Novel Approaches to Gluten Degradation

Syed Insha Rafiq, Sourav Garg, Syed Mansha Rafiq, and Aamir Hussain Dar

1 Introduction

Gluten being the most important storage protein naturally found in several grains like wheat, barley, rye, and spelt, comprises around 80% of whole grain proteins. It arises entirely in the endosperm of grains and comprises of numerous diverse proteins, mostly gliadins and glutenins in wheat, secalin in rye, hordein in barley, and avenins present in oats, are all referred to as "gluten." Wheat gluten attains a top position amongst all the gluten proteins of various cereals due to the visco-elastic polymeric network capable of exclusive baking performance of wheat flour (Wieser, 2007) as the gluten protein is responsible for the bread making as well as wheat flour properties. In addition, it acts as a binder that holds the food together and thus adding a "stretchy" quality. The gluten proteins are further classified into subgroups as alpha, beta, gamma and omega gliadins depending on the primary structures (Shewry & Lookhart, 2003). The exclusive parameters of gluten are attained from the structure and interaction of gluten proteins bound through covalent and non-covalent forces. The composition of these gluten proteins varies with different wheat varieties (Wieser, 2007).

S. I. Rafiq
National Dairy Research Institute, Karnal, Haryana, India

S. Garg
National Institute of Technology Rourkela, Rourkela, Odisha, India

S. M. Rafiq
Department of Food Technology, NIFTEM, Sonepat, Haryana, India

A. H. Dar (✉)
Department of Food Technology, Islamic University of Science and Technology, Awantipora, Jammu and Kashmir, India

S. A. Mir et al. (eds.), *Gluten-free Bread Technology*,
https://doi.org/10.1007/978-3-030-73898-3_13

2 Gluten Function for Bread Development

The visco-elastic characteristics of dough made with wheat flour makes it suitable for bread making. The dough prepared may be either weak or strong depending mostly on the quantity and quality of the wheat proteins. The protein content of wheat grain varies widely but for bread making it should be at least 11% (Wilderjans et al., 2008; Mariotti et al., 2013). The gluten must be strong enough for bread making so as to hold the gas (carbon dioxide) produced during the fermentation process which allows the bread to rise. The rheological properties of dough are improved by kneading process that leads to development of the gluten structure which further improves the expanding ability of dough owing to the production of carbon dioxide gas through fermentation process (Edwards et al., 2003). This stage of gluten network formation may be referred to as 'ripening' or 'maturing' of the dough and the changes associated with gluten formation requires both the protein hydration of the flour as well as energy application by the kneading process. Moreover, the final bread quality is attributed by the quality of wheat flour from the mill as it contributes the proteins compulsory for gluten formation and beneficial for bread production process. In addition, the ability of gluten formation is unique to wheat and the quality and intensity of gluten proteins depends primarily upon variety of wheat, environmental effects as well as agricultural procedures (Lee et al., 2001).

Furthermore, the bread production depends upon the chemical parameters of gluten proteins that lead to the formation of leavened bread. The glutenin proteins that give bonding and elasticity properties are rich in charged and non-polar amino acids, that allow hydrogen bonding, hydrophobic and electrostatic interactions. In addition to these interactions, the main important bonding of gluten proteins occurs via disulphide bond formation and these bonds also lead to the development of extended protein networks due to the binding of protein subunits. The elastic behavior of gluten dough is achieved from the glutenin subunits which are categorized as high molecular weight (HMW) and low molecular weight (LMW) subunits. The dough elastic behavior can further be improved through several techniques wherein glutenin concentration is improved in the wheat variety like in case of "Bobwhite" wheat variety (Blechl & Anderson, 1996; Altpeter et al., 1996). The deviation in the concentration leads to increased elasticity of dough (Barro et al., 1997).

3 Methods and Techniques for Gluten Degradation

There have been a lot of studies emphasizing gluten degradation and ways to develop gluten-free food formulations. Various techniques used to develop gluten-free foods for celiac patients are discussed below:

3.1 Enzymatic Methods

Enzymes, due to their potency to catalyze various biochemical reactions and due to absence of any negative impact on health, are considered to be novel solutions and safe alternative against the usage of chemical ingredients for inhibiting the immuno-reactivity of gluten present in food systems (Rosell, 2009). In the past few years, enzymes have been utilised as a means for degradation of gluten present in various foods. Various enzymes have been found to break the glutamine and proline-rich gluten effectively inside the gastrointestinal tract. Clinical trials have shown that enzymes such as prolyl endopeptidase (isolated from *Sphingomonas capsulate*), cysteine endoprotease (isolated from barley), and prolyl endoprotease (isolated from *Aspergillus niger*) can degrade gluten effectively in the gastrointestinal tract (Bethune et al., 2006; Ehren et al., 2008; Mitea et al., 2008). Prolyl endoprotease (isolated from *Aspergillus niger*) is available as a dietary supplement in United States market as GlutnGo™ (Bricker Labs, Chandler, AZ, USA) and SpectraZyme® (Metagenics, Aliso Viejo, CA. USA), but is marketed as Tolerase®G by DSM Nutritional Products (Heerlen, The Netherlands). Tolerase®G is aimed to degrade unintentional gluten present in the gluten-free foods and should not be confused with a means for prevention of celiac diseases or as a replacement of gluten-free foods. In an experimental study, Sestak et al. (2016) determined the effect of oral supplementation of Tolerase®G (at recommended dosage) along with reduced gluten barley diet on gluten sensitive rhesus macaques model. The intake of 32–64 mg gluten per day from reduced gluten barley diet was found to get degraded by prolyl endoprotease present in Tolerase®G and the overall effect was found to be similar to that of gluten-free diet.

Another approach to hinder the reactivity of gluten peptides is to reduce their binding ability with HLA-DQ2/8 by introducing a bulky molecule into the system. Transamidation of wheat flour using an enzyme and a suitable amine donor can be used to block the gliadin immunotoxicity by hindering the secretion of interferon-γ by intestinal T cells of celiac diseased patients (Gianfrani et al., 2007; Mazzarella et al., 2012).

Enzymes are widely used for shelf-life enhancement and for modification of rheological properties of dough of various gluten-free products. They are known to improve the rheological characteristics and product quality by forming protein cross-linkages, and promoting hydrolysis and oxidation in the gluten-free batters (Renzetti et al., 2008a, 2008b; Renzetti & Arendt, 2009; Rosell, 2009; Segura & Rosell, 2011). Various enzymes such as transglutaminase, glucose oxidase, tyrosinase, laccase, cyclodextrin glycosyltransferase have been found to modify the dough characteristics resulting in formulation of gluten-free products with desirable texture characteristics and functionality.

