Millennial consumers' acceptance of the sensory properties of gluten-free bread as predisposed by health and taste attitudes

By

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DECLARATION

I, Nomzamo Magano declare that the dissertation, which I hereby submit for the degree MSc Food Science at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE: NN Magano

DATE: September 2020

This study was approved by the ethical clearance committee of the Faculty of Natural and Agricultural Science, University of Pretoria (reference number: NAS187/2019).

DEDICATION

To the good Lord who made it all possible.

To my husband and family for their love and support.

To the future; to anyone who stumbles upon this document in pursuit of answers. I hope you find something in here that will help build the puzzle of your own research.

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I am because you are

ABSTRACT

Millennial consumers' acceptance of the sensory properties of gluten-free bread as predisposed by health and taste attitudes

By

Nomzamo Magano

Degree: MSc Food Science

Supervisor: Prof H. L. de Kock

Co-supervisor: Prof G. E. du Rand

The hot and dry climate conditions of various parts of South Africa (SA) are partly why not enough wheat for breadmaking (the second most consumed staple food) is produced. Therefore, SA continues to import wheat, negatively impacting the economy. The use of flours from gluten-free (GF) indigenous climate-smart crops for bread products could offer economic advantages. There are GF commercial bread products available in SA, however, their sensory properties and drivers of liking and disliking have not been reported. Determining the acceptability of GF bread may be useful in bringing insight for the development of bread using alternative indigenous and sustainable crops like sorghum and the millets, which also happen to be GF. Food choices made by consumers, however, are affected by factors such as health and taste related considerations. The Roininen health and taste attitudes (HTA) questionnaire was developed to measure the impact consumers' health and taste predispositions have on food choice and consumption. The use of this questionnaire has not yet been explored in Africa.

The objectives of this work were (1) to determine the characteristics of selected commercial GF white, brown and seeded bread brands, (2) to determine the HTAs of a selected group of millennial consumers and (3), to determine whether the HTAs of millennial consumers' (n=173) have an effect on the acceptability of the sensory properties of commercial GF bread. Lastly, to determine the general perceptions millennial consumers' have on GF bread.

The white and brown GF breads were firmer and had more toasted, coffee and nutty flavours, compared to their wheat controls. The seeded bread had similar physical characteristics but differed in flavour profile, where one GF sample had a toasted and coffee flavour and the other one was perceived to have a nutty flavour. The control sample had a distinct wheaty flavour.

The HTAs questionnaire presented itself to be reliable for measuring the HTAs of the consumers (based on the coefficient alpha values of the factors). Surprisingly, no significant effect of HTA classification of the 173 consumers was found on the acceptability of the sensory properties of brown GF and wheat bread. However, most of the participants had the perception that GF bread is healthier than wheat bread. The sensory properties of the control wheat bread were the most preferred across all HTA groups in conditions where consumers were both informed about the nature of the bread (GF/ wheat bread) and uninformed (blind-coded samples). However, information about the GF/wheat containing nature of the bread had a negative effect on the acceptability of the smell of GF bread. A significant interaction effect of HTA grouping and the samples was found for the acceptability of the appearance and taste of the bread samples. This implies that the consumers in the different HTA groups had different perceptions of the appearance and taste of the samples.

The crumbly, dry and firm texture of GF bread was identified as a development challenge which will need to be addressed during the development of GF bread from climate-smart crop flours, bearing in mind that the soft and moist characteristics of wheat bread should also be mimicked as much as possible. The research provides insight for the development of bread made from GF, climate-smart crop flours. Participants preferred the sensory properties of wheat bread which they are more familiar with, regardless of their HTAs and their perception that GF bread was healthier. Furthermore, information that a sample was GF had a negative effect on the acceptability of the smell of the sample. The consumers had a general perception that GF bread provides health benefits and it is more natural and organic than wheat bread. They also thought that wheat bread was more accessible, tasty, convenient and affordable than GF bread. More consumers believed that wheat bread is made from sustainable crops, which is not the case in the context of SA, hence the need for more consumer education.

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1.0 INTRODUCTION

Gluten is a type of protein which is formed in wheat flour after the addition of water and some mechanical action. Wheat is a highly consumed grain used as the main raw material in bread making. Not only is gluten responsible for the cohesive and viscoelastic properties of wheat dough, it is also vital for protein-starch interactions related to the dough's ability to retain gas during fermentation and partly for setting the dough during baking (Mahmoud, Yousif, Gadallah & Alawneh, 2013). The production of wheat in South Africa is insufficient for the population's needs, therefore, the supply shortage is heavily supplemented by the global market as imports (Van der Merwe, 2015). The price of wheat is therefore determined by the import parity price – which can be volatile (Van der Merwe, 2015). Harsh climate conditions also pose a threat to local wheat production. On the other hand, there is the issue of a seemingly global prevalence of coeliac disease (Lionetti, Gatti, Pulvirenti & Catassi, 2015) which requires a strict gluten-free diet. Indigenous crops that have some resistance to drought and that are gluten-free, such as sorghum, would seem to be a more economical and viable option for sustainable human consumption (Araujo, Junnyor, da Silva, Placido, Caliar, de Lima & Vieira, 2015; Shelef, Weisberg & Provenza, 2017). Thus, there is a need to explore the use of flours from indigenous "climate-smart" crops for use in widely consumed bakery products such as pan bread. However, the extent to which consumers will accept such products is an important underlying factor.

The consumer's perception is that gluten-free products are healthier (Allen & Orfila, 2018). However, one concern with commercial gluten-free breads is that there is a significant variation in the nutritional composition among the different types available compared to wheat-based breads (Segura & Rosell, 2011). Gluten-free breads are usually made from compositions that are based on rice and maize flours/starches. Segura and Rosell (2011) found that, in comparison to wheat bread, gluten-free breads generally have a lower contribution to the recommended daily protein intake and a higher contribution to the carbohydrate dietary reference intake, they also have a relatively higher fat content. This deems commercial gluten-free breads nutritionally inferior to wheat bread. Moreover, in South Africa, wheat bread also happens to be made with wheat flour that is fortified with vitamin A, thiamin, riboflavin, niacin, pyridoxine, folic acid, iron and zinc as of 2003 (FACS, 2019b). This is currently not the case with gluten-free flours.

There are different types of consumers, some are more particular about the foods they choose to consume than others. As summarised by Costell, Tárrega and Bayarri (2010), the choices consumers make about food are guided by various factors such as information gained from observation, exposure and consumption of the food. In addition to these are social (e.g. health consciousness) factors, cultural factors, and physiological effects (e.g. pleasure and dislike) resulting from the eating experience and finally, the effect of past experiences (Costell *et al.*, 2010). King, Snow, Meiselman, Sainsbury, Carr, McCafferty, Serrano, Gillette, Millard and Li (2015) and Meiselman (2016) encouraged researchers not to rely on sensory measurements, when measuring factors affecting food choice but to also use psychographic measurement tools (e.g., the Health and Taste Attitudes Scales). There is currently no data published on the health and taste attitudes of consumers in South Africa. Thus, this study aims to determine the health and taste attitudes of a selected group of millennial students and, to determine their acceptance of the sensory properties of commercial gluten-free bread as well as their general perceptions towards gluten-free bread.

2.0 LITERATURE REVIEW

The main subjects of this study are gluten-free and wheat bread; therefore, this literature review aims to cover various aspects relating to the science, technology, economic importance, consumer acceptance and characterisation methods pertaining to these bread types. This review also includes an overview of the relevance of wheat and its production in South Africa. Gluten is also discussed as it is important for bread quality but is however an allergen. Considering the impact that the absence of gluten has on the structure of bread, the literature review also delves into some of the commonly used ingredients and technologies used to produce gluten-free bread which mimics wheat bread.

Since bread is meant for human consumption, methods used to determine the quality and acceptability of bread are described. These methods include mechanical methods and sensory testing methods using humans. Consumers happen to have inherent health and taste attitudes which are factors affecting their food choices. The questionnaire used to measure the health and taste attitudes of consumers is discussed. A short description of millennials follows this as a selected group of millennial students were the consumers chosen to participate in this research. The literature review is concluded by highlighting the consumption of bread in South Africa, the perceptions consumers have on gluten-free bread, the nutritional quality of bread and finally, the gaps in the knowledge are highlighted.

2.1 Status of wheat production relative to indigenous crops in South Africa

According to Rosegrant, Agcaoili-Sombilla and Perez (1995), the demand for wheat in developing countries is expected to increase by 60% by 2050, while temperature increases caused by climate change are expected to reduce wheat production in developing countries by 29%. This is in agreement with Gbetibouo and Hassan (2005), who stated that future climate shifts and increased climate variability pose a threat to the agricultural sector in the Southern African region. The main crops produced in this region are maize, wheat, sugarcane and sorghum (Gbetibouo & Hassan, 2005). The two researchers also found that based on rainfall levels, increasing temperatures in both summer and winter reduce net revenue related to these crops. At the same time, increasing summer rainfall negatively affects the net revenue. Therefore, Gbetibouo and Hassan (2005) suggested that more research for breeding heat tolerance rather than drought tolerance in crops should be done. In the case of South Africa, an example of a target crop for such research would be sorghum (Pennisi, 2009).

Wheat production is not only affected by climate change, other factors such as poor yields, increasing irrigation and fertilizer costs as well as virulent diseases and pest strains such as the Ug99 stem rust fungus affect wheat production (Singh, Hodson, Huerta-Espino, Jin, Bhavani, Njau, Herrera-Foessel, Singh, Singh & Govindan, 2011). However, modern agricultural systems promote the commercial cultivation of only a few high-input and high-yielding crops, causing a decline in cultivation of the indigenous crops (Chivenge, Mabhaudhi, Modi & Mafongoya, 2015). Even though indigenous crops such as sorghum, cowpea, amaranth, Bambara ground nuts and millet could offer genetic biodiversity and have the potential to improve food and nutritional security, the cultivation thereof continues to decline (Chivenge *et al.*, 2015).

It is therefore justified that researchers such as Taylor (2003) affirmed that a cereal such as sorghum is the only feasible food grain crop for people living in developing regions such as sub-Saharan Africa. The researcher furthermore states that sorghum is vital for food security in Africa as it is uniquely drought resistant and heat tolerant amongst other cereals (Taylor, 2003). A challenge, however, is to transform it into products that will be acceptable to consumers.

2.2 The significance of gluten

Gluten is a type of protein which is predominantly found in wheat. Gluten develops after the addition of water to the flour followed by mechanical action (kneading). Not only is it responsible for the cohesive and viscoelastic properties of dough, but it is also vital for protein-starch interactions related to the dough's ability to retain carbon dioxide gas during fermentation and partly for setting the dough during baking (Mahmoud *et al.*, 2013). Gluten is comprised of several related but distinct proteins – gliadin and glutenin being the main proteins and collectively classified as prolamins (Wieser, 2007; Biesiekierski, 2017).

The unique rheological properties of gluten containing doughs are brought about by the ratio and interaction of these two proteins (Biesiekierski, 2017). Hydrated gliadins have little elasticity and cohesive properties compared to glutenins, hence they contribute mainly to the viscosity and extensibility of the dough system (Wieser, 2007). On the other hand, hydrated glutenins are both cohesive and elastic, therefore, glutenin is responsible for dough strength and elasticity (Wieser, 2007). Each component is therefore vital for ensuring the viscoelastic properties and the resulting quality of the final product.

Proteins similar to the gliadin found in wheat occur as secalin in rye, hordein in barley, and avenins in oats – these are collectively referred to as "gluten" (Biesiekierski, 2017). The issue with gluten, however, is the negative health effects it has on those who are sensitive to it. Gluten (wheat) related disorders include: coeliac disease, wheat allergy and non-coeliac gluten sensitivity.

Coeliac disease is a chronic systematic autoimmune disorder caused by a permanent intolerance to gluten proteins in genetically susceptible individuals (Saturni, Ferretti & Bacchetti, 2010). The ingestion of gluten causes an immune response which is initiated by the toxic peptides in the gliadin portion of the gluten proteins. Consequently, an immune response is triggered and it causes mucosal inflammation, small intestinal villous atrophy and increased gut permeability (Biesiekierski, 2017). Coeliac disease affects about one in 266 people worldwide (Mahmoud *et al.*, 2013).

Wheat allergy is an IgE-mediated reaction to the insoluble gliadins of wheat; the symptoms include itching, swelling, skin rashes and fatal anaphylaxis (Biesiekierski, 2017). About 0.4 % people in the world have this allergy (Biesiekierski, 2017).

