higher tensile strength and similar texture profile as compared to wheat noodles. The mixture of sorghum, rice, corn flour, and potato starch has also been studied for the development of gluten-free pasta [42], the samples containing a higher proportion of sorghum flour and/or corn flour were found to be bitter due to phenolic acids explaining its limited use in GF products. It was stated that when the formulation contained a higher content of potato flour, quality indicators, such as cooking time, yield and density showed improved results.

Table 1. Different types of flour and additives utilisation in pasta production

Materials	Additives & technological	Reference
Wheat-based		
Durum wheat semolina (500g)	Bellevue (Marseille), dehusked Faba bean (*Vicia Faba*), and organic green lentil (*Urvum lens L.*) 500 g of each raw material	Laleg et al, (2021)
Wheat flour	10%-40% Banana flour	Tangthanantorn et al,2021
Wheat flour	Fermented cassava flour (50%) replacement with pre-gelatinization	Odey and Lee (2020)
Semolina flour	15-35% unripe plantain	Garcia-Valle et al, (2020)
Wheat flour	15-30% unripe banana pulp/peel	Castelo-Branco et al, (2017)
Wheat (*Triticum durum*) semolina	quinoa flour, Fermented quinoa dough by L*actobacillus plantarum* T6B10 and *Lactobacillus rossiae* T0A16	Lorusso et al,2017
Durum wheat semolina	Cassava flour replacement (0-50%), Arabic gum (2%), gelatin (3%), sodium carbonate (0.1%) and potassium carbonate (0.1%)	Oladunmoye, et al, (2017)
Wheat flour	Sourdough lactic acid bacteria,	Curiel et al,(2014)
Wheat flour	30% banana flour, β-glucan	Choo and Aziz (2010)
Semolina flour	15-45% unripe banana flour	Agama-Acevedo et al, (2009)
Wheat flour	Cassava flour (30%) and cassava	Charles et al. (2007)
Gluten-free		
Taro flour	Egg white powder (5 to 50% replacement in flour) and transglutaminase (0.005 to 0.05% flour base)	Campos& Almeida, (2021)
Polished rice flour		Bouasla & Wójtowicz, (2021)
White rice flour	Resistant starch from annealed sorghum starch (annRS) (5,10,15%), mono- and di-glycerides of fatty acids(0.5g)	Cervini et al, (2021)
Banana flour (40-60%)	Modified starch (7-27%)	Oupathumpanont & Wisansakkul, (2021)
Rice flour, Sweet potato flour, hydrolyzed soy protein concentrates	carboxymethyl cellulose gum	Scarton et al, (2021)
Rice flour (67%)	Freeze-dried whole egg / egg white	Witek et al. (2020)
Rice flour	Pea starch 10% and 30%	Jiao et al, (2020)
Rrice flour (RF) : lupin flour (LF) (70:90% and 10:30%)	whole egg (8:30%) and guar gum (0.15 :1%)	Albuja-Vaca et al, (2020)
Chickpea flour (65.7%)	Egg white (34.5%)	de Lima, et al, (2019)
Maize flour (73.5%) chickpea flour (12.5%), unripe plantain flour (12.5%)	Carboxy methyl cellulose (1.5%)	Agama-Acevedo et al, (2019)
Cassava flour (60-70%), amaranth flour (30-40%)	Carboxy methyl cellulose (0.21-0.25%), egg powder (2%), enzyme Veron (0.03%)	Ramirez et al. (2019)
amaranth flour (AF) and pea protein flour (PPF) (80 -95 % and 5 - 20%)		Gupta, (2019)
Maize flour (75%) chickpea flour (12.5%), pulp/whole unripe plantain flour (12.5%)	Carboxy methyl cellulose (1.5%)	Patiño-Rodríguez et al, (2018)
Pregelatinized rice flour (60-90%), soybean flour (0-20%), orange-fleshed sweet potato (0-10%)	Liquid egg albumen (10% w/w dry material)	Marengo et al. (2018)
Green banana flour (47%)	Egg white (31.5%), guar gum (2.5%), xanthan gum (2.5%)	Cheok et al, (2018)
Brown rice flour	amaranth flour, flaxseed flour and whey protein concentrate (WPC-70 powder	Aastha et al, (2017)

Table 1. Different types of flour and additives utilisation in pasta production (*continued*)