3.1.1 Transglutaminase

Transglutaminase can be used to catalyze the formation of intermolecular cross-linkages between protein molecules that may be from a single or multiple sources. Major classes of these proteins include dairy proteins, pea legume proteins, myosin, wheat proteins, oat globulins, lactalbumin, conalbumin, and soy proteins (Babiker et al., 1996; Ikura et al., 1980; Larre et al., 1993; Marco et al., 2007; Rosell et al., 2003; Siu et al., 2002). Transglutaminase has been widely applied to gluten-free bread formulations to modify the viscoelastic behaviour of the batters, and help in formation of protein networks, thus enhancing the quality of final product. For instance, transglutaminase was found to ameliorate the consistency and rheological characteristics of rice dough (Gujral & Rosell, 2004a; Pongjaruvat et al., 2014; Shin et al., 2010). It was found to promote cross-linkage formation between protein fragments present in rice and this was supported by the evidence that with increase in concentration of the enzyme, the concentration of free amine groups was found to decrease (Gujral & Rosell, 2004a; Pongjaruvat et al., 2014). With increasing enzyme concentration, the water binding capacity of dough was also found to enhance resulting in the structural modification of rice proteins. These structural changes and cross-linking of rice proteins improve the visco-elastic properties and handling behavior of dough, thus, making it suitable for formulating gluten-free breads and other similar products (Gujral & Rosell, 2004a; Pongjaruvat et al., 2014; Shin et al., 2010).

Rheological and processing attributes of gluten-free oat dough was found to be enhanced significantly by addition of exogenous proteins and 1% transglutaminase. The thermo-mechanical properties, cooking quality, elasticity, and hardness of noodles made from this dough were found to be enhanced and the cooking losses were lowered. Cross-linking between protein fractions was found to be catalyzed by the transglutaminase resulting in formation of new covalent bonds (Wang et al., 2011). Bread produced from brown rice flour, after treating it with transglutaminase was found to have improved textural properties, better elasticity and enhanced consistency due to polymerization of brown rice protein fractions to form bigger, insoluble complexes. α and β-glutelin subunits were found to be the primary substrates for this polymerization, while the globulin and albumin fragments were barely affected by transglutaminase.

Microbial transglutaminase was found to revamp the dough-handling characteristics of pre-gelatinised cassava starch and sorghum-based batter. Increasing the concentration of enzyme was found to intensify the elastic recovery and zero-shear viscosity of the resulting batter while reducing its resistance to deformation and compliance. Chewiness and firmness of the resulting bread crumb was also found to increase with increase in the concentration of enzyme while unaffecting its cohesiveness and springiness (Onyango et al., 2010). Rheological, biochemical and textural attributes of dough and batters prepared from damaged sorghum or wheat flour were also found to be boosted by incorporation of microbial transglutaminase (Onyango et al., 2010; Renzetti et al., 2008a, 2008b; Rosell, 2009). The enzyme was also proven to promote formation of covalent bonding between lysine and

glutamine residues in the gluten-free batter comprising of rice flour, cornflour, xanthan gum and potato starch which resulted in better protein linkage in the resulting batter (Moore et al., 2006).

Although, transglutaminase was found to have enhanced the rheological and textural properties of various gluten-free food formulations, its incorporation into food systems should always be cautious. Studies have proven that the transglutaminase, upon exposure to wheat proteins in the gut, can induce formation of autoantigen of celiac disease (Dieterich et al., 1997; Marsh, 1997).

3.1.2 Glucose Oxidase (EC 1.1.3.4)

Glucose oxidase is a widely used oxidising enzyme in the food industries and is steadily gaining importance in the bakery sector. It produces D-gluconic acid and hydrogen peroxide upon oxidising the β-D-glucose under aerobic conditions. Its ability to oxidise free sulphydryl units present in gluten proteins can be an advantage to tailor the rheological behaviour of wheat dough (Primo-Martin et al., 2003). Glucose oxidase can be used to enhance the rheological behaviour of gluten-free dough formulations by inducing cross-linkage of water-soluble wheat protein fractions, including both disulphide and non-disulphide linkages (Rasiah et al., 2005). Studies have shown that addition of glucose oxidase at a level of 1 unit/g of flour could promote disulphide bridge formation and therefore, reduce the amount of sulphydryl groups by 41.3% (Gujral & Rosell, 2004a).

Glucose oxidase was found to enhance the elasticity of rice flour proteins and modify their structural arrangement by oxidising the free sulphydryl units and forming the disulphide linkages. This functionality was found to rise with increase in level of the enzyme and thus results in formation of stronger dough. Rice flour, with the enhanced elastic behaviour can be further utilised in formulation of gluten-free foods (Gujral & Rosell, 2004b). In a study, Renzetti and Arendt (2009) examined the effect of addition of glucose oxidase in various gluten-free dough formulations. Elastic-like behaviour of sorghum and cornflour were found to increase by enzymatic treatment which was mainly due to polymerization of protein structures. The aggregates formation, as a result of protein polymerization, was found to be favoured by the surplus availability of free sulphydryl groups in these flours (Renzetti & Arendt, 2009).

3.1.3 Cyclodextrin Glycosyltransferase

Cyclodextrin glycosyltransferase is a special enzyme that promotes breakage of 1,4-glycosidic bonds in starch molecules and simultaneously, forming the bond between reducing and non-reducing ends to form cyclic compounds (Ohnishi et al., 1997). It can alter the adhesive properties of various starches by formation of cyclodextrins from their related sugars (Li et al., 2000; Liang et al., 2002). The cyclodextrin molecules, thus formed, can act as molecular container and can entrap

hydrophobic fragments within them. Since the rice proteins are hydrophobic in nature, they cannot be used as bread improvers and conditioners; therefore, this enzyme can improve their rheological properties. Due to multiple catalysing nature, cyclodextrin glycosyltransferase could act as a suitable means of modifying the structure of rice proteins making them suitable for formulating gluten-free rice-based bread and other products (Gujral et al., 2003).

Cyclodextrin glycosyltransferase was also found to enhance the baking characteristics and lower the rate of staling of bread (Gujral et al., 2003; Lee et al., 2002). The delayed staling could be attributed to the formation of complex networks between cyclodextrins and proteins and lipids, which decreases the amount of interfacial tensile forces acting due to presence of emulsifiers (Liang et al., 2002; Shimada et al., 1992).

3.1.4 Endopeptidases

The endopeptidases found largely in microorganisms and are used for the enzymatic degradation of gluten peptides to small and lesser immunogenic fragments. The process can also be performed by fungal and bacterial enzymes e.g., Latiglutenase may degrade gluten within the intestinal lumen resulting in non-antigenic peptides (Stepniak et al., 2006; Piper et al., 2004).