Finally, there is non-coeliac gluten sensitivity and the symptoms have been reported to include pain, reflux, diarrhea and constipation (Zanini, Baschè, Ferraresi, Ricci, Lanzarotto, Marullo, Villanacci, Hidalgo & Lanzini, 2015). Unlike coeliac disease, there is no substantial evidence showing that gluten proteins can initiate symptoms in patients with no features of coeliac disease (Biesiekierski, 2017). However, as concluded by Verdu, Armstrong and Murray (2009), non-coeliac gluten sensitivity and coeliac disease may share a common etiology – but gluten sensitivity does not meet the diagnostic measures for coeliac disease.

For the safety of the sufferers of the gluten allergy and gluten-related disorders, a complete removal of gluten from the diet is required (Saturni *et al.*, 2010).

2.3 The essence of the physical structure of bread

Bread is a porous and solid structure essentially made up of flour, yeast, water and salt. The process of baking comes down to three fundamental steps, i.e.: (1) mixing and fermenting, (2) formation of a porous structure through proofing and, (3) applying heat to set the foam structure (Scanlon & Zghal, 2001). Yeast produces CO_2 which dissolves in the liquid phase and then saturates the cells formed during mixing (Shehzad, Chiron, Della Valle, Kansou, Ndiaye & Réguerre, 2010). The CO_2 then evaporates into gas bubbles which expand and cause the dough system to increase in volume. The extent to which the aerated dough remains stable can be observed by its ability to keep its shape and size during proofing (Shehzad *et al.*, 2010). The solid and gaseous phase ratio basically define the structure of the bread crumb. The structure of the crumb affects attributes such as appearance and texture. According to Lassoued, Delarue, Launay and Michon (2008), one can predict that a bread crumb will have a soft and elastic texture if the crumb cells are smaller, thin-walled and of a similar size. Whereas, larger and thick-walled cell structures often yield a harder texture.

Apart from the ingredients used and the quality thereof, other aspects such as proofing time seem to play an important role in dough development. Zghal, Scanlon and Sapirstein (2002) found that as proofing time increases, the gas cells grow and the solid phase surrounding them becomes harder – thereby reducing the density. The solid phase surrounding the gas phase hardens the dough system due to either the decrease in solids phase volume or the hardening of the protein polymers aligned by gas cell expansion (Zghal *et al.*, 2002). Furthermore, as the proofing progresses, the cells coalesce, which softens the crumb due to "disappearing" cell walls.

2.4 Ingredients and technologies commonly used in gluten-free bread making

Several ingredients and technologies have been tried and tested in an effort to produce gluten-free dough-based products that have similar quality characteristics to their gluten containing counterparts. Previous efforts include the use of gluten-free flours in combination with polymeric substances as a way to produce gluten-free breads that are of good quality (Sakač, Torbica, Sedej & Hadnađev, 2011). More ingredients and technologies discussed below were identified by Collar (2019).

2.4.1 Hydrocolloids

Hydrocolloids can be described as natural or synthetic polysaccharides, with diverse chemical structures, which have the ability to swell significantly in water and form a structure similar to that of the gluten network in wheat dough (Gambuś, Sikora & Ziobro, 2007; Mir, Shah, Naik & Zargar, 2016). An example of a hydrocolloid which was observed as used in at least one South African gluten-free bread (personal observation) is hydroxypropyl methyl cellulose (HPMC). Other widely used hydrocolloids in gluten-free bread include: pectin, guar gum, arabic gum, galactomannans and methylcellulose (Gambuś *et al.*, 2007).

Hydrocolloids affect the rheological properties of dough even when included at low concentrations. They enhance viscosity, leading to the stabilisation of mixtures by preventing settling, phase separation, foam collapse and starch crystallisation (Mir *et al.*, 2016). In terms of farinograph (shear and viscosity) properties, Lazaridou, Duta, Papageorgiou, Belc and Biliaderis (2007) reported that hydrocolloids increased water absorption in gluten-free dough because they have a hydrophilic nature. This yields a farinograph curve that is similar to that of wheat dough – which is an indication of dough strength (Lazaridou *et al.*, 2007). Direct hydrogen bonding or aligning of water molecules within inter-molecular and intra-molecular spaces are ways in which water may be held in hydrocolloid systems (Anton & Artfield, 2008). These hydrocolloid-water interactions are partially dependent on temperature and pressure (Anton & Artfield, 2008). For dough thermal properties, Sabanis and Tzia (2011) reported an increase in gelatinisation temperature after the addition of 1.5 g/100 g HPMC in a maize starch-rice flour dough. This was attributed to the changes in the thermal properties of flour-water mixtures by hydrocolloids and low-molecular weight dextrins through (i) acting as a physical barrier to inhibit amylopectin chain aggregation during storage, (ii) restricting enzyme-substrate interaction and (iii) application of a viscosity effect which affects mobility within the stored system (Khanna & Tester, 2006).

For loaf volume, again, after the addition of 1.5 g/100 g of HPMC and guar gum in a maize starch-rice flour dough – Sabanis and Tzia (2011) observed an improvement in loaf volume by 9% and 7%, respectively, compared to a control. The reason suggested for this was that HPMC can affect both aqueous and non-aqueous regions of a dough system, thereby ensuring uniformity and stability. This affinity for water is however lost during baking, causing the HPMC polymers to form a polymer network gel. In addition to increasing viscosity, this strengthens the gas cell walls and prevents excess moisture loss (Sabanis & Tzia, 2011).

Among all the hydrocolloids which have been applied in gluten-free breads, xanthan gum and HPMC have been found to be the most frequently used as they are closest in displaying gluten-like properties (Mir *et al.*, 2016). Xanthan gum is an exocellular heteropolysaccharide synthesised by a microorganism, *Xanthomonas campestris*, through fermentation (Anton & Artfield, 2008). Whereas, HPMC is a cellulose ether which is made from alkali-treated cellulose that is reacted with methyl chloride and propylene oxide (Anton & Artfield, 2008). However, although it enhances dough viscosity, it cannot produce a honeycomb-like structure when added alone in gluten-free doughs. Proteins are needed to assist in forming a continuous phase and to stabilise the CO_2 gas cells (Sabanis & Tzia, 2011) formed during fermentation.

2.4.2 Enzymes

Enzymes are seen as good alternatives to other chemical additives because they are considered safe, they can catalyse reactions and they become inactive after being denatured during bread baking (Rosell, 2009). They usually play a role in dough structure development, improving fresh bread quality, and extending shelf life. The incorporation of covalent crosslinking bonds to proteins by the use of enzymes has been shown to enhance the physical and textural characteristics of gluten-free breads (Nonaka, Tanaka, Okiyama, Motoki, Ando, Umeda & Matsuura, 1989) by somewhat imitating the protein network unique to gluten-containing systems (Moore, Heinbockel, Dockery, Ulmer & Arendt, 2006). According to Nonaka *et al.* (1989), transglutaminase (an enzyme) facilitates the formation of covalent crosslinks between peptides by catalysing a Ca^{2+} dependent acyl-transfer reaction from the peptide's γ-carboxy-amide groups to acyl accepting peptide-lysine residues. This thereby forms protein modifying ε-(γ-Glu)Lys crosslinks (Figure 2.1). Moore *et al.* (2006) determined the effect of transglutaminase on the structure and quality of gluten-free bread using soya flour, egg powder and skim milk as protein sources. They noted that transglutaminase formed crosslinks, as suggested by Nonaka *et al.* (1989), in the formulations that contained skim milk powder and egg powder. This was however not the case with soya flour because the globular nature of the main soya proteins prevented them from acting as substrates for transglutaminase reactions (Moore *et al.*, 2006).

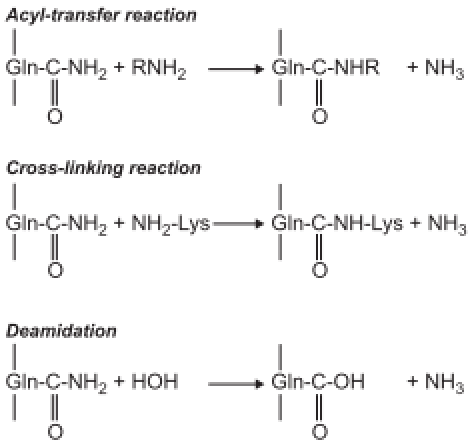


Figure 2.1 Reactions catalysed by the transglutaminase enzyme (Rosell, 2009)

Hamada, Suzuki, Aoki and Suzuki (2013) investigated the use of *Aspergillus oryzae* and its protease enzymes as additives in the production of rice flour-based gluten-free breads. They found that the rising of gluten-free bread was mainly attributed to protease activity which increased during incubation. Similarly, Kawamura-Konishi, Shoda, Koga and Honda (2013) evaluated the effect of protease enzymes on gluten-free rice breads. They also found that all four proteases tested produced bread with an improved height compared to the controls. Furthermore, they noted that of the four proteases tested, two of them (proteases from *Aspergillus oryzae* and *Bacillus stearothermophilus*) facilitated more CO_2 retention during proofing by forming a structure which was capable of holding more CO_2 gas.

Amongst other additives, Sciarini, Ribotta, Leon and Perez (2012) determined the effect of glucose oxidase and α-amylase on gluten-free bread quality. They reported an increase in specific bread volume and a reduction in initial crumb firmness with the addition of α-amylase. With the addition of glucose oxidase, breads with a specific bread volume similar to their control were observed, also the crumb firmness was reduced. Renzetti and Arendt (2009) also observed an increased specific volume in sorghum-based and corn-based breads after treatment with glucose oxidase. Glucose oxidase helps to improve the quality of gluten-free bread by acting as a catalyst during the oxidation of glucose, this then forms gluconolactone and hydrogen peroxide (Figure 2.2). The hydrogen peroxide molecule is thus responsible for oxidising the protein's sulfhydryl groups, thereby forming disulfide cross-linkages which improve the stability of the dough system (Rosell, 2009). On the other hand, α-amylases function by hydrolysing the α-(1-4) bonds in starch chains into shorter dextrins (Sciarini *et al.*, 2012). Dextrins are more readily fermentable and thus increase the amount of substrate available for fermentation and reduce the amount of starch available for retrogradation.

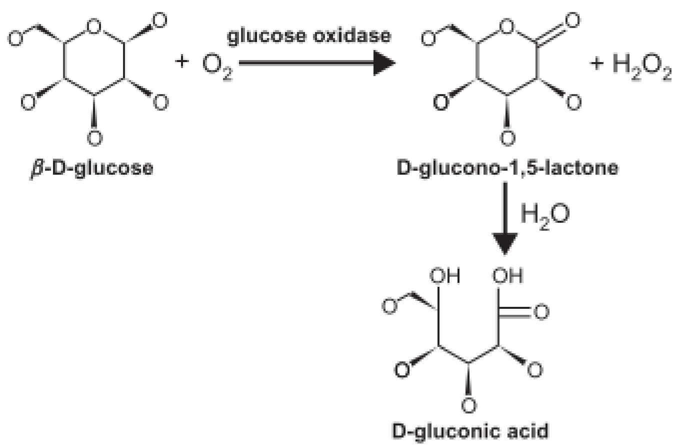


Figure 2.2 Glucose oxidation reaction catalysed by glucose oxidase (Rosell, 2009)

2.4.3 Other starches and flours

The starch in wheat dough preparations absorbs about 46% water and, upon the addition of heat, moisture and time – the starch granules gelatinise and swell (Goesaert, Brijs, Veraverbeke, Courtin, Gebruers & Delcour, 2005). This thus facilitates the formation of a gluten-containing bread structure that is porous and yet does not collapse. When coming to gluten-free breadmaking, ingredients such as maize flour, maize starch, rice flour, potato starch, tapioca flour, tapioca starch and sorghum flour have been explored. Rice flour contains a low amount of prolamins (such as gliadin and glutenin), this makes it appropriate as a cereal flour in gluten-free bread making (Sakač *et al.*, 2011). It is also relatively low in sodium and high in readily digestible carbohydrates. Starch components of maize and cassava are also suitable as they pose no harm to those with gluten sensitivity. However, they bring about an unusual taste to bread and they impose technological challenges in breadmaking (Sanchez, Osella & De La Torre, 2002). The prolamins in sorghum are more related to those in maize than wheat (Shewry & Halford, 2002) – making it a reasonable option for use in gluten-free bread. Sorghum also forms part of the ingredient list of some of the gluten-free brown breads available in South Africa (personal observation). However, due to the lack of gluten forming proteins in sorghum, added technologies and ingredients are required to produce a gas holding sorghum-based dough (Schober, Messerschmidt, Bean, Park & Arendt, 2005).