Sorghum flour (70-100%)	Xanthan gum (0-2.5%) / egg albumen (0-11%) / egg powder (0-9%) / pregelatinized corn starch (0-30%) (w/w dry material)	Palavecino et al. (2017)
Faba bean (Vicia Faba) flour	Lactobacillus plantarum DPPMAB24W (10, 30, and 50%) and Lactobacillus rossiae T0A16	Rizzello et al, (2017)
Broken rice flour (75-100%)	Defatted soy flour (0-25%)	Udachan and Sahoo (2017)
Rice flour (57-67%)	Soy protein concentrate / egg albumen / rice bran protein concentrate / whey protein concentrate (0-9%), distilled monoglyceride (1%)	Phongthai et al, (2017)
Rice, Quinoa, Amaranth	Egg whites (10-18%)	Makdoud and Rosentrater, 2017
Rice flour : yellow pea flour (2:1)		Bouasla et al, (2016)
Brown rice, corn grits		da Silva et al. (2016)
Corn starch, Rice flour, Pea protein isolate	Hydroxypropyl methylcellulose (HPMC), Psyllium fibre, Maltose, GF fresh yeast extract and refreshed GF sourdough	Picozzi et al. (2016)
Faba bean flour, Faba bean flour fermented	lactic acid bacteria (LAB)	Rosa-Sibakov, et al,2016
Brown Rice Flour 100g	Soy protein isolate 8.0 g, monoglyceride 1.0 g + guar gum 0.4 g + sodium alginate 0.4g + xanthan gum 0.4 g	Wang et al., 2016
Sorghum flour (40-60%), rice flour (15–30%), and/or corn (10–20%) and potato starch (10– 40%)	Whole egg (25% w/w flour), soybean oil (2% v/w flour)	Ferreira et al. (2016)
corn starch and corn flour mixture (4:1) (49.6-56.2%)	Dried whole egg (2.45-6%), egg white (0.25-0.6%), mix of xanthan gum and locust bean gum (2:1) (2.5%)	Larrosa et al, (2016)
Rice flour (81-90%) , Rice waxy flour (9-10%)	Soy protein isolate (0-10%)	Detchewa et al, (2016)
Glutinous rice flour, rice flour	Xanthan gum	Cai et al. (2016)
Rice flour (90-100%)	Soy protein isolate (10% w/w flour) / ogaja fruit extract (7 % w/w flour)	Lee et all, (2016)
Buckwheat		Oniszczuk, (2016)
Dried Potato Pulp 65-80g + Extruded Potato Pulp 7-17g + Amaranth Flour 10-25g	Fresh egg 56 g per 100 g mixture	Bastos et al. (2016)
amaranth/quinoa/buckwheat, millet/white bean		D'Amico et al. (2015)
Rice flour: bean flour (60-100:20-40)		Giuberti et al., 2015
Teff four; buckwheat flour; quinoa flour; amaranth flour	Guar gum	Kahlon & Chiu (2015)
Rice flour (60-100%), banana powder / fresh banana / fresh banana with ascorbic acid pre-treatment (0-40%)	1 fresh whole egg per 100 g flour	Radoi et al, (2015)
Rice flour, corn starch	Milk protein, guar gum, xanthan gum, cheese	Sanguinetti et al. (2015)
Corn flour, corn starch, pumpkin flour, durian seed flour Dry	egg powder	Mirhosseini et al. (2015)
Chickpea flour (60-70%), unripe plantain flour (15- 30%), maize flour (0-20%)	Carboxy methyl cellulose (0.5%)	Flores-Silva et al, (2014)
Rice flour (40-85%), green plantain flour (15-60%)	Distilled monoglyceride (0.5%), pre-gelatinization flour, egg albumen (3.5-6%)	Sarawong et al, (2014)
Parboiled milled rice (85-100%)	Egg white protein (0-15%) / Whey protein (0-5%)	Marti et al. (2014)
Corn flour, millet flour, brown rice flour, sorghum flour, garbanzo flour	Guar gum	Kahlon et al. (2013)
Teff flour (62.8%) / Oat flour (64.7%)	Egg white powder (9.7-11%) and pasta emulsifier (1.1-1.3%)	Hager et al, (2013)
Cassava starch (60%), cassava flour (10%), amaranth flour (30%)	Pre-gelatinization flour, fresh whole egg (48 % w/w dry mixture)	Fiorda et al, (2013)
Amaranth, Quinoa, Buckwheat	Egg white powder (0%-12% of flour), Distilled monoglycerides 0-6% of flour	Schoenlechner et al.,2010
Buckwheat (40%), rice (25-27%)	Fresh whole egg (30%)	Alamprese, et al, (2007)