3.2 High Pressure Treatment

For the past few years, numerous studies have been conducted to modify the physical structure and the application of high pressure to cereal flours to improve the functional attributes have been done (Bárcenas et al., 2010; Hüttner et al., 2009; Kieffer et al., 2007; Michel & Autio, 2001; Schurer et al., 2007). Most importantly, it tailors the structure of carbohydrates and protein fragments in the food system to induce desirable functionalities (Rastogi et al., 2007). Application of high pressure has been proven to reform the structural and viscoelastic properties of various cereal batters, including, rice, buckwheat, sorghum, teff and oats by changing the structural orientation of protein fractions and gelatinizing the starch present in them (Hüttner et al., 2009; Vallons et al., 2011). It is evident to be a suitable technique to improve the structure of gluten-free batters and doughs (Angioloni & Collar, 2012a, 2012b; Vallons et al., 2011). Various studies have demonstrated utilization of high pressure varying from 100 to 1000 MPa to enhance functionality of proteins and starches in gluten-free foods where it enables the gelatinisation of starch and allows it to swell up without disturbing the integrity of its granular structure (Gomes et al., 1998; Vallons & Arendt, 2009).

High pressure alters the structure of proteins in the same manner as thermal or chemical induced denaturation, although the mechanism of structural alteration varies greatly in this technique. Application of high pressure promotes occurrence of

hydrophobic interactions, Van der Walls interactions and hydrogen bonding in the biomolecules which accounts for a greater packing density of the molecules (Knorr et al., 2006). Depending on the amount of pressure applied, this technique can enhance the reactivity of sulphydryl groups and can easily distort the tertiary and quarternary protein structures, however, primary and secondary structure of proteins (α-helices and β-sheet structures) remain unaltered due to their incompressibility (Boonyaratanakornkit et al., 2002; Rivalain et al., 2010). High pressure also promotes polymerisation of protein fragments and can enhance the rheology of batter by improving its elasticity (Renzetti & Arendt, 2009). It acts as a promising technique for development of gluten-free dough using nutritionally rich cereals like sorghum, oats, and millets by improving their machinability and textural attributes (Angioloni & Collar, 2012a, 2012b).

In order to improve consistency of gluten-free batters, formation of a rigid gel is highly favorable. Gelatinization temperature reduces significantly upon application of high pressure to the batters which modifies its rheological attributes (Bauer & Knorr, 2005; Liu et al., 2008; Muhr et al., 1982). High-pressure processing induces formation of creamy texture in barley starch, similar to that of corn, wheat, and tapioca starches, which enhances its rheological properties and help in formulation of gluten-free products using barley flour but having texture similar to that of wheat-based products (Stolt et al., 2000).

High-pressure processing technology have also been found to affect the gluten and gliadin fractions in wheat flour by rearranging the disulphide bonds, thus altering the rheology of dough and batter produced from it (Kieffer et al., 2007). However, it should be noted that these rheological modifications vary greatly with the amount of pressure applied. A low-pressure treatment of gluten at 200 MPa and 30 °C was found to lower the strength of gluten network. An increase in pressure and temperature leads to increase in concentration of insoluble protein fragments which in turn, increases the strength of gluten and its resistance to extend further. However, gluten was found to completely lose its cohesive character upon application of extremely high amount of pressure of 800 MPa at 60 °C (Apichartsrangkoon et al., 1998; Kieffer et al., 2007). Hence, it is very important that high pressure treatment should be applied to enhance the properties of doughs and batters only after proper optimization of processing parameters.

3.3 Sourdough Fermentation Technique

Sourdough is the dough prepared by incorporation of starter culture of lactic acid bacteria and yeasts into flour and water. These starter cultures can either be present in flour as contaminants or may be added intentionally (De Vuyst & Degeest, 1999). This fermentation process is well-known to enhance the flavour, texture, volume, and nutritional attributes of the bread and hinders its spoilage by bacterial or mould infestation (Tafti et al., 2013). In the past few years, this technique has been widely applied for enhancement of the dough-handling attributes of gluten-free batters (De

Vuyst & Degeest, 1999; Houben et al., 2010; Moroni et al., 2010; Schober et al., 2007). A detailed knowledge of microbial interactions happening during the fermentation process is highly required to control their growth and to maintain the uniformity in quality attributes of the gluten-free dough. In this type of fermentation method, the carbohydrate profile of the gluten-free flour is of key importance. For instance, Galle et al. (2010) found that deficiency of maltose in sorghum sourdough, during initial stage of fermentation, was found to hinder the growth of starter strain (*Lactobacillus sanfranciscensis*), while presence of glucose in excessive amount favoured growth of *Weissella* spp.

Sourdough fermentation technique also involves degradation of proteins which alters its viscoelastic characteristics, improves its overall quality and promotes formation of precursors for the flavouring compounds. Various functionalities of sourdough fermentation method are described below:

3.3.1 Gluten Detoxification

An important application of sourdough fermentation method is the exclusion of gluten present in flours by hydrolyzing the toxic metabolic substances. Rizzello et al. (2007) found that gluten (*Triticum aestivum*) concentration could be reduced to less than 10 ppm by using suitable *Lactobacilii* and fungal proteases together. This technique was found appropriate for formulation of pasta for celiac patients using a mixture of pre-fermented durum wheat semolina (*Triticum turgidum L.var. durum*) and buckwheat flour (*Fagopyrum esculentum*). In another study, wheat semi-liquid dough was initially allowed to ferment with selected *Lactobacilii* for a period of 24 h at 37 °C, and was then blended with miller, oat, buckwheat flour and baker's yeast. The resulting dough was then fermented at 37 °C for 2 h and was then baked at 220 °C for 20 min which produced bread tolerated to coeliac patients (Di Cagno et al., 2004).

3.3.2 Formation of Extracellular Exopolysaccharides

Lactic acid bacteria, due to their ability to release extracellular exopolysaccharides, have drawn ample interest of researchers working on development of gluten-free food formulations. These compounds were found to have potential applications as bio-thickeners which can stabilize, emulsify, viscosity and induce gelation of numerous gluten-free foods (De Vuyst & Degeest, 1999; Waldherr & Vogel, 2009). The rheological properties of resulting gluten-free dough were enhanced due to the potency of these polysaccharides to act as replacement for hydrocolloids (Galle et al., 2011, 2012; Katina et al., 2009). Moreover, these extracellular exopolysaccharides were found to promote growth of *Bifidobacteria* in the gut.