Schober *et al.* (2005) conducted a baking trial using sorghum hybrid flours (with different rates of starch damage), maize starch, water, salt, sugar and dried yeast. They found that the breads which were made with highly damaged sorghum starch had a larger mean cell area, a lower number of cells and a softer crumb. This was partially attributed to the ability of damaged starch granules to rapidly bind water. It was also noted that flour particle size also had an effect on water binding, where small flour particles may have enhanced water binding in the batters (Schober *et al.*, 2005).

Sanchez *et al.* (2002) baked gluten-free bread using rice flour, maize-starch and cassava starch. They found that the formulation which produced the most optimal results (in terms of sensory acceptance and crumb structure quality) was the one that contained 74.2% maize starch, 17.2% rice flour and 8.6% cassava starch. Furthermore, by adding 0.5% soya flour, it was found that the crumb-structure quality improved. This was said to be due to the water-binding and stabilisation properties imparted by the soya proteins (Sanchez *et al.*, 2002).

Pasqualone, Caponio, Summo, Paradiso, Bottega and Pagani (2010) investigated the use of (i) cassava flour with oil, (ii) cassava flour with egg white and, (iii) cassava flour with oil and egg white in combination to bake bread samples. They found that there was not a significant difference in specific volume between the wheat bread and bread made from cassava, oil and egg white. This was explained to be likely due to the notion that egg white albumins give the dough the ability to retain gas by enhancing the coherence between the starch granules, thereby increasing the stability of the dough (Pasqualone *et al.*, 2010). The difference in crumb moisture in the wheat bread, (ii) cassava bread with egg white and the bread made from (iii) cassava, oil and egg white was also reported to be insignificant. There was however a significant difference between the protein content of wheat bread (10.2 g/100 g dry solids) and all the cassava-based breads (1.3-5.4 g/100 g dry solids), with the wheat bread having a higher protein content. This is a common shortfall with gluten-free breads. The breads with the highest overall acceptability were the wheat bread and the (iii) cassava bread with oil and egg white, with the difference between the scores of the two being insignificant. The (iii) cassava-oil-egg bread had a thin crust, homogeneous crumb structure and a reduced distinctive cassava odour and flavour – making it more like wheat bread and hence having similar acceptable sensory properties.

In addition to the types of flours which can be used, it would appear that the particle size of the flour used may have an effect on the quality of the resulting gluten-free bread. de la Hera, Martinez and Gómez (2013) studied the impact of rice flour particle size on bread quality. They found that long-grain rice-flour fractions (>80 µm) and the 80 to 106 µm short-grain flour fractions produced breads with a higher volume. This was explained to may have been due to the differences in gas retention during fermentation and changes occurring during baking. All of this goes to show that the flour type, cultivar, physical structure and other ingredients included all have an effect on the quality of the resulting gluten-free bread.

2.4.4 Germinated flours

Commercial gluten-free alternatives usually comprise of more fibre, salt and fat, however, less sugar and protein (Allen & Orfila, 2018) in comparison to wheat-based products. Therefore, consumers who suffer from coeliac disease often suffer nutritional deficiencies (Saturni *et al.*, 2010). Considering the relative nutritional inadequacy and unbalanced nature of the gluten-free diet, it is important to look at ways to enhance the nutritional value of ingredients used in gluten-free products, one such method is germination. Germination is the process where a seed undergoes sprouting in the presence of water. During germination, metabolic activity occurs which results in storage proteins and carbohydrates being hydrolysed (Cáceres, Martínez-Villaluenga, Amigo & Frias, 2014), thereby improving digestibility. The process also facilitates the production or accumulation of polyphenols with potential health promoting properties and antioxidant activity (Cornejo, Caceres, Martínez-Villaluenga, Rosell & Frias, 2015). Moreover, germination helps to reduce the presence of antinutrients, increases oligosaccharides and enhances the digestibility of proteins and starches in legumes (Phattanakulkaewmorie, Paseephol & Moongngarm, 2011).

Yousif and Safaa (2014) looked at including germinated legume flours (chickpea and lupine) in gluten-free bread. Although the nutritional content of the resulting composite breads was not determined, they found that germination brought about a reduction in antinutritional factors inherent in raw legumes (tannins, phytic acid and trypsin inhibitor). They also found germinated sweet lupin flour to contain the highest crude protein, crude fibre and lipids compared to yellow maize, rice and chickpea flours. Cornejo *et al.* (2015) investigated the effect of using germinated brown rice grains on the nutritive value of the resulting bread. They also noted an increase in protein, however, a decrease in carbohydrate and ash content in the bread made with brown rice germinated for 12 hours. With regards to antioxidant activity, Cáceres *et al.* (2014) recorded higher antioxidant activity in germinated brown rice compared to the ungerminated grain; this increase was also directly proportional to the germination time and temperature. Several researchers noted a decrease in ash content, and this is attributed to the leaching of minerals during soaking. It is however unclear whether germinated flours are used in the production of commercial gluten-free bread in South Africa.

2.4.5 Non-cereal, non-grain, gluten-free ingredients

The relatively low protein content and protein contribution of gluten-free breads has been discussed by several authors (Moroni, Dal Bello & Arendt, 2009; Saturni *et al.*, 2010; Segura & Rosell, 2011; Matos & Rosell, 2015; Allen & Orfila, 2018). It is for this reason that researchers such as Krupa-Kozak, Bączek and Rosell (2013) determined the potential use of low-lactose dairy proteins (calcium caseinate, sodium caseinate, spray dried whey protein isolate and hydrolysed whey proteins) to improve the technological and nutritional properties of gluten-free bread. All the samples which contained dairy powders had a significant increase in protein and mineral content compared to the control gluten-free bread (with no dairy protein inclusion). The dairy proteins were included at 12 and 24 g per 100 g flour. It was found that a 12 g/100 g addition of all the dairy proteins significantly increased the specific volume of the bread samples. However, breads enriched with the two whey protein types had a significant decrease in springiness, which may have a negative effect on the perception of freshness. The two whey protein types also decreased the cohesiveness of the breads significantly, which resulted in breads with low elasticity. The researchers could therefore conclude that certain dairy proteins have good potential to improve the nutritional and technological properties of gluten-free bread. Also, Nunes, Ryan and Arendt (2009b) evaluated the use of low-lactose dairy proteins in the production of gluten-free bread. Both Krupa-Kozak *et al.* (2013) and Nunes *et al.* (2009b) used low-lactose dairy proteins because a symptom of coeliac disease happens to be secondary lactose intolerance (Murray, 1999). Similar to Krupa-Kozak *et al.* (2013), Nunes *et al.* (2009b) found that the use of whey proteins significantly increased the specific volume of gluten-free loaves. This was suggested to be due to the unfolding of whey globules which establish other structure improving protein-protein bonds during baking (Nunes *et al.*, 2009b).

Moore *et al.* (2006) studied the use of either soya flour, egg powder or skim milk powder as protein sources, in combination with an enzyme (transglutaminase) to produce gluten-free bread. In the control samples, where no enzyme was included, the loaf which contained egg powder had a higher specific volume than that of soya and skim milk powder containing loaves, although the difference was not significant. This trend was explained by the ability of egg powder to facilitate foam and emulsion development for forming viscoelastic films needed for stable foaming. Egg also seems to be the most prominent non-cereal protein containing ingredient used in commercial gluten-free bread in South Africa (personal observation).

2.4.6 Pseudocereals

Pseudocereals are not true cereals, however their seeds are similar to that of true cereals in terms of function and composition (Alvarez-Jubete, Arendt & Gallagher, 2010). Furthermore, unlike most cereals that are monocotyledonous, pseudocereals are from dicotyledonous plants. Examples of pseudocereals include buckwheat, chia, quinoa and amaranth; whereas true cereals include sorghum, maize, millets, wheat and rice. As concluded by Alvarez-Jubete *et al.* (2010), pseudocereals have plausible potential to be used as gluten-free ingredients because of their relatively high quality protein, fibre and mineral content. They also contain bioactive compounds (e.g., polyphenols) which may have health promoting properties. This was shown in research done by Costantini, Lukšič, Molinari, Kreft, Bonafaccia, Manzi and Merendino (2014), who reported a significantly higher protein, lipid, insoluble dietary fibre and ash content in wheat bread composited with chia flour (90:10) and breads made from buckwheat flour (100:0) and buckwheat with chia flour (90:10). This was compared to a control wheat bread (100:0). Their experimental bread samples also displayed a higher total phenolic content (4.5 – 14.8 mg gallic acid equivalents per g) and antioxidant capacity (86.7-100.8 mmol gallic acid equivalents per g) compared to the control (3.3 mg gallic acid equivalents per g total phenolic content and 31.4 mmol gallic acid equivalents per g total antioxidant capacity).

Pseudocereals are not only useful as wheat replacers in terms of their nutritive value. Studies have shown that some have the capacity to enhance the quality of gluten-free bread. Wronkowska, Haros and Soral-Śmietana (2013) replaced 10 to 40% of the maize starch in a gluten-free bread formulation with buckwheat flour. They noted a significant increase in specific volume in all the experimental samples compared to the control sample (0% buckwheat flour). The hardness of the bread had also reduced significantly in the 30% and 40% buckwheat samples after 24 and 48 hours of storage. This reflects buckwheat being able to impart a delay in staling as well as an increase in loaf volume. The chemistry explaining how buckwheat delays staling is however not clear because the formulation contained other starch sources (maize and potato starch) which have varying enthalpy values that are associated with amylopectin retrogradation. Staling can also be affected by various other factors such as: crumb macro- and micro-structure, moisture transfer and, polymer restructuring (Mariotti, Pagani & Lucisano, 2013).

Contrary to Wronkowska *et al.* (2013), Mariotti *et al.* (2013) reported no significant difference between the specific loaf volume of the control sample (gluten-free bread containing 0% buckwheat flour) and the experimental gluten-free bread which had 40% buckwheat flour. However, the experimental sample (containing 40% buckwheat flour) had a higher crumb hardness. It is also worth noting that the gluten-free formulation used by Wronkowska *et al.* (2013) contained pectin, which is a hydrocolloid. Therefore, the finding by Mariotti *et al.* (2013) was explained to be due to the lack of hydrocolloids in the formulation which would otherwise complement the buckwheat flour by binding water and disrupting protein-starch interactions which reduce the staling rate (Mariotti *et al.*, 2013).

2.4.7 Sourdough through fermentation

Sourdough is usually produced through spontaneous fermentation whereby; the microorganisms already present on milled grains are activated at optimal moisture and temperature conditions. The metabolic activity of the lactic acid bacteria causes the release of lactic acid and acetic acid which lower the pH to acidic levels. On the other hand, the yeasts present produce CO_2 and ethanol. Certain enzymes also become activated or enhanced as the fermentation progresses, these include: phytases, proteases, amylases and hemicellulases (Poutanen, Flander & Katina, 2009). All of this metabolic activity combined helps to bring about enhanced functionality, microbiological safety, nutritional quality and increased bioavailability (Moroni *et al.*, 2009).

As reviewed by Arendt, Morrissey, Moore and Dal Bello (2008), the inclusion of sourdough in gluten-free bread helps to improve: loaf volume, crumb structure, flavour, nutritional quality as well as increase the shelf life. The crumb structure is possibly improved by the swelling of the polysaccharides in the gluten-free flour as a result of the acidification inflicted by the sourdough (Arendt *et al.*, 2008). Some of these positive effects were shown in a study by Schober, Bean and Boyle (2007), who observed a good volume and no hole in the crumb of gluten-free bread which contained sorghum flour sourdough. This was majorly different to samples which contained no sourdough. They suggested that the sourdough fermentation led to the degradation of the soluble proteins in the dough liquid. In their intact state, these proteins would otherwise have aggregated during baking and disrupted the starch gel – thereby increasing the chances of the formation of a large hole in the crumb (Schober *et al.*, 2007).

One challenge with sourdough is that it tends to impart a sour flavour in gluten-free breads (depending on the percentage inclusion). Therefore, the acceptability by those who are not exposed to it may be limited. However, Moroni *et al.* (2009) suggested that choosing suitable starter cultures and process parameters could help produce gluten-free bread which is acceptable to consumers. It is however not clear whether sourdough is incorporated in the current commercial gluten-free breads in South Africa.