Giuberti et al, (2015) [51] have also tried using legume flour for the nutritional improvement of gluten-free pasta products. Gluten-free pasta was developed using rice flour and white-seeded low phytic acid and lectin-free bean flour (ws+lpa+lf), modified product was observed to have increased protein, ash and dietary fiber contents, while total starch content decreased with the inclusion of new white-seeded low phytic acid and lectin free bean flour (ws+lpa+lf). However, the negative impact of bean flour addition on the pasta color was reported, as the lightness (L* value) decreased with addition of bean flour.

Kahlon et al. (2013) [68] developed whole grain, high protein, gluten-free, egg-free pasta without chemicals added by using whole grain cereal flour (corn, millet, brown rice, sorghum flours), and whole garbanzo flour to increase the protein content and guar gum. The results indicated that brown rice-garbanzo pasta was better in odor, flavor, and texture/Mouth feel than other whole grain high protein pasta tested, the brown rice pasta and corn-garbanzo pasta was well Sensory acceptance higher than millet-garbanzo and sorghum-garbanzo pasta.

Amaranth, Buckwheat, quinoa, teff and oat are becoming increasingly popular as ingredients in pasta formulations as they improve the nutritional quality of GF pasta.

Gupta, (2019) [55] used amaranth flour (AF) and pea protein flour (PPF) (80 -100 % and 5 - 20% respectively for production gluten-free pasta, A slight decrease in optimal cooking time was observed as PPF was added. Moreover, a substantial increase in protein content from 17.3g to 25.6g was observed with the addition of 20% PPF. An increase in protein content also had a significant effect on pasta firmness, as it increased by 289.65% with the addition of 20% PPF.

Aastha et al, (2017) [1] studied that the effect of amaranth flour (5-20%), flaxseed flour (5-20%) and WPC70 (1-5%) on the sensory attributes, physical properties and cooking loss (%) for brown rice flour for production gluten-free pasta. The results revealed the most desirable attributes (desirability, 0.899) resulted from mixing 20.00% amaranth flour, 10.00% flaxseed flour and 3.00% WPC-70 levels.

Makdoud & Rosentrater, (2017) [82] used amaranth, quinoa and rice flour s , water and eggs to develop gluten free pasta , It was de termined that the best pasta formulation was 10% amaranth flour, 40% quinoa flour and 50% rice flour with 18% eggs white and 39 % water, 80% of consumers did not refuse to eat this pasta again and with addition of tomato sauce, individual sample analysis did indicate that consumers did not appreciate the formulation’s sticky texture, thus this parameter would have to be reworked to achieve higher quality.

Bostos et al. (2016) used amaranth flour with dried potato pulp, extruded potato pulp, and fresh egg to develop pasta. It was observed that GF spaghetti made of amaranth flour with extruded potato pulp was reported to have better colour, less solid loss to cooking water and higher yield, and required less cooking time compared to fresh commercial wheat spaghetti. Similar results were reported by *Fiorda et al. (2013)* [43] where amaranth was used as one of the main ingredients, to develop GF pasta and they reported to increase the firmness and decrease the stickiness of the pasta.

Kahlon & Chiu (2015) [69] prepared GF egg-free pasta from different pseudo-cereals including teff, buckwheat, quinoa and amaranth. Odour of buckwheat pasta and texture/mouthfeel of teff pasta were significantly better than quinoa and amaranth pasta. Taste/flavor of teff and buckwheat pasta was similar and significantly better than quinoa and amaranth pasta.

Schoenlechner et al. (2010) [133] developed pasta using all three pseudo cereals amaranth, quinoa, and buckwheat at various concentrations. Negative effects of amaranth on texture firmness, cooking weight, and cooking loss were discussed in this study. Buckwheat was reported to be best suitable for gluten-free noodle production, as it had a positive effect on firmness and cooking weight cooking loss when combined with the other two flours in the ratio of 60% buckwheat, 20% amaranth and 20% quinoa, dough matrix was improved. It was observed that Precooked buckwheat pasta contained natural polyphenolic antioxidants and composite of gallic, protocatechuic, gentisic, 4-OH-benzoic, vanillic, trans caffeic, cis-caffeic, trans-pcoumaric, cis-pcoumaric, trans-ferulic, cis-ferulic and salicylic [102].