3.3.3 Development of Dried Sourdough

Dried sourdough has been used as an appropriate bakery ingredient for over four decades due to consistent quality, lower transportation cost and lesser end-product quality variations in comparison with fresh sourdough (Brandt, 2006). Tafti et al. (2013) produced spray-dried sourdough and determined its physico-chemical and functional attributes. Drying of sourdough was found to drastically decrease the population of lactic acid bacteria. Incorporation of spray-dried sourdough was found to delay the staling process of bread and improve its overall flavour. Although, studies have been performed to formulate and use stable dried sourdough as a crucial ingredient for wheat-based bakery products (Kulp & Lorenz, 2003) its usage for modification of gluten-free formulations still needs an in-depth research in future (Deora et al., 2014).

3.4 Extrusion Technology

Extrusion technology has been proven to improve the functional characteristics like water solubility, rheological attributes, water absorption index, and breaking strength of starch-based food formulations (Choi et al., 2008). Extrusion of rice flour at a moisture level of 20 mL/100 g and barrel temperature of 180 °C was found to modify its functional attributes by gelatinising the starch granules. The resulting extruded rice flour can act as a substitute for gluten in formulating the gluten-free foods. This modified functionality is mainly acknowledged to the formation of ample hydrogen bonds with water which is a result of pre-gelatinisation of starch (Jeong et al., 2011). Clerici et al. (2009) developed gluten-free bread using a mixture of raw rice flour and acidic extruded rice flour which was found to have better textural attributes with improved crust colour. The results advocated for the suitability of acidic extruded rice flour as a novel alternative to gluten for formulating bread for coeliac patients.

The effect of incorporating extruded maize flour in the gluten-free bread formulations with buckwheat flour, rice flour, maize flour and extruded maize flour have been studied (Ozola et al., 2011) and the addition of extruded maize flour was found to impart uniform porosity, higher softness and moisture content to the gluten-free bread. Although, extrusion technology can be greatly used as a cost-efficient and novel method of developing gluten-free bakery products, its application on utilization of other cereals is still a major area of research in near future.

Extrusion technology can also be used to fasten the process of liquefaction. Extrusion-enzyme liquefaction method is based on the principle that extrusion degrades and gelatinises the starch in a thermo-mechanical manner which makes it more prone to be affected by the enzymatic attack. This technique can also be applied to concentrate protein fragments (de Mesa-Stonestreet et al., 2012) which can be further used as replacement for gluten in gluten-free food formulations due to the deficiency of proteins. Proteins from sorghum flour have been successfully

concentrated by this method which were further utilized to enhance viscoelastic nature of the gluten-free dough (de Mesa et al., 2009). Liquefaction of starch becomes easy and fast due to extrusion and the sorghum protein concentrate, thus obtained, has better digestibility and desirable functional attributes for its potential usage in food formulations and beverage industries (de Mesa-Stonestreet et al., 2012).

3.5 Genetic Modification

One of the methods to reduce the toxicity of gluten is genetic modification. Wheat has a hexaploid genome AABBDD, wherein chromosomes 1 and 6 predominantly harbor the genes known to code for immunotoxic components of gluten (Marino et al., 1996). Genetic modification of wheat has been done to attenuate immunotoxicity effect which however, may also alter the gastronomic properties of wheat, the yield etc., if these properties are governed by the same or neighboring genetic loci. A study explored a variant formed by the removal of genes on chromosome 1 that code for β, γ, and ω gliadin fractions. While the toxicity was attenuated, the mechanical properties of wheat were not altered. However, when α fraction was attenuated instead, the mechanical properties were compromised while also significantly reducing the dose of immunogenic T cell epitopes (van den Broeck et al., 2009). The International Wheat Genome Sequencing Consortium delivered a high-quality annotated reference genome sequences of the Chinese spring wheat. This has the potential to fast track development of genetically engineered wheat with attenuated immunotoxicity while preserving its gastronomic or agronomic properties.

3.6 Microwave Treatment

Microwave treatment has been used to detoxify wheat gluten proteins (Bevilacqua et al., 2016). The microwave energy is applied prior to milling, for a few seconds to cleaned, hydrated wheat kernels at 15–18% humidity, to reach a high temperature within a short period of time. The process is repeated over several cycles until a temperature of 80–90 °C and moisture of 13–13.5% in the grains is reached. After this, grains are dried over 24 h at room temperature and milled. This process had been proposed to attenuate the immunotoxicity of gluten by 99%, as detected by the R5 monoclonal antibody method, which is a method of detection of gluten immunogenic peptides (Lamacchia et al., 2016). The bread from this flour was called "gluten friendly or GLUFR." However, a later study found the immunotoxicity of this flour to be unchanged, when checked by the G12 method (another antibody-based gluten immunogenic detection test), mass spectrometry-based proteomics and in vitro assay with T cells of celiac subjects (Gianfrani et al., 2017). The microwave treatment causes reconfiguration of the gluten structure that interferes with detection of gluten immunogenic peptides by R5 ELISA method.

3.7 Immune Modulation

The immune modulation may restore gluten tolerance and for this a vaccine may induce immune tolerance to some of the gluten immunogenic peptides. The celiac disease can also be treated by the use of nanoparticle-based therapeutic agents that reverse gluten sensitivity and stimulate immune tolerance by delivering encapsulated gliadin to tolerogenic immune cells (Akbari et al., 2006). Tolerogenic therapies using vaccines have been developed to hypo-sensitize the adaptive immunity and is a potential therapeutic approach to allergic and autoimmune diseases. In a departure from their traditional use of immunization, vaccines are now being tested for desensitization. Examples in the case of Ced, the peptide-based vaccine called NexVax2. It was developed by a US based company, ImmunoSanT, Inc. NexVax2 is composed of three proprietary, immunodominant gliadin peptides named NPL001, NPL002, and NPL003 each of which is 15–16 amino acid long. The vaccine target is the HLADQ2.5-epitope-TCR complex linking the antigen presenting cell to the gluten-reactive CD4+ T cells. It engages specific immune cells and a signature pathway has been discovered based on that. In animal studies in HLADQ2.5 transgenic mice having gluten-sensitive T cells, it was found to be efficacious (Anderson & Jabri, 2013).