2.4.8 Pre-gelatinised flour

Pregelatinisation is a form of physical modification done to starch (Miyazaki, Van Hung, Maeda & Morita, 2006) usually by applying heat and moisture. As the starch gelatinises, it competes for water in the system – thus setting the structure of the baked product and also contributing to the texture (Miyazaki *et al.*, 2006). Bourekoua, Benatallah, Zidoune and Rosell (2016) suggested that heat and moisture treatment leads to structural disorder and amylose release which re-aligns during cooling, thereby contributes to setting. Seeing as gluten-free flours lack certain functional properties e.g. elasticity, starches which have undergone pregelatinisation are often incorporated.

Purhagen, Sjöö and Eliasson (2012) observed bread with increased water holding capacity during storage in bread which contained pregelatinised barley flour. Also, Bourekoua *et al.*

(2016) noted an improved specific volume in gluten-free breads which contained pregelatinised starch. The pregelatinised starch gives the dough system the ability to be able to endure/resist the gas cell expansion during mixing and the early phases of baking (Bourekoua *et al.*, 2016). This altogether contributes to the quality of the resulting bread.

2.4.9 Emulsifiers

Emulsifiers are unique additives in that they have both hydrophilic and lipophilic properties. These properties allow them to interface between two distinct phases (water and oil), decrease the surface tension and form dispersions (Nunes, Moore, Ryan & Arendt, 2009a). The hydrophilic-lipophilic balance (HLB) of the emulsifier is determined by whether it is more hydrophilic, i.e. higher HLB value and hence an oil-in-water emulsion; or whether it is more lipophilic, i.e. lower HLB value and therefore an water-in-oil emulsion (Nunes *et al.*, 2009a). Emulsifiers are said to increase dough stability by associating with the hydrophobic areas of proteins, and their lipophilic area facilitates protein denaturation during fermentation. They also alter the gelatinisation properties of starch by creating complexes with amylose, thereby reducing the water penetration and hence softening the dough (Demirkesen, Mert, Sumnu & Sahin, 2010).

These properties give emulsifiers the potential to be able to able to interface between starch, fat or protein phases in gluten-free systems (Nunes *et al.*, 2009a). Nunes *et al.* (2009a) determined the use of lecithin (LC), di-acetyl tartaric ester of monoglycerides (DATEM), distilled monoglycerides (DM) and sodium stearoyl lactylate (SSL) as emulsifiers in gluten-free bread. They noted an overall increase in specific volume compared to the control, the highest being bread containing DM. With regards to hardness, DATEM at medium level-containing bread had lower hardness than the control, which indicates its potential ability to delay staling. These findings agree with Onyango, Unbehend and Lindhauer (2009), who found a decrease in crumb hardness with the addition of emulsifiers at a concentration of 2.4% w/w. This is suggested to be due to the emulsifier-starch granule interaction which forms a complex that restricts granule swelling, and hence reduces the gelatinised starch available for recrystallisation (Onyango *et al.*, 2009). Such complex formations were confirmed by Purhagen *et al.* (2012) who also found significantly higher complex formations (as determined by enthalpy) in bread which contained emulsifiers. It is for the above reasons that emulsifiers feature in many of the commercial gluten-free formulations.

2.5 Sensory evaluation as a tool for determining the characteristics and acceptability of bread

Bread has a relatively short shelf life, which usually affects the quality and hence consumer acceptability as the freshness decreases. Laureati, Giussani and Pagliarini (2012) stated that the appearance, taste, aroma and texture of food are very important in predicting the extent to which a consumer would consume a food item. It is therefore rather useful to use human participants as a method to assess the sensory properties of bread products.

2.5.1 Descriptive sensory evaluation of gluten-free bread

Descriptive sensory analysis is used to identify and quantify the perceived sensory characteristics of a product (Lawless & Heymann, 2010c), usually pertaining to the product's appearance, aroma, flavour, texture, aftertaste and sound characteristics. This method can also be used to evaluate changes within a product over time to determine aspects like the effect of shelf life, formulation changes and storage conditions. The panellists used in descriptive sensory evaluation ought to undergo some screening to test their ability to use their senses. They should not only be trained but they should also be committed to the process because training is where panellists develop the descriptive terms differentiating the samples or are familiarised with them (Murray, Delahunty & Baxter, 2001). The number of panellists used is much smaller (often between 8 and 12) than in consumer tests, this is justified by the training phase which calibrates the panellists to use the scales in a similar way (Lawless & Heymann, 2010c), also, the evaluations are objective. Descriptive sensory evaluation findings can also be used to explain hedonic evaluations of food (Murray *et al.*, 2001). It is for this reason that researchers have often employed both methods in their studies (Laureati *et al.*, 2012; Bernstein & Rose, 2015; Pacyński, Wojtasiak & Mildner-Szkudlarz, 2015).

Regarding descriptive sensory analysis pertaining to gluten-free products specifically, de Kock and Magano (2020), highlighted that the methods used for evaluating the sensory properties of gluten-free products are no different than those used for gluten-containing products. Using conventional sensory profiling and hedonic rating methods, Laureati *et al.* (2012) aimed to determine if there is a difference in the way in which coeliac and non-coeliac subjects (as descriptive sensory panellists) experience the sensory properties of gluten-free breads. It was found that both groups may perceive gluten-free breads in a similar way as the difference in their rating scores was not significant. This was with the exception of the difference in their perception of cheese aroma and maize flavour – although the differences were quite small. In terms of hedonic rating, again, degree of liking of the bread for two groups of consumers (n = 21 coeliac and n = 85 non-coeliac subjects) did not differ significantly. Softness, homogenous crumb porosity, sweet taste and to some degree maize aroma and flavour had a positive effect on preference for both groups. Optimisation of these properties therefore gives guidance to developing gluten-free breads with improved sensory acceptability for all consumer types (gluten-sensitive and non-gluten-sensitive consumers).

2.5.2 Acceptability of the sensory properties of gluten-free bread by consumers

Affective testing is described as the type of sensory tests employed to determine the degree of liking or disliking of a product by consumers (Lawless & Heymann, 2010c). The degree of liking or disliking is considered to be a reflection of acceptability (Crisosto, Crisosto & Metheney, 2003). On a nine-point hedonic scale which is used to assess liking or disliking from 1 (dislike extremely) to 9 (like extremely), a value below 5 (neither like nor dislike) reflects low acceptability or dislike and a value above 5 reflects high acceptability or liking (Grosso & Resurreccion, 2002). Affective tests also require a larger number of participants/panellists (generally 75 to 150 participants per product) to compensate for the differences in individual preferences, thereby ensuring statistical reliability (Lawless & Heymann, 2010c). Descriptive sensory analysis has been used to predict acceptability (Grosso & Resurreccion, 2002), however, many studies use both descriptive sensory analysis and consumer acceptability tests to determine the sensory traits that are acceptable to consumers.

Bernstein and Rose (2015) used a trained panel to objectively determine the differences in whole wheat breads that are commercially available in the USA. They also evaluated the overall consumer acceptability of appearance, flavour, texture and overall liking in the six whole wheat breads using preference mapping. They were able to classify the consumers into three different clusters based on their most preferred attributes of bread. They concluded that the first two clusters (81% of the consumers) were most important as the bulk of the consumers fell within them. The liking scores of the six whole wheat bread samples were generally high but not significantly different for cluster one consumers (37% of the consumers). However, significant differences were found for drivers of liking in clusters two and three. This study assisted the researchers in understanding that there are different types of consumers and they have different preferences, it also highlighted drivers of liking within each cluster of people (Table 2.1). Knowing the drivers of liking or disliking for the different consumer types makes it easier to decide on which formulation to use during product development. It also highlights the sensory traits in a product that are important or that need improvement.

Table 2.1: Drivers of liking of whole wheat bread samples by three clusters of consumers (n = 75) as identified by Bernstein and Rose (2015)

Cluster (number of panellists)	Drivers of liking
1 (n = 28, 37%)	Darker crumb colour, fruity aroma, sweet flavour, moist and cohesive flavour
2 (n =33, 44%)	Doughy and sweet flavour, adhesive and moist texture
3 (n = 14, 19%)	butter, fermented and whole wheat aroma and butter flavour

Using 30 consumers, Ming-Yin, Yung-Ho, Sy-Yu and Cheng-Chang (2012) evaluated the preference for colour, odour, texture and overall preference of steamed wheat bread. The steamed wheat bread samples varied in wheat bran substitution (0 to 30%). Using a 7-point hedonic scale, they found that the steamed bread with 30% bran substitution was the least preferred in terms of colour, odour, texture and overall acceptability. Furthermore, the steamed bread with 10% and 20% bran substitution were perceived to have no significant difference compared to the control. It was therefore proposed that in order to increase the intake of dietary fibre, steamed wheat breads could be supplemented with 20% wheat bran with no significant impact on the sensory experience.

Gosine and McSweeney (2019) determined the food products, made with grains alternative to wheat, that consumers are willing to consume. This was done using a choice-based conjoint analysis survey with Canadian consumers. The scenario-based survey entailed the consumers being presented with 22 combinations each consisting of three choice sets to choose the most preferred one from. The sets varied in grain type (spelt, millet, buckwheat, sorghum, amaranth and quinoa), product type, flavour and nutritional claims. They found that bread would be among one of the most acceptable products when made using alternative grains. Products like crackers and snacks would not be acceptable to consumers if they were made with alternative grains. They also found that bland and nutty flavours were the two flavours that drove the disliking of foods made with alternative grains. Of the grains which they studied, amaranth and sorghum were the most disliked due to them being relatively foreign to those consumers and quinoa was most liked. However, flavour and product type were the most important traits affecting consumer choice more than grain type. These findings somewhat justify bread as the chosen product for the application of alternative grains, especially grains that are climate-smart.

2.6 Instrumental analysis as a tool for determining the properties of bread

In as much as sensory analysis is a useful tool to assess the attributes of food, instrumental analysis also adds value to the objective characterisation of food. Consumers relate the texture of bread to its level of freshness, making it important to determine the acceptability levels by measuring the textural properties (Nkhabutlane, de Kock & du Rand, 2019).

Brady and Mayer (1985) used a sensory panel as well as an Instron compression test to measure the hardness, cohesiveness, elasticity and chewiness of rye and French breads. Significant correlation existed between the instrumental and sensory measurements only for cohesiveness (r = 0.49) and chewiness (r = -0.58) with rye bread. However, with French bread, only the chewiness parameter showed correlation between the sensory and instrumental measurements. Brady and Mayer (1985) suggested that the difference in the nature of the two methods were possibly the reason for the low correlation. The bread samples would therefore not be comparable. During sensory evaluation, the effects of moisture and temperature in the mouth alter the physicochemical properties of bread. Whereas, only compression forces are applied during the instrumental texture analysis. Also, rye bread showed better correlation between sensory and instrumental measurements than French bread. This suggests that there may have been variation in the sensitivity between the methods.

Curic, Novotni, Skevin, Rosell, Collar, Le Bail, Colic-Baric and Gabric (2008) investigated the possibility of formulating a global method to determine the quality of wheat-based pan bread using a quality index expression. This entailed normalising the instrumental measurements by linear transformation equations. The quality index values for both descriptive sensory analysis and instrumental analysis ranged between 0 and 1. Like Brady and Mayer (1985), Curic *et al.* (2008) found a high correlation between sensory analysis and instrumental analysis for all their bread samples (conventional bread, fully baked & frozen bread and, bread from unfermented and frozen dough) (r = 0.983) except for one (partially baked and frozen bread). The partially baked and frozen bread had the lowest quality index, and this was attributed to its high crumb firmness and flaking as well as its low specific volume and low porosity. The researchers were able to conclude that for commercial application, quality index based instrumental analysis could provide useful information on appearance, texture and structure. However, for strong changes in flavour, sensory evaluation would be more suitable for quality measurement.