Mirhosseini et al. (2015) [91] used pumpkin flour or durian seed flour to produce GF pasta. The addition of 25% pumpkin flour to the formulation led to improved colour and texture properties and sensory acceptance of GF pasta, the ash content of gluten-free pasta was found to increase as the percentage of durian seed flour or PF in the formulation was increased. Additionally, a positive effect on cooking yield with partial replacement of corn flour with durian seed flour and PF were also reported due to the formation of stable polymeric networks. Pasta developed by using durian seed flour was observed to have higher hardness and lower adhesiveness and firmness than the control which confirmed some positive effect of durian seed flour on texture properties of gluten-free pasta.

The use of cassava flour in either wheat-based or gluten-free pasta is still limited. Most research has implemented a pre-gelatinization process of cassava flour to produce desirable pasta, and used functional additives to improve pasta quality as can be seen in the same Table. cassava flour was used as suitable alternative for producing gluten-free pasta where cassava flour contains high amount of carbohydrate (85-92%), a small amount of fat and protein (0.92-0.96% and 0.44-1%, respectively), and some resistant starch and fibre (0.1-2.2% and 2-5%, respectively) [78, 99, 101, 110].

Ramirez et al. (2019) [118] noted that a lower hardness with increased cassava flour portion in gluten-free pasta formulation which showed the effect of cassava flour on the textural properties of gluten-free pasta. *Fiorda et al. (2013)* [43] succeeded in using 60% cassava starch with 10% pregelatinized cassava flour and 30% amaranth flour to give the best quality with good consumer acceptance (7.2 out of 9 scale) of a gluten-free pasta product and obtained 42% buying intention amongst the consumers. Their research found that the amount of cassava flour and starch in gluten-free pasta formulation altered cooking properties (decreased optimum cooking time, decreased mass increase and increased loss of solids).

Functional additives

Hydrocolloids are commonly added in GF pasta formulations to improve firmness, increase rehydration and reduce the sticky texture of GF pasta and improve cooking as the GF pasta typically has an inferior texture and usually does not tolerate overcooking .The most common hydrocolloid is guar gum followed with xanthan gum and carboxymethylcellulose (CMC). Other commonly used hydrocolloids are hydroxypropyl methylcellulose (HPMC), sodium alginate and locust bean gum. When adding both xanthan gum (XG), guar gum (GG), and carboxymethyl cellulose (CMC) individually at 1.0% and 1.5% levels for studying quality of dried noodles substituted with 30% banana flour (DBF30) it was observed that (DBF30) with XG had the shortest rehydration time (6.5 min), while DBF30 with CMC had the slowest rehydration (8.5 min). The added hydrocolloids increased rehydration and decreased the cooking loss and increasing tensile strength and elasticity of DBF30. Furthermore, the hydrocolloids increased RS content and reduced GI of DBF30 [140]. Effect of xanthan and guar gum on GF pasta was evaluated by *Sanguinetti et al. (2015)* [129], Where the use of xanthan gum led to gum pasta retains moisture during storage, hence inhibiting development of crack fractures on the dough surface, which appeared on the guar gum pasta after 7 days of storage. It also used hydrocolloids (guar gum (2.5%), and xanthan gum (2.5%) as the additives to improve pasta quality [31, 152].