The use of oral agents that acts locally in the gut is another way of inducing immune tolerogenesis. The Lactobacillus lactis, genetically engineered to release modified, non-toxic gliadin was administered orally to secrete a deamidated DQ8 gliadin epitope in the intestinal lumen of transgenic NOD-2 mice with ABoDQ8 haplotype. This induced suppression of the lamina propria and systemic DQ8-restricted T-cell responses, downregulation of IL-12 secretion, systemic production of IL-10 and TGF-β and induction of Foxp3+ Tregs in the lamina propria. These findings suggest development of mucosal tolerance to the gliadin (Huibregtse et al., 2009). Similarly a study used Bacillus subtilis spores as a long-lived, protease-resistant adjuvant system for administering gliadin peptides to HLA-DQ8-transgenic mice. The spore-adsorbed gliadin activated the dendritic cells and elicited a T-cell response in the gut. This mechanism (Bonavita et al., 2015) can be utilized for developing immune tolerance.

3.8 Probiotics

Probiotics play a significant part in the intestinal microbial imbalances of individuals with celiac disease due to increased *Bacteroides* spp. and decreased *Bifidobacterium* spp. irrespective of gluten-free diet. The patients suffer from persistent gastrointestinal symptoms due to gut microbiota composition but certain strains of probiotics may act on gluten immunogenicity, assist with intestinal healing, and improve patients' symptoms (Fasano, 2009). Studies have found a reduction in the relative proportion of *Firmicutes, Proteobacteria, Bifidobacterium* and a

relative increase in *Bacteroides* and *E. coli* in celiac disease patients compared to controls. Oligofructose-enriched inulin a prebiotic, increased the *Bifidobacterium* count in the gut significantly, with no side effects (Drabinska et al., 2018). These findings point to a possible causative role of gut dysbiosis in celiac disease, although the exact mechanism remains obscure. Many studies have suggested low use of short chain polysaccharides like fructans, lactose, mannitol, sorbitol etc. which are hard to digest, resulting in fermentation in the bowel and flatulence, and are implicated in causing some of the symptoms of Irritable Bowel Syndrome (IBS) (Magge & Lembo, 2012).

4 Conclusions

The gluten replacement with different ingredients and processing techniques in various food products has been done but the feature of these foods is not equal to gluten foods. In addition, the low accessibility, high cost and frequently critical sensory and textural parameters of food products from foods free from gluten add as a burden to celiac individuals. The gluten is removed from the food products by different mechanisms either by using enzymes like peptidases or microbial transglutaminase, microwave treatments or genetic engineering. The superior quality of foods free from gluten can thus be developed with these products (wheat, barley and rye) after removal or degradation of gluten.

References

Akbari, M. R., Mohammadkhani, A., Fakheri, H., Zahedi, M. J., Shahbazkhani, B., Nouraie, M., & Malekzadeh, R. (2006). Screening of the adult population in Iran for coeliac disease: Comparison of the tissue-transglutaminase antibody and anti-endomysial antibody tests. *European Journal of Gastroenterology & Hepatology, 18*(11), 1181–1186.

Altpeter, F., Vasil, V., Srivastava, V., & Vasil, I. K. (1996). Integration and expression of the high-molecular-weight glutenin subunit 1Ax1 gene into wheat. *Nature Biotechnology, 14*(9), 1155.

Anderson, R. P., & Jabri, B. (2013). Vaccine against autoimmune disease: Antigen-specific immunotherapy. *Current Opinion in Immunology, 25*(3), 410–417.

Angioloni, A., & Collar, C. (2012a). Effects of pressure treatment of hydrated oat, finger millet and sorghum flours on the quality and nutritional properties of composite wheat breads. *Journal of Cereal Science, 56*(3), 713–719.

Angioloni, A., & Collar, C. (2012b). Promoting dough viscoelastic structure in composite cereal matrices by high hydrostatic pressure. *Journal of Food Engineering, 111*(4), 598–605.

Apichartsrangkoon, A., Ledward, D., Bell, A., & Brennan, J. (1998). Physicochemical properties of high pressure treated wheat gluten. *Food Chemistry, 63*(2), 215–220.

Babiker, E. F. E., Fujisawa, N., Matsudomi, N., & Kato, A. (1996). Improvement in the functional properties of gluten by protease digestion or acid hydrolysis followed by microbial transglutaminase treatment. *Journal of Agricultural and Food Chemistry, 44*(12), 3746–3750.

Bárcenas, M. E., Altamirano-Fortoul, R., & Rosell, C. M. (2010). Effect of high pressure processing on wheat dough and bread characteristics. *LWT - Food Science and Technology, 43*(1), 12–19.

Barro, F., Rooke, L., Békés, F., Gras, P., Tatham, A. S., Fido, R., & Barceló, P. (1997). Transformation of wheat with high molecular weight subunit genes results in improved functional properties. *Nature Biotechnology, 15*(12), 1295.

Bauer, B., & Knorr, D. (2005). The impact of pressure, temperature and treatment time on starches: Pressure-induced starch gelatinisation as pressure time temperature indicator for high hydrostatic pressure processing. *Journal of Food Engineering, 68*(3), 329–334.

Bethune, M. T., Strop, P., Tang, Y., Sollid, L. M., & Khosla, C. (2006). Heterologous expression, purification, refolding, and structural-functional characterization of EP-B2, a self-activating barley cysteine endoprotease. *Chemistry & Biology, 13*(6), 637–647.

Bevilacqua, A., Costabile, A., Bergillos-Meca, T., Gonzalez, I., Landriscina, L., Ciuffreda, E., … Lamacchia, C. (2016). Impact of gluten-friendly bread on the metabolism and function of in vitro gut microbiota in healthy human and coeliac subjects. *PLoS One, 11*(9), e0162770.

Blechl, A. E., & Anderson, O. D. (1996). Expression of a novel high-molecular-weight glutenin subunit gene in transgenic wheat. *Nature Biotechnology, 14*(7), 875.

Bonavita, R., Isticato, R., Maurano, F., Ricca, E., & Rossi, M. (2015). Mucosal immunity induced by gliadin-presenting spores of Bacillus subtilis in HLA-DQ8-transgenic mice. *Immunology Letters, 165*(2), 84–89.

Boonyaratanakornkit, B. B., Park, C. B., & Clark, D. S. (2002). Pressure effects on intra-and intermolecular interactions within proteins. *Biochimica et Biophysica Acta (BBA) - Protein Structure and Molecular Enzymology, 1595*(1–2), 235–249.

Brandt, M. (2006). Geschichte des sauerteiges. In *Handbuch sauerteig* (Vol. 6, pp. 1–5). Behr's Verlag.

Choi, I., Song, J., Lee, C.-K., Kim, K.-J., Suh, S.-J., Son, J.-R., Ryu, G.-H., & Kim, J.-H. (2008). Effects of moisture and barrel temperature of extrusion process on physicochemical and functional properties of specialty rice cultivars. *Food Science and Biotechnology, 17*(2), 319–323.