With the aim of including jackfruit rind flour in bread to increase the fibre content, Feili, Abdullah and Yang (2013) determined the physical properties of jackfruit-based high fibre bread. The density (g/cm^3) of the bread was measured by dividing the weight (g) of the bread by the loaf volume (cm^3). A texture profile analysis was done using a texture analyser. The parameters measured were hardness, adhesiveness, springiness, cohesiveness, gumminess and chewiness. Colour was also measured based on the L*a*b* scale. The researchers found an increase in bread density as the inclusion rate (5%, 10% and 15%) of the jackfruit fibre increased. There was however no significant difference between the densities of the control bread (0% jackfruit fibre) and the bread with 5% jackfruit fibre. It was found that the increase in the jackfruit fibre inclusion was proportional to the increase in hardness, adhesiveness, gumminess and chewiness and; inversely proportional to the springiness and cohesiveness. The overall acceptability of the sensory properties among the breads was highest in the sample which contained 5% jackfruit fibre. Based on the instrumental and sensory measurements, not only were the researchers able to determine the effect of the various jackfruit fibre inclusion rates on the quality of the bread; they were also able to determine the acceptable inclusion rate, acceptable texture, density and colour measurements.

2.7 Health and taste attitudes

The Health and Taste Attitudes Scales (three factors measuring health and three factors measuring taste attitudes) (Table 2.2) were developed by Roininen, Lahteenmaki & Tuorila in 1999. They were developed to measure consumers' perceptions towards the health and hedonic characteristics of food with the overall aim to improve nutrition education of and product marketing towards subgroups (Roininen, Lähteenmäki & Tuorila, 1999). These researchers started by developing a few statements that described the health and taste characteristics of foods. The statements consisted of both positive and negative statements that were then tested to determine whether they are clear or not to the respondents. According to Sauro and Lewis (2011), the significance of including both negative and positive wording in questionnaire items is to minimise responses made passively and with extreme bias. The final statements developed to describe the foods were tested using a 7-point scale with categories ranging from "strongly disagree" to "strongly agree." The predictive validity of the developed questionnaires was tested by pairing related foods (e.g. full fat milk and reduced fat milk) and asking respondents to select the most preferred food in a pair. The selected foods were then rated (on a 7-point scale) for pleasantness and healthfulness, "extremely unpleasant/ unhealthy" to "extremely pleasant/healthy," respectively.

Based on the factor loadings and reliability analyses of the statements, the researchers identified three health-related and three taste-related factors that could classify consumers in terms of health and taste attitudes. The health-related factors were termed: "General health interest", Light product interest", and "Natural product interest." The taste-related factors were labelled as: "Craving for sweet foods". "Using food as a reward", and "Pleasure". Each of the factors had associated statements/items which could be rated on a 7-point scale by the Finnish respondents (n=1005). Associations between gender, age and education were also drawn from the results. It was found that for this population of Finnish consumers, women ($p<0.001$), older participants ($p<0.001$) and participants who had completed 12 years of school rated higher in "General health interest" than men, younger participants and those who had not completed 12 years of schooling. The preliminary results of that predictive validity study were found to be promising (Roininen *et al.*, 1999).

The scales (Table 2.2) have since been used by other researchers (Zandstra, De Graaf & Van Staveren, 2001; Chen, 2013; Grubor, Djokic, Djokic & Kovac-Znidersic, 2015; Saba, Sinesio, Moneta, Dinnella, Laureati, Torri, Peparaio, Saggia Civitelli, Endrizzi, Gasperi, Bendini, Gallina Toschi, Predieri, Abbà, Bailetti, Proserpio & Spinelli, 2019) to measure the health and taste attitudes of consumers in different populations. Saba *et al.* (2019) used the scales (Table 2.2) with 1224 Italian adults. As predicted by (Roininen *et al.*, 1999), the researchers in Italy found the pleasure factor to be statistically problematic based on low reliability (coefficient alpha = 0.34) and identified three items which did not load on any factors. Hence they did not include the pleasure factor in the study. They ended up using the data from the three Health factors to classify the consumers into those having either a low, medium or high health attitude. They then related the health attitudes to the consumers' food-related lifestyles, preferences and familiarity with foods (fruits and vegetables, fish, red meat, preserved processed meat products, cheese, saturated and unsaturated fats, sweets, alcoholic beverages and spirits).

Zandstra *et al.* (2001) used all the scales (Table 2.2) to measure the health and taste attitudes of consumers in combination with a 104-item food frequency questionnaire on 132 adult consumers. This was with the intention of measuring the relationship between their health and taste attitudes and their total dietary behaviour. The researchers too found that the pleasure factor was poor in predicting food choices and frequency of food item use. However, unlike Saba *et al.* (2019), they also found the natural product interest factor to be a poor predictor. This could have been due to the difference in application of the tool between the two studies.

Chen (2013) also used the health and taste attitude scales (Table 2.2) with 533 Taiwanese consumers. However, they used it in relation to consumers' variation in concerns about modern tainted food (e.g. pesticides in food) using the Modern Health Worries Scale. They also used it to determine whether gender had an effect on the health and taste attitudes of consumers. The pleasure sub-scale delivered a low coefficient alpha value (<0.6), however, after deleting one item (*I finish my meal even when I do not like the taste of a food*) from it – they could continue to use all six sub-scales.

Lastly, Grubor *et al.* (2015) used the scales to determine consumers' health and taste attitudes and frequency of consumption of certain foods in relation to their socio-demographic context. This was done in Serbia, using 300 consumers. As opposed to all the studies previously discussed, Grubor *et al.* (2015) found that all six subscales were strongly reliable. This was explained to be probably due to the distinct and more similar stance Serbian consumers have regarding their health and taste attitudes.

Table 2.2: Health and taste attitude scales (Roininen *et al.*, 1999)

Subscales	Item	Statement
Health attitude		**General health interest***
	1	I am very particular about the healthiness of food
	2	I always follow a healthy and balanced diet
	3	It is important for me that my diet is low in fat
	4	It is important for me that my daily diet contains a lot of vitamins and minerals
	5R	I eat what I like, and I do not worry much about the healthiness of food
	6R	I do not avoid foods, even if they may raise my cholesterol
	7R	The healthiness of food has little impact on my food choices
	8R	The healthiness of snacks makes no difference to me
		Light product interest*
	1R	In my opinion, the use of light products does not improve one's health
	2R	I do not think that light products are healthier that conventional products
	3	I believe that eating light products keeps one's cholesterol level under control
	4R	In my opinion, light products don't help to drop cholesterol levels
	5	I believe that eating light products keeps one's body in good shape
	6	In my opinion, by eating light products, one can eat more without getting too many calories
		Natural product interest*

	1R	I do not care about additives in my daily diet I try to eat foods that do not contain additives
	2R	In my opinion, organically grown foods are not better for my health than those grown conventionally
	3R	In my opinion, artificially flavoured foods are not harmful for my health
	4	I try to eat foods that do not contain additives
	5	I would like to eat only organically grown vegetables
	6	I do not eat processed foods, because I do not know what they contain
Taste attitude		**Craving for sweet foods***
	1R	In my opinion it is strange that some people have cravings for chocolate
	2R	In my opinion it is strange that some people have cravings for sweets
	3R	In my opinion it is strange that some people have cravings for ice-cream
	4	I often have cravings for sweets
	5	I often have cravings for chocolate
	6	I often have cravings for ice-cream
		Using food as a reward*
	1	I reward myself by buying something really tasty
	2	I indulge myself by buying something really delicious
	3	When I am feeling down I want to treat myself with something really delicious
	4R	I avoid rewarding myself with food
	5R	In my opinion, comforting myself by eating is self-deception
	6R	I try to avoid eating delicious food when I am feeling down
		Pleasure*
	1R	I do not believe that food should always be a source of pleasure
	2R	The appearance of food makes no difference to me
	3	It is important for me to eat delicious food on weekdays as well as weekends
	4	When I eat, I concentrate on enjoying the taste of food
	5R	I finish my meal even when I do not like the taste of a food
	6	An essential part of my weekend is eating delicious food

*Factors

2.8 Consumer attitudes and perceptions

Consumers are generally distinguished by their attitudes when it comes to food choice (Roininen *et al.*, 1999). Pickens (2005) defined attitudes as being “a mindset or a tendency to act in a particular way due to both an individual's experience and temperament." The author further stated that when reference is made to a person's attitude, it is actually referring to their emotions and behaviours; how people see situations and behave as a result. Attitudes are formed by three factors: 1) the affective factor which is defined by feelings, 2) cognition, which refers to thoughts or beliefs and, 3) behaviour in the form of actions.

Perceptions, on the other hand, are interpretations of external cues into something meaningful based on past experiences (Pickens, 2005). These interpretations may not necessarily reflect the reality. Furthermore, humans tend to be selective in what they perceive, and filter out information based on their capacity to take in new information, in conjunction with thoughts and ideas they already have (Pickens, 2005). According to Pickens (2005), perceptions are the identification, organisation and interpretation of sensory information. The interpretation is formed and analysed based on past experiences, thoughts or beliefs.

2.9 Significance of South African millennials

The millennial generation, or "Generation Y" generally consists of people who were born between 1980 and 2000 (Lu, Bock & Joseph, 2013). This generation is much larger than "Generation X" – the preceding generation (Nowak, Thach & Olsen, 2006) and it accounts for about 35.47% of the South African population (StatsSA, 2017). It is therefore a significant market group – justifying this group as the target consumer group for the proposed study. Millennials are generally described to be market savvy when it comes to consumer product purchases (Nowak *et al.*, 2006). They have also been reported to be slightly more health conscious compared to previous generations (Kuhns & Saksena, 2016) and have an affinity for green consumerism (Muposhi, Surujlal & Dhurup, 2015). South African millennials, specifically, are more educated than the previous generation (StatsSA, 2020), quite brand conscious (Botha, 2016) and more technologically advanced (Padayachee, 2017). Their education and capability to use technology, and hence access the internet, probably implies that their health and taste attitudes are likely to be affected by their access to more information. South African millennials might therefore also be more likely to be interested in whether the food that they consume contains gluten or not.

2.10 Bread consumption in South Africa

Bread is South Africa's second most consumed staple after maize meal. Labadarios, Steyn, Maunder, MacIntryre, Gericke, Swart, Huskisson, Dannhauser, Vorster and Nesmvuni (2005) found that the most consumed and purchased food items in South African homes are: maize meal, sugar, tea, whole milk, hard margarine and brown bread. Between October 2017 and September 2018, the baking industry produced 2.278 billion loaves of bread. Of these, 49.06% was white bread, 50.78% was brown and whole wheat bread and specialty bread made up 0.16% (FACS, 2019a). In South Africa, both white and brown bread flours are mandatorily fortified with vitamin A, thiamine (vitamin B1), riboflavin, (vitamin B2), niacin (vitamin B3), folic acid, pyridoxine (vitamin B6), and iron and zinc (FACS, 2019a) – making bread an important source of micronutrients for many people.

It is also important to note that in South Africa, wheat flour for bread making is subsidised for the manufacturer (Mncube, 2014). This is however with the exception of white bread as its price is inclusive of value added tax (Mncube, 2014). This is largely how and probably why wheat bread out-competes breads made with alternative grains with regards to price.

In a study done by Ronquest-Ross, Vink and Sigge (2015), it was found that between 1999 and 2012, conventional/industrial bread consumption in South Africa decreased by 9.3%. The suggested reasons for this decrease was that it was due to innovation in value-added breakfast cereals and lower income consumers opting for maize as a more affordable source of starch.

2.11 Consumer perception of healthfulness, sensory properties and the price of gluten-free breads

Dunn, House and Shelnutt (2014) studied the effect of gluten-free labels on study participant's perceptions of overall likeability, texture and flavour of cookies and chips. The pairs of products presented were identical gluten-free products (chips, n=2; cookies, n=2), however, one product had a gluten-free label and the other did not. No significant differences were found for the overall likeability, taste or texture of either product pairs. Further results were as follows: 57% of the respondents said that gluten-free products could be used as medicine, 32% believed that they can be prescribed for weight loss, 31% agreed that refraining from gluten could improve a healthy individual's health and 32% believed that a gluten-free diet could improve digestive health. It was concluded that gluten-free labels do not have a significant impact on consumers' perceptions of food quality, although the consumers may have unjustified beliefs about the healthfulness and potential positive impact of gluten-free diets (Dunn *et al.*, 2014). The conclusion by Dunn *et al.* (2014) on the unsubstantiated belief that gluten-free products are healthier was supported by Gaesser and Angadi (2012), who stated that avoiding gluten may not be necessary for individuals who are healthy.