Egg white protein has been used as a functional ingredient to replace gluten functionality to enhance the quality of gluten-free pasta products. Egg white proteins benefit human nutrition because they have a high nutritional value due to content of essential amino acids, which reach 385 amino acids in ovalbumin only, predominantly containing lysine and sulfur. The main ones can be highlighted: ovalbumin, Ovo transferrin, ovomucoid, ovomucin, lysozyme, and globulin [138]. Some of the research applied egg protein at a fixed proportion, while others used variable values to determine the optimum proportion that gave the best effect on the quality of gluten-free pasta, and it is also noted that egg white protein was employed more frequently than egg yolk or whole egg. Egg white protein was shown to improve the cooking properties, while egg yolk improved the textural properties of gluten-free pasta [108]. From a consumer perspective, it was found that egg white protein application in gluten-free pasta had a better sensory acceptance (above 7 out of 9) compared to egg yolk or whole egg (5 out of 9) [150]. The disadvantage found in these studies was the high amount of egg white composition (31.5%) required to make an acceptable product compared to similar studies in gluten-free pasta based on banana flour that applied up to 6% egg compotation and found banana flour contains a high amount of resistant starch and dietary fibre and led to higher amounts of resistant starch and dietary fibre in the gluten-free pasta as well banana added led to improved iron and manganese content as well as increasing the total phenolic content compared to rice pasta control [116, 131]. However, it used less whole egg portion (39.4%) compared to the wheat pasta control (60.6%), therefore protein content was much lower (9.30% of 19.3%). *Sarawong et al.*, (2014) [131] only used 6% egg albumen, but it implemented pre-treatment on rice flour (pregelatinized rice flour) where the preparation of pregelatinized GPF induces starch gelatinisation followed by retrogradation during the heating and cooling cycles.

Soy bean protein has also been used in many studies as an additive in cereal products is mainly because of its functionality and nutrition content. The most frequently used soy protein in gluten-free development is soy protein isolate.

Some researchers used soy bean protein as an additive in cereal products is mainly because of its functionality and nutrition content. The most frequently used soy protein in gluten-free development is soy protein isolate and found that type of soy protein (soy protein concentrate or DSF) did not give significant differences in cooking quality and texture properties of gluten free pasta made of sweet potato flour. It was reported that 15% soy protein inclusion was considered as an optimum condition in improving gluten-free pasta quality [79, 145].

Different technological approaches to improve GF pasta quality

Extrusion-cooking

As starch is the major component of the rice kernel, changes in physicochemical properties during extrusion processes will dictate the properties of rice pasta. The extrusion-cooking process caused strong interactions of amylopectin and/or amylose. Consequently, the product had a low cooking loss but a high firmness [86, 87].

Bouasla & Wójtowicz, (2021) [16] produced gluten-free pasta by extrusion cooking for polished rice flour to investigate the effect of feed moisture (28, 30 and 32%) and screw speed (60, 80 and 100 rpm) on selected pasta quality traits, the results showed that feed moisture significantly affected all tested quality characteristics of rice noodles, where raising the feed moisture increased the cooking time, water absorption, cooking loss, hardness and stickiness while screw speed showed a significant effect on all quality traits except for cooking time and stickiness where increasing screw speed enhanced cooking loss and hardness, but decreased water absorption and pasta stability with lower feed moisture. 30% prepared rice noodles. The moisture content and at 80 rpm showed a decent quality, as evidenced by a solid texture and low loss of stickiness during cooking. Microstructure analysis showed a compact and dense internal structure of the dry pasta, the surface was smooth and even when at least 30% moisture was applied at a screw speed of 80 rpm during curing.

Bouasla et al, (2016) [17] used rice/yellow pea flour blend (2/1 ratio) to produce gluten-free precooked pasta using a single-screw modified extrusion-cooker TS-45. Results indicated that dough moisture content (28%, 30%, and 32%) influenced all tested quality parameters of precooked pasta except firmness. Screw speed (60, 80, and 100 rpm) showed an effect only on some quality parameters. The extrusion-cooking process at 30% of dough moisture with 80 rpm is appropriate to obtain rice-yellow pea precooked pasta with high content of phenolics and adequate quality, these pasta products exhibited firm texture, low stickiness, and regular and compact interne structure confirmed by high score in sensory overall acceptability. Some researchers went to study the effect of extrusion temperature and screw speed on the extrusion system parameters and the qualities of brown rice pasta, and indicated that brown rice can be used to produce gluten-free pasta with improved nutrition, it was noted that the extrusion temperature and screw speed significantly affected on the cooking quality and textural properties of brown rice pasta. The pasta produced at an extrusion temperature of 120°C and screw speed of 120rpm had the best quality with a cooking loss, hardness and adhesiveness of 6.7%, 2387.2g and -7.0g·s, respectively [149].

da Silva et al. (2016) [35] prepared GF pasta with brown rice (BR) and corn meal (CM) blends and reported that the pasta produced with a 40:60 (CM: BR) blend and has been processed via extrusion cooking with A 32 central composite rotation design was used to evaluate the effects of the extrusion variables, i.e., temperature, feed moisture and CM content, on the pasting properties and cooking quality of the extrudates. recorded better sensory evaluation compared to other pasta formulations. Pasta products are usually produced using cold single screw extrusion process. The twin screw extruder can be successfully applied in the production of gluten free brown rice pasta. At the optimized condition [feed moisture (31.1%), screw speed (177.9 rpm) and barrel temperature (87 °C)], the cooking loss was less than 10% indicating good quality products [117].