Clerici, M. T. P. S., Airoldi, C., & El-Dash, A. A. (2009). Production of acidic extruded rice flour and its influence on the qualities of gluten-free bread. *LWT - Food Science and Technology, 42*(2), 618–623.

de Mesa, N. J. E., Alavi, S., Singh, N., Shi, Y.-C., Dogan, H., & Sang, Y. (2009). Soy protein-fortified expanded extrudates: Baseline study using normal corn starch. *Journal of Food Engineering, 90*(2), 262–270.

de Mesa-Stonestreet, N. J., Alavi, S., & Gwirtz, J. (2012). Extrusion-enzyme liquefaction as a method for producing sorghum protein concentrates. *Journal of Food Engineering, 108*(2), 365–375.

De Vuyst, L., & Degeest, B. (1999). Heteropolysaccharides from lactic acid bacteria. *FEMS Microbiology Reviews, 23*(2), 153–177.

Deora, N. S., Deswal, A., & Mishra, H. N. (2014). Alternative approaches towards gluten-free dough development: Recent trends. *Food Engineering Reviews, 6*(3), 89–104.

Di Cagno, R., De Angelis, M., Auricchio, S., Greco, L., Clarke, C., De Vincenzi, M., Giovannini, C., D'Archivio, M., Landolfo, F., & Parrilli, G. (2004). Sourdough bread made from wheat and nontoxic flours and started with selected lactobacilli is tolerated in celiac sprue patients. *Applied and Environmental Microbiology, 70*(2), 1088–1096.

Dieterich, W., Ehnis, T., Bauer, M., Donner, P., Volta, U., Riecken, E. O., & Schuppan, D. (1997). Identification of tissue transglutaminase as the autoantigen of celiac disease. *Nature Medicine, 3*(7), 797.

Drabinska, N., Jarocka-Cyrta, E., Markiewicz, L. H., & Krupa-Kozak, U. (2018). The effect of oligofructose-enriched inulin on faecal bacterial counts and microbiotaassociated characteristics in celiac disease children following a gluten-free diet: Results of a randomized, placebo-controlled trial. *Nutrients, 10*, 201. https://doi.org/10.3390/nu10020201

Edwards, N. M., Mulvaney, S. J., Scanlon, M. G., & Dexter, J. E. (2003). Role of gluten and its components in determining durum semolina dough viscoelastic properties. *Cereal Chemistry, 80*(6), 755–763.

Ehren, J., Govindarajan, S., Morón, B., Minshull, J., & Khosla, C. (2008). Protein engineering of improved prolyl endopeptidases for celiac sprue therapy. *Protein Engineering, Design & Selection, 21*(12), 699–707.

Fasano, A. (2009). Celiac disease insights: Clues to solving autoimmunity. *Scientific American*, 49–57.

Galle, S., Schwab, C., Arendt, E., & Gänzle, M. (2010). Exopolysaccharide-forming Weissella strains as starter cultures for sorghum and wheat sourdoughs. *Journal of Agricultural and Food Chemistry, 58*(9), 5834–5841.

Galle, S., Schwab, C., Arendt, E. K., & Gänzle, M. G. (2011). Structural and rheological characterisation of heteropolysaccharides produced by lactic acid bacteria in wheat and sorghum sourdough. *Food Microbiology, 28*(3), 547–553.

Galle, S., Schwab, C., Dal Bello, F., Coffey, A., Gänzle, M. G., & Arendt, E. K. (2012). Influence of in-situ synthesized exopolysaccharides on the quality of gluten-free sorghum sourdough bread. *International Journal of Food Microbiology, 155*(3), 105–112.

Gianfrani, C., Siciliano, R. A., Facchiano, A. M., Camarca, A., Mazzeo, M. F., Costantini, S., Salvati, V. M., Maurano, F., Mazzarella, G., & Iaquinto, G. (2007). Transamidation of wheat flour inhibits the response to gliadin of intestinal T cells in celiac disease. *Gastroenterology, 133*(3), 780–789.

Gianfrani, C., Mamone, G., La Gatta, B., Camarca, A., Di Stasio, L., Maurano, F., … Di Luccia, A. (2017). Microwave-based treatments of wheat kernels do not abolish gluten epitopes implicated in celiac disease. *Food and Chemical Toxicology, 101*, 105–113.

Gomes, M. R. A., Clark, R., & Ledward, D. A. (1998). Effects of high pressure on amylases and starch in wheat and barley flours. *Food Chemistry, 63*(3), 363–372.

Gujral, H. S., & Rosell, C. M. (2004a). Functionality of rice flour modified with a microbial transglutaminase. *Journal of Cereal Science, 39*(2), 225–230.

Gujral, H. S., & Rosell, C. M. (2004b). Improvement of the breadmaking quality of rice flour by glucose oxidase. *Food Research International, 37*(1), 75–81.

Gujral, H. S., Guardiola, I., Carbonell, J. V., & Rosell, C. M. (2003). Effect of cyclodextrinase on dough rheology and bread quality from rice flour. *Journal of Agricultural and Food Chemistry, 51*(13), 3814–3818.

Houben, A., Götz, H., Mitzscherling, M., & Becker, T. (2010). Modification of the rheological behavior of amaranth (Amaranthus hypochondriacus) dough. *Journal of Cereal Science, 51*(3), 350–356.

Huibregtse, I. L., Marietta, E. V., Rashtak, S., Koning, F., Rottiers, P., David, C. S., … Murray, J. A. (2009). Induction of antigen-specific tolerance by oral administration of Lactococcus lactis delivered immunodominant DQ8-restricted gliadin peptide in sensitized nonobese diabetic Ab Dq8 transgenic mice. *The Journal of Immunology, 183*(4), 2390–2396.

Hüttner, E. K., Dal Bello, F., Poutanen, K., & Arendt, E. K. (2009). Fundamental evaluation of the impact of high hydrostatic pressure on oat batters. *Journal of Cereal Science, 49*(3), 363–370.

Ikura, K., Kometani, T., Sasaki, R., & Chiba, H. (1980). Crosslinking of soybean 7S and 11S proteins by transglutaminase. *Agricultural and Biological Chemistry, 44*(12), 2979–2984.

Jeong, S.-H., Kang, W.-S., & Shin, M.-S. (2011). Physicochemical properties of high yielding non-waxy rice flours extruded with different moisture contents. *Korean Journal of Food and Cookery Science, 27*(6), 745–754.

Katina, K., Maina, N. H., Juvonen, R., Flander, L., Johansson, L., Virkki, L., Tenkanen, M., & Laitila, A. (2009). In situ production and analysis of Weissella confusa dextran in wheat sourdough. *Food Microbiology, 26*(7), 734–743.