In a consumer sensory evaluation study of the aroma quality of gluten-free versus wheat bread crumbs, it was found that the liking of wheat bread crumb aroma scored higher than that of gluten-free bread crumbs (except for oat bread crumbs) (Hager, Wolter, Czerny, Bez, Zannini, Arendt & Czerny, 2012). It was also stated that the "medium intense yeast-like" and "weak malty and buttery" aroma notes in wheat bread crumbs were the reason for higher liking. This was opposed to the "mouldy" and "vinegar-like" notes which were detected in the buckwheat bread crumbs (Hager *et al.*, 2012). Gluten-free bread in particular has often been described to have a firm, dry and crumbly texture (Schober *et al.*, 2005; Onyango, Mutungi, Unbehend & Lindhauer, 2010; Torbica, Hadnađev & Dapčević, 2010) which is often undesirable to consumers.

Lee, Ng, Zivin and Green (2007) evaluated the cost of following a gluten-free diet in the USA. They found that gluten-free products bought at health food stores were more expensive than those bought at normal grocery stores, with gluten-free products being 123% more expensive in health food stores. They also found that all the gluten-free products they evaluated were more expensive than their wheat containing counterparts, with gluten-free products in general being 240% more expensive. This corresponds with a report by Stevens and Rashid (2008) who found that in Canada, gluten-free products were 242% more expensive than gluten-containing products. The literature is not clear on the reasons why commercial gluten-free products are so much more expensive, perhaps it can be attributed to the relatively small-scale production of gluten-free breads (particularly in South Africa) as well as the use of speciality ingredients. Also, the cost of the gluten-free diet in South Africa has not yet been reported.

2.12 The nutritional quality of gluten-free products

Several studies have described the gluten-free diet to be low in protein, rich in carbohydrates, high in fibre and of a high glycaemic index in relation to the dietary reference intake (Segura & Rosell, 2011; Matos & Rosell, 2015; Allen & Orfila, 2018). Considering the increasing interest in gluten-free products, the removal of wheat products from one's diet could result in nutrient deficiencies (Segura & Rosell, 2011; Allen & Orfila, 2018). Up until now, there is no single substitute able to fulfil all the functional properties of gluten. Instead, a combination of refined unfortified gluten-free cereal flours (e.g., maize and rice), hydrocolloids (e.g. hydroxypropyl methylcellulose) and proteins (e.g., egg white and soya) are used to make gluten-free products (Capriles & Arêas, 2014). Allen and Orfila (2018) found that only 28% of the gluten-free breads they analysed in Europe were fortified with calcium and iron, and only 5% of the total gluten-free breads were fortified with all four fortification minerals (calcium, iron, niacin and thiamin), in addition to folic acid and riboflavin. Furthermore, only two of the 14 gluten-free manufacturers fortified their products (Allen & Orfila, 2018). The authors went on to suggest that fortification ought to be made mandatory for gluten-free foods as it is relatively cheap, nutritionally beneficial for consumers and convenient for manufacturers (Allen & Orfila, 2018).

Although most commercial gluten-free products are nutritionally inferior to their gluten containing alternatives, it is important to consider that those who follow gluten-free diets take in other sources of nutrients as well (Allen & Orfila, 2018), which could be considered as supplementary. Also, other promising ingredients and processes such as the use of nutrient-dense grains (e.g., amaranth, sorghum, teff) and fermenting gluten-free flours with certain starter cultures could improve the intakes of protein, iron, calcium and fibre (Moroni *et al.*, 2009; Saturni *et al.*, 2010). However, overall, the gluten-free diet remains a concern in terms of nutritional adequacy.

2.13 Gaps in the knowledge

Gluten-free products produced in developed parts of the world, particularly Europe and the USA, have been extensively characterised and evaluated for intention to purchase and consumer acceptability. The sensory properties of gluten-free bread available in South Africa however, has not been characterised. This is needed as it could offer insights for the development of gluten-free bread made from the climate-smart food crops of Southern Africa.

The health and taste attitudes scales have been used in combination with other psychographic scales e.g. food frequency questionnaires, however, it has seldomly been related to consumer perceptions of physical product sensory evaluation. Such an application is necessary to determine if the acceptability of the sensory properties of gluten-free bread may be influenced by the health and taste attitudes of consumers. The health and taste attitude scales have not been explored in South African thus far. Doing this may provide insight into the health consciousness and taste attitudes of the group of South African millennials used in this study, relative to consumers from other countries. Such studies could possibly highlight the need for consumer education when it comes to the impact food has on health.

The perceptions consumers have about gluten has been studied in other countries, however, there is no evidence of such a study in South Africa. Knowing the perceptions that consumers have about gluten could inform food product developers on how to market gluten-free products or on how to use product labelling to educate consumers about product benefits.

3.0 HYPOTHESES AND OBJECTIVES

3.1 Hypothesis 1

Gluten-free white, brown and seeded bread samples from two commercial companies (labelled GFA and GFB) will be perceived as more crumbly, dry and hard compared to commercially sourced wheat control bread samples.

Gluten-free bread has been described as dry, crumbly (Schober *et al.*, 2005; Onyango *et al.*, 2010; Torbica *et al.*, 2010), firm and to have a lower specific volume and a higher staling rate (Mahmoud *et al.*, 2013) compared to gluten-containing bread. These poor qualities are largely due to the absence of gluten. Hydrated gluten molecules impart elasticity, cohesiveness, viscosity and extensibility in wheat doughs (Wieser, 2007). This allows for carbon dioxide-filled gas cells to form during proofing and the gas to be retained as the bread rises (Mahmoud *et al.*, 2013), thereby contributing to desirable loaf volume, softness and moisture retention quality properties (Salmenkallio-Marttila, Roininen & Autio, 2004). Although gluten-free bread formulations often contain additives (e.g., enzymes and hydrocolloids) that try to mimic the action of gluten, gluten-containing formulations often still produce bread with more desirable quality properties (Capriles & Arêas, 2014).

3.2 Objective 1

To determine and compare the sensory characteristics of designated commercial gluten-free and gluten-containing white, brown and seeded bread using a descriptive sensory panel and physical analyses.

3.3 Hypothesis 2

The sensory properties of the gluten-free bread samples will have a greater impact on the hedonic ratings of consumers with a high taste attitude compared to those with a low taste attitude.

Gluten-free food is often considered healthy yet unappealing to consumers compared to the gluten-containing counterparts (Potter, Stojceska & Plunkett, 2014; Cayres, Ramírez Ascheri, Peixoto Gimenes Couto, Almeida & Melo, 2020). It was found in a study in Poland that consumers who consider taste as an important factor in food are less willing to consume food with health benefits (e.g., added fibre and reduced salt) than consumers who do not consider the taste of food to be important (Sajdakowska, Gębski, Żakowska-Biemans & Jeżewska-Zychowicz, 2019). Roininen, Tuorila, Zandstra, de Graaf, Vehkalahti, Stubenitsky and Mela (2001), using the Health and Taste attitudes questionnaire, found that respondents who have a high taste attitude stated that they consume more full fat chocolate bars and not reduced fat chocolate bars than those who have a low taste attitude. This shows that consumers with a high taste attitude may be more concerned with the taste of food rather than the health effects. Furthermore, the most important motives for choosing bread amongst Polish consumers was found to be freshness and taste (Sajdakowska *et al.*, 2019).

3.4 Objective 2

To determine the effect of the consumers' taste attitudes on the acceptability of the sensory properties of commercial gluten-free bread when the gluten-free status of the bread sample is known (informed) or not known (blind).

3.5 Hypothesis 3

Consumers' health attitude, whether high or low, will not have a significant impact on their perception of the sensory properties of gluten-free bread.

Consumers were found to assume that gluten-free products are healthier than the gluten containing alternatives (Dunn *et al.*, 2014). However, most consumers expect sensory properties similar to the standard (gluten-containing) products, in products presumed to have added health benefits (Vázquez-Araújo, Chambers IV & Cherdchu, 2012). Thunström and Nordström (2015) found that ultimately, taste is the main factor when it comes to the consumer's experience of bread and potato chips. Sandvik, Nydahl, Marklinder, Næs and Kihlberg (2017) also noted that consumers (young and old) regard sensory appeal (above natural content, health and price), to be most important when it comes to common food items eaten regularly. Also, freshness and taste are the most highly regarded factors in bread choice amongst most consumers (Sajdakowska *et al.*, 2019). Therefore, those with an inherent high health attitude are likely to be interested in gluten-free bread but their acceptance of it is likely to be dependent on their perception of the sensory properties (Vázquez-Araújo *et al.*, 2012).

3.6 Objective 3

To determine the effect of consumers' health attitudes on their perception of the acceptability of the sensory properties of gluten-free bread.

4.0 RESEARCH

4.1 Physical characterisation and sensory profiling of commercial gluten-free bread

4.1.1 Abstract

Introduction: Wheat bread is the second most consumed staple food in South Africa. However, the hot and dry climate conditions of various parts of South Africa play a significant role in the country not being able to produce enough wheat for breadmaking. For this reason, South Africa continues to import wheat to balance the supply shortage and this has a negative impact on the economy. The use of gluten-free indigenous climate-smart crops for bread products could offer economic advantages. These include crops such as millet and sorghum. **Objective:** The objective of this work was to determine the characteristics of selected commercial gluten-free white, brown and seeded breads. The information obtained could inform the development of gluten-free bread made from climate-smart crops. **Results:** A number of differences between the gluten-free and control bread samples were observed, especially in terms of texture, flavour and nutritional content. There were also some differences between the two gluten-free bread brands. The white and brown gluten-free breads were generally firmer and perceived to have more toasted, coffee and nutty flavours, compared to the controls. The seeded bread had similar physical characteristics but differed in flavour profile, where one gluten-free sample was described to have a toasted and coffee flavour and the other one was perceived to have a nutty flavour. The control sample was described to have a distinct wheaty flavour. **Conclusions:** The main characteristics that gluten-free white, brown and seeded breads from gluten-free, climate-smart crop flours need to possess to be similar to current commercial gluten-free breads or wheat bread were identified. The crumbly, dry and firm texture of gluten-free bread is a development challenge which will need to be addressed during the development of gluten-free bread from climate-smart crop flours, bearing in mind that the soft and moist characteristics of wheat bread should also be mimicked as much as possible. The research therefore provides insight for the development of bread made from gluten-free, climate-smart crop flours.

4.1.2 Introduction

Wheat bread is a staple food in South Africa, it is also the second most consumed food after maize meal (Meyer & Kirsten, 2005). However, considering factors such as drought and high heat climate conditions, which are unfavourable to wheat cultivation, it is increasingly becoming a challenge to produce high yields of wheat in the country (Curtis & Halford, 2014). This challenge is also affected by southern Africa's relatively poor agricultural infrastructure and dependence on rain rather than irrigation for crop growing (Ringler, Zhu, Cai, Koo & Wang, 2010). Rapid urbanisation and the increase in income and purchasing power of middle-class consumers is increasing the demand for wheat-based food products (Baiyegunhi & Sikhosana, 2012). In fact, Baiyegunhi and Sikhosana (2012) suggested that a 10% increase in income of consumers translates to a 16.3% increase in wheat imports. It is for these reasons, among others, that South Africa continues to depend on imports to balance the increasing demand for wheat-based food products. Due to wheat bread being a staple, the price of wheat flour is subsidised by the government to benefit both the producer and consumer (Mncube, 2014; De Wet & Liebenberg, 2018). This ultimately has a negative effect on the economy as revenue is spent in supplying bread to consumers at a net loss (De Wet & Liebenberg, 2018).

Climate smart food crops (CSFCs) such as sorghum and the millets however offer a potential solution. These crops are indigenous to southern Africa and have the ability to grow and thrive in dry, hot conditions due to their resilience (Thierfelder, Chivenge, Mupangwa, Rosenstock, Lamanna & Eyre, 2017). The challenge with CSFCs however, is that due to their lack of gluten-forming proteins (gliadin and glutenin), the bakery products made from them have undesirable textural characteristics (Naqash, Gani, Gani & Masoodi, 2017). They also exhibit inferior nutritional quality compared to their gluten-containing counterparts (Allen & Orfila, 2018). The texture difference can be attributed to the viscoelastic and gas holding capacity that gluten formation offers to wheat-based bakery products. However, by use of alternative functional ingredients such as hydrocolloids, several companies have managed to produce gluten-free bread loaves. Commercial gluten-free bread loaves have also become available in the South African market. These have however not been characterised or profiled in terms of their physical and sensory properties.