Enzymes technology

Enzymes are usually added into GF product formulations to improve the dough-handling properties, the water-binding capacity, the crumb softness, the shelf life, and to enhance the final product quality [126]. Enzymes such as fungal amylase, esterase, hemicellulase, glucose oxidase and transglutaminase were used in gluten free flour (buckwheat, corn and rice) to investigate the effects on pasting properties of flour and texture profiles of the dough, the result showed that fungal amylase enzyme consistently affected the flour properties where breakdown of complex starch molecules by enzymes into simpler sugars decreased the overall viscosity parameters during the application of heating, shearing and cooling cycle, The hardest gel was found as corn flour at the highest amylase enzyme concentration (10 g/100 kg flour), and has been observed that the highest springiness, resilience, cohesiveness and adhesiveness value was for buckwheat starch gel [107]. The cross-linking enzyme transglutaminase mainly acted on properties of pasta prepared with Faba bean flour, reducing the in vitro starch hydrolysis index and increased some textural parameters (hardness, cohesiveness, chewiness and resilience) likely due to cross-links in the protein network [125].

Temperature control

Laleg et al, (2021) [74] studied and solved the problem of agglomeration that leads to the formation of large sticky and gummy dough pieces during the pasta hydration and mixing step by studying the change in mixing conditions including mixing temperature, addition of antioxidants, and flour pretreatment for production100% pasta made from legume high nutritional potential (rich in protein and gluten free). they results suggest that enzymatic reactions, notably lipoxygenase related redox activity, are responsible for this impairment of dough mixing and extrusion, low temperature mixing preferred as it makes legume pasta more resistant to cooking. Antioxidants could also be used at food safe levels in addition to thermal solutions.

Gupta, (2019) [53] studied effect of various drying temperatures (60°C, 80°C, 100°C) and time (12 and 24 hr.) on the cooking quality of pasta processed by amaranth flour (AF) and pea protein flour, and it was found that high temperature drying has a positive effect but resulted in a porous pasta structure, which resulted in decreased unit density by 32.35% with an increase in temperature from 60°C to 100°C. Additionally, a darker colored pasta was obtained at higher temperatures.

D'Amico et al. (2015) [36] went to another direction, where he studied the effect of drying temperature on gluten-free pasta, where no information about high temperature drying is available on respect to gluten-free noodles. Two types of gluten-free pasta (one amaranth/quinoa/buckwheat and second millet/white bean) were produced und dried under different conditions. Durum wheat pasta was used as a reference. and reported the effect of using drying temperatures 60, 80, and 100 °C on GF pasta prepared. A positive effect of higher drying temperature was reported due to the modification of protein and starch structures. Compared to the millet/white bean pasta, the pasta from amaranth/quinoa/buckwheat exposed a higher degree of quality improvement after high temperature drying. The differences can be explained predominately by differences in the chemical composition, especially their amino acid composition. Texture properties reached values comparable to the wheat reference.

Bio fermentation

Bioprocessing fermentation has been applied to eliminate or reduce the gluten protein in wheat flour. *Curiel et al. (2014)* [33] prepared gluten free wheat flour (GFWF), by sourdough lactic acid bacteria fermentation (*Lactobacillus sanfranciscensis, Lactobacillus Alimentarius, Lactobacillus brevis and Lactobacillus hilgardii*) and fungal proteases from *Aspergillus oryzae* and *Aspergillus niger* , these LAB were selected based on their ability to hydrolyze gliadin fractions and various proline-rich oligopeptides, including the 33-mer epitope, considered as the key-factor in determining gluten-related disorders, they reported that in the absence of gluten network, supplementing pregelatinized rice flour could provide structural properties of GFWF pasta comparable to that of the durum wheat pasta ,where this GF pasta exhibited rapid water uptake and shorter optimal cooking time, and its essential amino acid profile, biological value and nutritional index were higher than durum wheat paste . *Lactobacillus amylovorus* and other lactic acid bacteria (LAB) have also been used to improve texture. *Picozzi et al. (2016)* [112] utilized a GF matrix inoculated with Lactobacillus sanfranciscensis and Candida humilis, fermented to pH 4.0 and constantly propagated for ten times to obtain a type I GF sourdough, which improved the overall quality of GF baked products.