Kieffer, R., Schurer, F., Köhler, P., & Wieser, H. (2007). Effect of hydrostatic pressure and temperature on the chemical and functional properties of wheat gluten: Studies on gluten, gliadin and glutenin. *Journal of Cereal Science, 45*(3), 285–292.

Knorr, D., Heinz, V., & Buckow, R. (2006). High pressure application for food biopolymers. *Biochimica et Biophysica Acta (BBA) - Proteins and Proteomics, 1764*(3), 619–631.

Kulp, K., & Lorenz, K. (2003). *Handbook of dough fermentations* (Vol. 127). CRC Press.

Lamacchia, C., Landriscina, L., & D'Agnello, P. (2016). Changes in wheat kernel proteins induced by microwave treatment. *Food Chemistry, 197*, 634–640.

Larre, C., Chiarello, M., Dudek, S., Chenu, M., & Gueguen, J. (1993). Action of transglutaminase on the constitutive polypeptides of pea legumin. *Journal of Agricultural and Food Chemistry, 41*(11), 1816–1820.

Lee, M. R., Swanson, B. G., & Baik, B. K. (2001). Influence of amylose content on properties of wheat starch and breadmaking quality of starch and gluten blends. *Cereal Chemistry, 78*(6), 701–706.

Lee, S.-H., Kim, Y.-W., Lee, S., Auh, J.-H., Yoo, S.-S., Kim, T.-J., Kim, J.-W., Kim, S.-T., Rho, H.-J., & Choi, J.-H. (2002). Modulation of cyclizing activity and thermostability of cyclodextrin glucanotransferase and its application as an antistaling enzyme. *Journal of Agricultural and Food Chemistry, 50*(6), 1411–1415.

Li, W., Huang, J., & Corke, H. (2000). Effect of β-cyclodextrin on pasting properties of wheat starch. *Food/Nahrung, 44*(3), 164–167.

Liang, X., King, J. M., & Shih, F. F. (2002). Pasting property differences of commercial and isolated rice starch with added lipids and β-cyclodextrin. *Cereal Chemistry, 79*(6), 812–818.

Liu, Y., Selomulyo, V. O., & Zhou, W. (2008). Effect of high pressure on some physicochemical properties of several native starches. *Journal of Food Engineering, 88*(1), 126–136.

Magge, S., & Lembo, A. (2012). Low-FODMAP diet for treatment of irritable bowel syndrome. *Gastroenterología y Hepatología, 8*, 739–745.

Marco, C., Pérez, G., Ribotta, P., & Rosell, C. M. (2007). Effect of microbial transglutaminase on the protein fractions of rice, pea and their blends. *Journal of the Science of Food and Agriculture, 87*(14), 2576–2582.

Marino, C. L., Tuleen, N. A., Hart, G. E., Nelson, J. C., Sorrells, M. E., Lu, Y. H., … Lopes, C. R. (1996). Molecular genetic maps of the group 6 chromosomes of hexaploid wheat (Triticum aestivum L. em. Thell.). *Genome, 39*(2), 359–366.

Mariotti, M., Pagani, M. A., & Lucisano, M. (2013). The role of buckwheat and HPMC on the breadmaking properties of some commercial gluten-free bread mixtures. *Food Hydrocolloids, 30*(1), 393–400.

Marsh, M. N. (1997). Transglutaminase, gluten and celiac disease: Food for thought. *Nature Medicine, 3*(7), 725–726.

Mazzarella, G., Salvati, V. M., Iaquinto, G., Stefanile, R., Capobianco, F., Luongo, D., Bergamo, P., Maurano, F., Giardullo, N., & Malamisura, B. (2012). Reintroduction of gluten following flour transamidation in adult celiac patients: A randomized, controlled clinical study. *Clinical and Developmental Immunology, 2012*, 329150.

Michel, M., & Autio, K. (2001). Effects of high pressure on protein-and polysaccharide-based structures. In *Ultra high pressure treatments of foods* (pp. 189–214). Springer.

Mitea, C., Havenaar, R., Drijfhout, J. W., Edens, L., Dekking, L., & Koning, F. (2008). Efficient degradation of gluten by a prolyl endoprotease in a gastrointestinal model: Implications for coeliac disease. *Gut, 57*(1), 25–32.

Moore, M. M., Heinbockel, M., Dockery, P., Ulmer, H., & Arendt, E. K. (2006). Network formation in gluten-free bread with application of transglutaminase. *Cereal Chemistry, 83*(1), 28–36.

Moroni, A. V., Arendt, E. K., Morrissey, J. P., & Dal Bello, F. (2010). Development of buckwheat and teff sourdoughs with the use of commercial starters. *International Journal of Food Microbiology, 142*(1–2), 142–148.

Muhr, A., Wetton, R., & Blanshard, J. (1982). Effect of hydrostatic pressure on starch gelatinisation, as determined by DTA. *Carbohydrate Polymers, 2*(2), 91–102.

Ohnishi, M., Mitsune, T., Tabata, M., Kubota, M., & Rokushika, S. (1997). An attempt to evaluate the subsite structure of cycloamylose glucanotransferase from Bacillus stearothermophilus: Based on its transfer reaction with substrate malto-oligosaccharides. *Starch-Stärke, 49*(9), 360–363.

Onyango, C., Mutungi, C., Unbehend, G., & Lindhauer, M. G. (2010). Rheological and baking characteristics of batter and bread prepared from pregelatinised cassava starch and sorghum and modified using microbial transglutaminase. *Journal of Food Engineering, 97*(4), 465–470.

Ozola, L., Straumite, E., & Klava, D. (2011). Extruded maize flour effect on the quality of gluten-free bread. In *Conference Proceedings of 6th Baltic Conference on Food Science and Technology "Innovations for Food Science and Production"–FOODBALT*, pp. 5–6.

Piper, J. L., Gray, G. M., & Khosla, C. (2004). Effect of prolyl endopeptidase on digestive-resistant gliadin peptides in vivo. *Journal of Pharmacology and Experimental Therapeutics, 311*(1), 213–219.

Pongjaruvat, W., Methacanon, P., Seetapan, N., Fuongfuchat, A., & Gamonpilas, C. (2014). Influence of pregelatinised tapioca starch and transglutaminase on dough rheology and quality of gluten-free jasmine rice breads. *Food Hydrocolloids, 36*, 143–150.

Primo-Martin, C., Valera, R., & Martinez-Anaya, M. (2003). Effect of pentosanase and oxidases on the characteristics of doughs and the glutenin macropolymer (GMP). *Journal of Agricultural and Food Chemistry, 51*(16), 4673–4679.