Considering that it is in Southern Africa's best interest to produce bread using gluten-free CSFCs (Jiri, Mafongoya & Chivenge, 2017) that is similar to wheat bread, it is necessary to determine the characteristics of the gluten-free bread that is currently commercially available. These insights will assist with the further development of bread made from CSFCs with sensory properties that are acceptable or familiar to consumers but that are also price-competitive to wheat bread. Therefore, the aim of this research was to characterise and compare the physical and sensory properties of designated commercial gluten-free bread brands. A popular and widely used brand of wheat bread was included as a control and point of reference. A further objective was to compare the information supplied on the labels of the different bread products in order to determine the differences and similarities in the ingredients used as well as the price points. The white, brown and seeded types from each brand were included in the characterisation and; the comparisons were made by bread type.

4.1.3 Materials and methods

4.1.3.1 Experimental design

Figure 4.1 shows the experimental design for the characterisation and descriptive sensory analysis of the gluten-free and control bread samples. The pan bread loaves were purchased from retail outlets and one brand was sourced directly from the manufacturing company. All the loaves were stored in their packaging at room temperature (± 22 °C) upon purchasing/collection. The samples were as follows:

- Three different brands [Gluten-free A (GFA), Gluten-free B (GFB) and a wheat control];
- Three bread types per brand, i.e., brown, white and seeded bread;
- Three different production batches were procured for each bread type and;
- Each batch was represented by three loaves
- The total number of samples was therefore 81

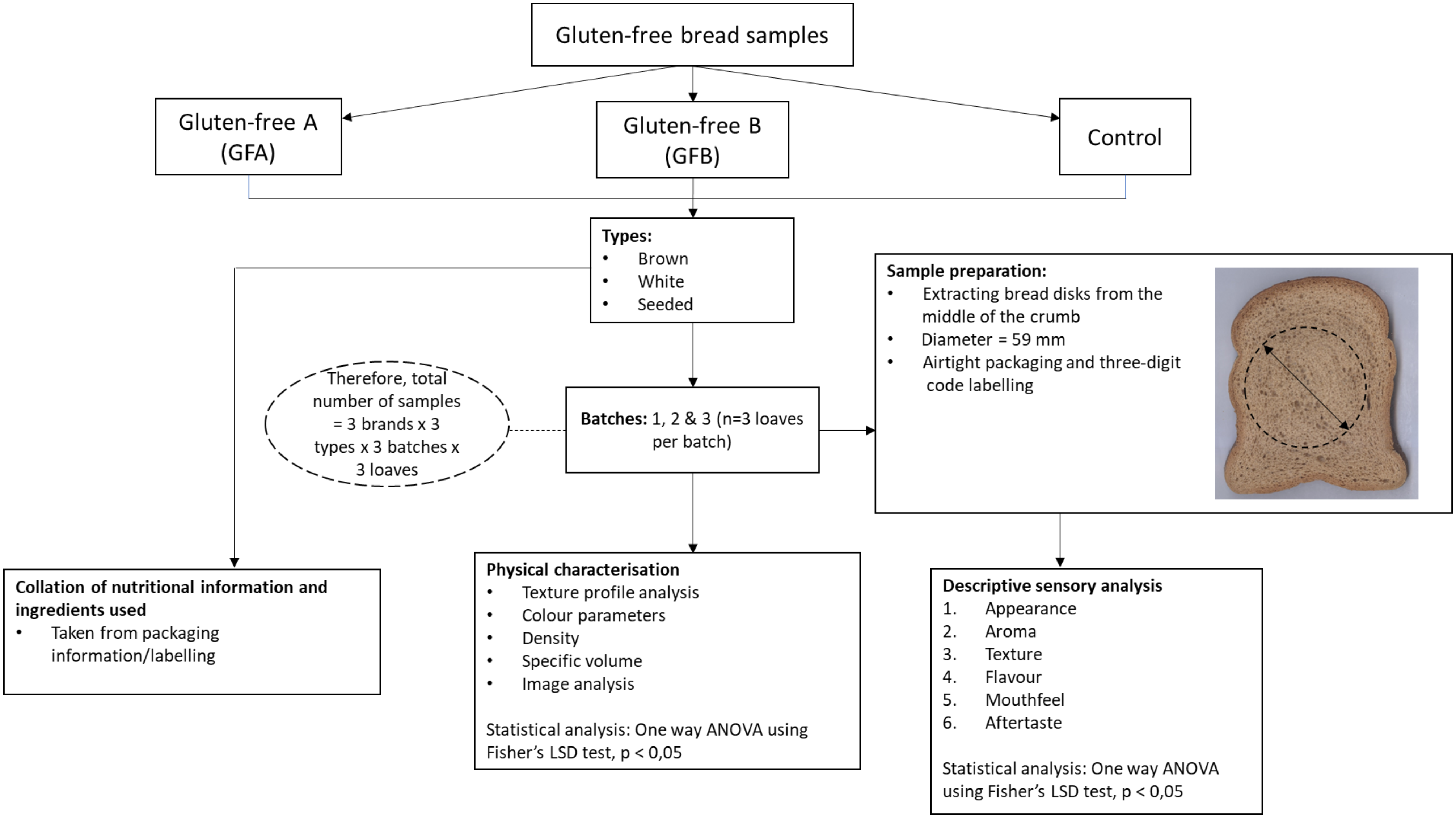


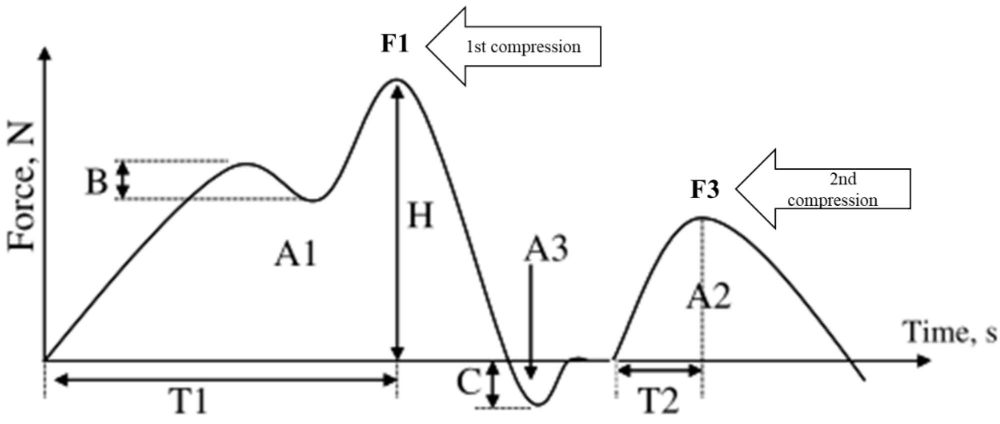
Figure 4.1: The experimental design for the characterisation and descriptive sensory analysis of the gluten-free and control bread samples

4.1.3.2 Survey of information on bread packaging and price per kilogram:

Information on the packaging of each bread brand and type was collected and tabulated. This included the nutritional information and list of ingredients. The price per kilogram at the time of purchase was also recorded.

4.1.3.3 Determination of texture:

For texture analysis, a two series Texture Profile Analysis (TPA) was conducted according to Fiszman, Salvador and Varela (2005) and Krupa-Kozak *et al.* (2013) using the Shimadzu EZ-L texture analyser (Shimadzu Corporation, Kyoto, Japan). Two full slices from the middle of each loaf (i.e. three loaves per batch per bread type and per sample/brand) were used for each texture measurement. The height of the two slices was measured using a Vernier caliper and factored into the measurement before each test. The crumb area of a two-slice stack per loaf taken from the centre of the loaf was compressed twice to 40 % of its original height using a 20 mm diameter round flat plastic disk. The test speed used was 60 mm/min, with a resting time of 5 s in between the compressions, at a trigger force of 0.05 N (GåMbaro, Varela, GiméNez, Aldrovandi, Fiszman & Hough, 2002; Correa & Ferrero, 2015), using a 200 N load cell. The double compression gave a two-bite texture profile curve from which the following textural properties were extracted: firmness (N), elasticity (%), resilience (%) and adhesive force (N). Also, all of the samples slices which were used for this analysis were obtained from loaves which were purchased/delivered one day before analysis. The firmness, elasticity, resilience and adhesiveness were derived as follows:



Where: Peak force [Firmness] = F1 (N); Adhesive force = C (mN); Elasticity = (T2/T1) x 100 (%); Peak force 2 = F3 (N) and; Resilience = (F3/F1) x 100 (%)

Figure 4.2: Force (N) against time (s) texture profile curve produced from the double compression of bread crumb texture analysis and formulas. Adapted from (Kealy, 2006)

4.1.3.4 Determination of the density, specific volume and average mass per slice:

Three slices in the centre of a loaf were used for each density measurement. The density (g/cm^3) was calculated using the volume (cm^3) and mass (g) measurements of a square crumb area gently extracted from a bread slice using a 58.5 mm square cookie cutter. The actual dimensions (length, height and width) of each extracted piece was measured using a Vernier caliper to calculate volume (length x width x height). The mass of the bread squares was measured in grams. The respective densities were calculated (Feili *et al.*, 2013): Density (g/cm^3) = Mass (g)/ Volume (cm^3). The specific volume calculation is the inverse of the density calculation, therefore: Specific volume (cm^3/g) = Volume (cm^3)/ Mass (g). The average slice mass was also determined as follows: Average slice mass = Net loaf mass declared on label(g)/ Total number of slices.

4.1.3.5 Determination of the colour:

The colour of the crumb was measured using a calibrated Chroma Meter CR-400 (Konika Minolta Inc., Japan) and it was based on the L* a* b* scales. L* represents lightness [where L* = 0 (black) and L* = 100 (white)], a* represents redness-greenness (where -a* = greenness and +a* = redness) and b* represents yellowness-bluishness (where -b* = blueness and +b* = yellowness) (Ribotta, Pérez, Añón & León, 2010; Krupa-Kozak *et al.*, 2013). The measurements were taken on the middle of the crumb area of three bread slices from the middle of each loaf. Chroma (C*) is used to quantify colourfulness by predicting how different a hue is compared to a grey colour with the same lightness (Pathare, Opara & Al-Said, 2013). This measurement indicates the colour intensity of the sample as perceived by humans and it was derived from the formula (Pathare *et al.*, 2013):

$$C* = \sqrt{a*^2 + b*^2}$$

4.1.3.6 Descriptive sensory analysis:

Recruitment

A total of 55 prospective panellists were screened based on their ability to distinguish between the five basic tastes (sour, bitter, sweet, umami and salty), rank colour intensities, identify aromas on blind coded smelling strips and describe textures of a variety of food items. Their total scores for the screening tests were ranked from highest to lowest and the top ten scoring participants were selected to be panelists. However, only nine participated in the training and evaluation sessions (3 men and 6 women).

Training

The panellists were advised of the objective of the training, which was to identify the differences in the sensory characteristics of the nine bread samples (three samples at a time). Training was conducted over three consecutive days consisting of a two-hour session on each day in an oval boardroom setting. The panellists were each provided with samples of sections of the crumb area of slices from each of the bread brands (white crumb samples, followed by brown then seeded crumb samples) with filtered water for pallet cleansing (Figure 4.3). The training method used was adapted from Lawless and Heymann (2010b) and it involved: (1) individually smelling, tasting, feeling and observing the appearance of the blind coded crumb samples and producing non-hedonic terms to describe and distinguish them. The panellists were instructed to classify their descriptors according to appearance, aroma, texture, flavour, mouthfeel and then aftertaste. The definitions for the classifications (appearance, aroma, texture, flavour, mouthfeel and aftertaste) were also clarified (Table 4.1). (2) The descriptors produced by all the panellists were collated, discussed, clarified and narrowed down by excluding synonymous words. (3) Lastly, the final list of all descriptors, reference samples and definitions of terms in line with literature (Curic *et al.*, 2008; Heenan, Dufour, Hamid, Harvey & Delahunty, 2008; Callejo, 2011; Bernstein & Rose, 2015; Campo, del Arco, Urtasun, Oria & Ferrer-Mairal, 2016) were finalised (Table 4.2). Using the descriptors agreed on and the physical reference samples, the panellists then evaluated the samples in a Sensory Science Laboratory with individual booths to familiarise themselves with the style and nature of the task. The samples were blind coded with randomly selected three-digit numbers and served one at a time under white daylight with filtered water as a pallet cleanser.