Faba bean (*Vicia Faba L.*) flour is obtained from the dehulled seeds, is considered a source of the amino acids of which cereal-based products are lacking (i.e., lysine and threonine). Due to the fact that the beans contain anti-nutrition compounds including condensed tannins, - galactosidases, pyrimidine glycosides, and trypsin inhibitors, which limit its utilization, fermentation with LAB was successfully applied to removing them, Faba bean (Vicia Faba) flour fermented by Lactobacillus plantarum DPPMAB24W was used in different amounts (10, 30, and 50%) to substitute semolina, results indicated that Increase of protein digestibility and protein quality indexes, reduction of glycemic index degradation of trypsin inhibitors, and condensed tannins [124]. Fermented Faba bean flour was also used as the sole ingredient for pasta production [125], LAB fermentation lasted 48 h at 30 C and fermented dough was freeze dried before use in pasta making. Fermentation showed an important role in the improvement of sensory and textural characteristics of gluten free Faba bean pasta was increased of protein and resistant starch content and Low beany-flavor perception. Quinoa flour fermented by *Lactobacillus rossiae T0A16* and *Lactobacillus plantarum T6B10* was used at 20% substitution level for pasta making, the fortification with fermented quinoa flour increased all nutritional indexes and significantly decreased the hydrolysis index (HI) of pasta to 52.7% [80].

Advanced transgenesis techniques to eliminate gluten genes

Due to the large number of gluten genes and the complexity of the wheat genome, wheat that is free gluten and coeliac-safe cannot be produced by conventional breeding alone where CD is triggered by immunogenic epitopes, notably those present in α-, γ-, and ω-gliadins. RNA interference (RNAi) has been used to make low-gliadin lines. Recently, used of advanced transgenesis techniques to eliminate gluten genes, such as CRISPR/Cas9 technology has been applied to gliadins, these methods produce wheat with deleted, and/or edited gliadins and almost certainly, that edited genes from different lines must be combined by crossing and selection within a breeding program [50, 66]. Alteration of protein structure has been achieved through genetic manipulation of specific gluten proteins to reduce the gluten immunoresponse by reducing the gliadin content by up to 97%, The transgenesis technological properties of doughs prepared from the low-gliadin lines might be applied to other nontoxic cereals, as raw material to produce GF products [49].

Conclusion

CD and many other gluten-related illnesses have emerged as a common type of food intolerance worldwide. The only available and safe treatment is the nutritional exclusion of gluten-containing grains, but these GF products are often expensive and of poor quality due to the lack of gluten that forms the basic structure needed for the appearance, texture, structure and flavor of many of these products. Therefore, many methods were applied to improve it, and the most used method was the use of substitute flour and food additives, and the most used types of flour were rice and corn flour compared to other types of flour and starches. It was noted that for GF products made from rice or corn, the combination of gelatinization of starch and protein denaturation is important Because it can help build a compact structure to increase the hardness of GF pasta. Many other grains have been used for different purposes that may be to increase dietary fiber, minerals or vitamins for GF pasta such as buckwheat, amaranth, quinoa, brown rice, sweet potatoes, pumpkin flour, cassava, teff and oats. Often substitutes for wheat flour alone cannot achieve satisfactory texture for GF products. Hydrocolloids were commonly used to improve pasta cooking behavior and egg protein was used to improve the stability of the pasta's internal structure. Various heating and processing steps have been applied to improve the quality of GF products, for example, extrusion cooking improves the hardness of cooked pasta. Bioprocess fermentation is a method that can help improve the texture of GF products. Enzymes and lactic acid bacteria have been used in the sourdough to improve the texture of the final GF products. Although the method of transgenesis of wheat is a new way to improve the quality of gluten-free products, it has been proven that is not able to reduce all the gliadin in wheat.

Compliance with Ethics Requirements. Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human or animal subjects (if exist) respect the specific regulation and standards.

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