Rasiah, I., Sutton, K., Low, F., Lin, H.-M., & Gerrard, J. (2005). Crosslinking of wheat dough proteins by glucose oxidase and the resulting effects on bread and croissants. *Food Chemistry, 89*(3), 325–332.

Rastogi, N., Raghavarao, K., Balasubramaniam, V., Niranjan, K., & Knorr, D. (2007). Opportunities and challenges in high pressure processing of foods. *Critical Reviews in Food Science and Nutrition, 47*(1), 69–112.

Renzetti, S., & Arendt, E. K. (2009). Effects of oxidase and protease treatments on the breadmaking functionality of a range of gluten-free flours. *European Food Research and Technology, 229*(2), 307–317.

Renzetti, S., Behr, J., Vogel, R., & Arendt, E. (2008a). Transglutaminase polymerisation of buckwheat (Fagopyrum esculentum Moench) proteins. *Journal of Cereal Science, 48*(3), 747–754.

Renzetti, S., Dal Bello, F., & Arendt, E. K. (2008b). Microstructure, fundamental rheology and baking characteristics of batters and breads from different gluten-free flours treated with a microbial transglutaminase. *Journal of Cereal Science, 48*(1), 33–45.

Rivalain, N., Roquain, J., & Demazeau, G. (2010). Development of high hydrostatic pressure in biosciences: Pressure effect on biological structures and potential applications in biotechnologies. *Biotechnology Advances, 28*(6), 659–672.

Rizzello, C. G., De Angelis, M., Di Cagno, R., Camarca, A., Silano, M., Losito, I., De Vincenzi, M., De Bari, M. D., Palmisano, F., & Maurano, F. (2007). Highly efficient gluten degradation by lactobacilli and fungal proteases during food processing: New perspectives for celiac disease. *Applied and Environmental Microbiology, 73*(14), 4499–4507.

Rosell, C. M. (2009). Enzymatic manipulation of gluten-free breads. In *Gluten-free food science and technology* (pp. 83–98). Wiley-Blackwell.

Rosell, C., Wang, J., Aja, S., Bean, S., & Lookhart, G. (2003). Wheat flour proteins as affected by transglutaminase and glucose oxidase. *Cereal Chemistry, 80*(1), 52–55.

Schober, T. J., Bean, S. R., & Boyle, D. L. (2007). Gluten-free sorghum bread improved by sourdough fermentation: Biochemical, rheological, and microstructural background. *Journal of Agricultural and Food Chemistry, 55*(13), 5137–5146.

Schurer, F., Kieffer, R., Wieser, H., & Koehler, P. (2007). Effect of hydrostatic pressure and temperature on the chemical and functional properties of wheat gluten II. Studies on the influence of additives. *Journal of Cereal Science, 46*(1), 39–48.

Segura, M. E. M., & Rosell, C. M. (2011). Chemical composition and starch digestibility of different gluten-free breads. *Plant Foods for Human Nutrition, 66*(3), 224.

Sestak, K., Thwin, H., Dufour, J., Liu, D., Alvarez, X., Laine, D., Clarke, A., Doyle, A., Aye, P., & Blanchard, J. (2016). Supplementation of reduced gluten barley diet with oral prolyl endopeptidase effectively abrogates enteropathy-associated changes in gluten-sensitive macaques. *Nutrients, 8*(7), 401.

Shewry, P. R., & Lookhart, G. L. (2003). *Wheat gluten protein analysis*. American Association of Cereal Chemists.

Shimada, K. A., Kawano, K. I., Ishii, J. U., & Nakamura, T. A. (1992). Structure of inclusion complexes of cyclodextrins with triglyceride at vegetable oil/water interface. *Journal of Food Science, 57*(3), 655–656.

Shin, M., Gang, D.-O., & Song, J.-Y. (2010). Effects of protein and transglutaminase on the preparation of gluten-free rice bread. *Food Science and Biotechnology, 19*(4), 951–956.

Siu, N.-C., Ma, C.-Y., & Mine, Y. (2002). Physicochemical and structural properties of oat globulin polymers formed by a microbial transglutaminase. *Journal of Agricultural and Food Chemistry, 50*(9), 2660–2665.

Stepniak, D., Spaenij-Dekking, L., Mitea, C., Moester, M., de Ru, A., Baak-Pablo, R., & Koning, F. (2006). Highly efficient gluten degradation with a newly identified prolyl endoprotease: Implications for celiac disease. *American Journal of Physiology-Gastrointestinal and Liver Physiology, 291*(4), G621–G629.

Stolt, M., Oinonen, S., & Autio, K. (2000). Effect of high pressure on the physical properties of barley starch. *Innovative Food Science & Emerging Technologies, 1*(3), 167–175.

Tafti, A. G., Peighambardoust, S. H., Hesari, J., Bahrami, A., & Bonab, E. S. (2013). Physicochemical and functional properties of spray-dried sourdough in breadmaking. *Food Science and Technology International, 19*(3), 271–278.

Vallons, K. J., & Arendt, E. K. (2009). Effects of high pressure and temperature on the structural and rheological properties of sorghum starch. *Innovative Food Science & Emerging Technologies, 10*(4), 449–456.

Vallons, K. J., Ryan, L. A., & Arendt, E. K. (2011). Promoting structure formation by high pressure in gluten-free flours. *LWT - Food Science and Technology, 44*(7), 1672–1680.

van den Broeck, H. C., van Herpen, T. W., Schuit, C., Salentijn, E. M., Dekking, L., Bosch, D., … van der Meer, I. M. (2009). Removing celiac disease-related gluten proteins from bread wheat while retaining technological properties: A study with Chinese Spring deletion lines. *BMC Plant Biology, 9*(1), 41.

Waldherr, F. W., & Vogel, R. F. (2009). Commercial exploitation of homo-exopolysaccharides in non-dairy food. In *Bacterial polysaccharides: Current innovations and future trends* (pp. 314–329). Caister Academic Press.

Wang, F., Huang, W., Kim, Y., Liu, R., & Tilley, M. (2011). Effects of transglutaminase on the rheological and noodle-making characteristics of oat dough containing vital wheat gluten or egg albumin. *Journal of Cereal Science, 54*(1), 53–59.

Wieser, H. (2007). Chemistry of gluten proteins. *Food Microbiology, 24*(2), 115–119.

Wilderjans, E., Pareyt, B., Goesaert, H., Brijs, K., & Delcour, J. A. (2008). The role of gluten in a pound cake system: A model approach based on gluten–starch blends. *Food Chemistry, 110*(4), 909–915.