Figure 4.3: Example of brown bread crumb samples served to panellists for generating descriptors during training

Table 4.1: Definitions of attributes used to classify descriptive terms for the descriptive sensory evaluation of gluten free bread crumb samples

Attribute	**Definition**
Appearance	What you see when you look at the bread
Aroma	How the bread smells to you
Texture	How the bread feels in your fingers
Flavour	The joint perception of taste and aroma in your mouth
Mouthfeel	How the bread feels in your mouth
Aftertaste	The taste that lingers in your mouth after swallowing the bread, before drinking water

Table 4.2: List of descriptors and their definitions, physical reference material and rating scales used for the descriptive sensory evaluation of the gluten-free bread crumb samples by the trained panel

Descriptor	Definition*	Reference material	Rating scale
		Appearance	
Pore size	The average size of pores on surface of bread slice	A 15 cm ruler was provided for reference. ≤1 mm diameter = small. ≥5 mm diameter = large.	Small = 0, Large = 10
Pore quantity	The quantity of crumb cells/pores	A moist chocolate sponge cake slice was used as reference (rated 10)	No pores = 0, Many pores = 10
Specks	The number of visual specks throughout the bread	Seeded wheat bread (rated 10)	No specks = 0, Many specks = 10
Seeds	The degree to which the sample contains seeds of various sizes	Multi-seed crackers (rated 10)	No seeds = 0, Many seeds = 10
		Aroma	
Yeast	The intensity of the aroma associated with fermented dough/a yeast-like odour	Fermented white wheat bread dough (rated 10)	No yeast aroma = 0, Intense yeast aroma = 10
Toasted	The intensity of the aroma associated with grain products that have been browned or have been subjected to heat enough to cause some burnt notes	Toasted brown bread crumb (rated 10)	No toasted aroma = 0, Intense toasted aroma = 10
Wheat	The intensity of the aroma associated with freshly baked brown wheat bread	Freshly baked brown wheat bread roll	No wheat aroma = 0, Intense wheat aroma = 10
Sweet	The intensity of the aroma associated with slightly heated brown sugar	Brown sugar (as is)	No sweet aroma = 0, Intense sweet aroma = 10
		Texture	

Firm	The force needed to compress the sample with one finger	Stale brown wheat bread roll (rated 10)	Not firm = 0, Very firm = 10
Elastic	The extent of crumb sample recovery after pressing with one finger	Mini doughnuts (rated 10)	Not elastic = 0, Very elastic = 10
Dense	The degree of compactness after compressing the crumb with one finger	Moist chocolate sponge cake slice (rated 10)	Not dense = 0, Very dense = 10
Crumbly	The ease with which small crumbs fall off from the sample during hand manipulation	Rusks (rated 10)	Not crumbly = 0, Very crumbly = 10
Dry	The extent of perceived dryness of the sample	Rusks (rated 10)	Very moist = 0, Very dry = 10
Smooth	The extent of smoothness of the surface referring to an absence of dimples or blisters	Similar to the surface of a flapjack (rated 10)**	Not smooth = 0, Very smooth = 10
	Flavour		
Yeast	The intensity of a fermented yeast-like flavour	Freshly baked brown wheat bread roll (rated 10)	No yeast flavour = 0, Intense yeast flavour = 10
Toasted	The intensity of the flavour associated with grain products that have been browned or been subjected to heat enough to cause some burnt notes	Toasted brown wheat bread (rated 10)	No toasted flavour = 0, Intense toasted flavour = 10
Wheat	The intensity of the flavour similar to what is perceived from a fresh brown wheat roll	Freshly baked brown wheat bread roll (rated 10)	No wheat flavour = 0, Intense wheat flavour = 10
Nutty (almond)	The intensity of the flavour typical of almond nuts	Raw almond nuts (rated 10)	No nutty flavour = 0, Intense nutty flavour = 10
Coffee	The intensity of the flavour of coffee	Nescafe gold unsweetened cappuccino powder (rated 10)	No coffee flavour = 0, Intense coffee flavour = 10
Salty	The intensity of the taste sensation evoked by salt	10% table salt solution (rated 10)	No salty taste = 0, Intense salty taste = 10

	Mouthfeel		
Dry	The extent to which the sample feels dry/related to the amount of saliva absorbed by the sample	Rusks (rated 10)	Very moist = 0, Very dry = 10
Soft	The ease of biting and chewing the sample	Similar to the softness experienced during the chewing of a flapjack (rated 10)**	Not soft = 0, Very soft = 10
Chewy	The number of chews required to prepare a sample for swallowing. The higher the number the more chewy.	Mini doughnuts (rated 10)	Not chewy = 0, Very chewy = 10
Grainy	The degree to which particles of various sizes can be perceived during oral processing	Oat crunchies (rated 10)	Not grainy = 0, Very grainy = 10
Adhesive	The force required to remove a sample completely from the palate, using the tongue during consumption	Similar to the adhesiveness experienced during the chewing of a flapjack (rated 10)**	Not sticky = 0, Very sticky = 10
Seedy	The degree to which sample contains seeds of various sizes as perceived between the teeth and between the tongue and pallet	Seeded crackers (rated 10)	No seeds = 0, Many seeds = 10
	Aftertaste		
Toasted	The intensity of a lingering flavour (after swallowing) associated with grain products that have been browned or been subjected to heat enough to cause some burnt notes	Toasted brown bread (rated 10)	No toasted aftertaste = 0, Intense toasted aftertaste = 10
Yeast	The intensity of a lingering fermented yeast-like flavour (after swallowing)	Freshly baked brown wheat bread roll (rated 10)	No yeast aftertaste = 0, Intense yeast aftertaste = 10
Wheat	The intensity of a lingering flavour of brown wheat bread after swallowing	Freshly baked brown wheat bread roll (rated 10)	No wheat aftertaste = 0, Intense wheat aftertaste = 10

Sweet	The intensity of a lingering sweet taste of brown sugar	Brown sugar (as is) (rated 10)	No sweet aftertaste = 0, Intense sweet aftertaste = 10

*Definitions adapted from literature (Curic *et al.*, 2008; Heenan *et al.*, 2008; Callejo, 2011; Bernstein & Rose, 2015; Campo *et al.*, 2016).

**A flapjack is a light, fluffy, aerated and sweet fried batter usually made from wheat flour.

Evaluation

Samples for training and evaluation by the panel were prepared by cutting out circle-shaped pieces/discs from the crumb area of the bread slices and packaging them in Ziplock bags (120 mm x 180 mm, 40 micron) labelled with randomly selected three-digit codes (Figure 4.4). The diameter of the circle cookie cutter used was 59 mm. Each panellist did the full evaluation of all nine samples three times following a William's latin square order, using the final lexicon from the training. The samples were served monadically. The extent to which each term applied to each sample was then rated by the trained panel on an unstructured line scale of zero to ten. Zero represented an absence of the attribute and ten represented an intense presence of the attribute. The evaluations were done over three days consisting of two-hour sessions per day in a Sensory Science Laboratory. This laboratory has 16 individual booths, the evaluations were done under white daylight conditions and the room temperature was ±21 °C. Filtered water was provided to the panellists for pallet cleansing. Reference samples were also used to benchmark each descriptor (Table 4.2). Compusense Cloud (Compusense Inc., Guelph, Canada) software was used to produce the sample codes, presentation orders and to collect the rating data for each sample from each panellist.

Figure 4.4: Image of blind-coded bread crumb samples as served monadically to panellists for descriptive sensory evaluation in the Sensory Science Preparation Laboratory

4.1.3.7 Image analysis of commercial gluten-free bread slices:

Bread slice images were recorded by scanning the middle slice of each bread loaf. The full slices were scanned using an HP Scanjet G4010 Series Scanner (HP Inc., California, USA) in true colour at a resolution of 600 DPI. A ruler was also placed next to the slice for scale. The scanned images produced were saved in JPEG format.

For image analysis, the software ImageJ version 1.52a (National Institutes of Health, USA) was used. A representative area of 3.93 cm^2 was selected on the crumb areas of the bread slice images for analysis. The features chosen for analysis were the number of cells, the area of the cells (cm^2), the number of cells/cm^2 (density) and the diameter of the cells (cm). The diameter was derived from the area of the cells as follows (Scheuer, Ferreira, Mattioni, Miranda & Francisco, 2015):

If Area = πr^2 and;

Radius = $\sqrt{(A/\pi)}$ then;

Diameter = 2 x r

Where r = Radius and, A = Area

4.1.4 Statistical analysis

The results for the different bread types (white, brown seeded) were analysed separately.

The statistical analyses were conducted using SPSS version 25 (IBM Corporation ®, New York, USA). The effect of the three bread brands on the texture, density, specific volume, colour and image analysis data was analysed using one-way analysis of variance (ANOVA). The mean values in all the analyses were compared at $p<0.05$ by means of the Fisher's Least Significant difference (LSD) test. The descriptive sensory data was analysed through one-way ANOVA, compared at $p<0.05$ using Fisher's LSD test.

4.1.5 Results

Information on bread packaging

Tables 4.3 (white bread), 4.4 (brown bread) and 4.5 (seeded bread) show the list of ingredients and the nutritional information for the white, brown and seeded gluten-free breads. The major ingredients used in the current South African commercial gluten-free breads used in this research were maize starches, rice flours, cassava starches, sorghum as well as potato starches.

The white gluten-free breads (Table 4.3) contained multiple and different carbohydrate sources, cassava starch (tapioca) being the main one in GFA and, maize starch in GFB. Both gluten-free breads contained egg and psyllium husk and, all the products contained emulsifiers. In terms of nutritional information, GFA contained the highest amount of energy, dietary fibre and total sodium, however, the lowest protein of the options. The control wheat bread contained the lowest energy and total fat; however, the highest amount of protein was found in the control and GFB – the same amount. The price of GFA white was 792% higher than that of the white control sample. The price of GFB white was 647% higher than the white control sample.

In the brown breads (Table 4.4), the main carbohydrate sources were tapioca and sorghum flour in GFA and maize starch in GFB. GFB contained the highest energy and total fat content, however, the lowest protein and carbohydrate amount. The price of GFA brown was 903% higher than that of control brown. The price of GFB brown was 709% higher than that of control brown.

The seeded breads (Table 4.5) by GFA contained rice flour and tapioca starch as the main carbohydrate sources, whereas, GFB contained maize starch and golden linseed flour. GFA had the highest energy and total fat content. GFB had the lowest protein content but was intermediate in terms of energy, carbohydrate and total fat content. The price of GFA seeded was 622% higher than that of the control seeded. The price of GFB seeded was 517% higher than the price of control brown.

Table 4.3: Ingredients, nutritional information (per 100 g) and price (per kg) of gluten-free commercial white bread

	Ingredients	Energy (kJ)	Protein (g)	Carbohydrate (g)	Total sugar (g)	Total fat (g)	Dietary fibre (g)	Total sodium (mg)	Price per kg (ZAR)*
Control white bread	White bread wheat flour (gluten), water, yeast, salt, may contain acidity regulator seasonally, sugar, soybean flour, non-hydrogenated vegetable fat (palm fruit), emulsifiers (vegetable origin), preservative (calcium propionate), flavour enhancer, flavour improver, enzymes (non-animal origin), mineral salts (electrolytic iron and zinc oxide) and vitamins (vitamin B3, vitamin B6, vitamin B1, vitamin B2, vitamin A and folic acid)	1026	5.1	44	4.7	2.4	3.8	376	18.56
Gluten-free white bread A	Tapioca starch, maize starch, rice flour, psyllium husk, potato starch, sugar, egg powder, fibre, vegetable oil (sunflower seed), emulsifier (methocel), yeast, preservative (citric acid), salt	1045	4.1	43	1.8	4.8	8.5	484	165.47
Gluten-free white bread B	Water, maize starch, gluten-free flour (contains: legume flour, vegetable flour, whole flaxseed meal, millet flour, buckwheat flour, flavouring), rice flour, potato starch, vegetable fat (palm fruit), free range egg, sugar, yeast, emulsifier, modified starch, salt, cultured dextrose, psyllium husk, preservatives: calcium propionate, potassium sorbate	1039	5.1	39	3.3	6.9	3.6	306	138.64

*Price at the time of purchase

Table 4.4: Ingredients, nutritional information (per 100 g) and price (per kg) of gluten-free commercial brown bread

	Ingredients	Energy (kJ)	Protein (g)	Carbohydrate (g)	Total sugar (g)	Total fat (g)	Dietary fibre (g)	Total sodium (mg)	Price per kg (ZAR)*
Control brown bread	Brown bread wheat flour (gluten), water, yeast, salt, may contain acidity regulator seasonally, non-hydrogenated vegetable fat (palm fruit), soybean flour, preservative (calcium propionate), emulsifiers (vegetable origin), flavour enhancer, enzymes (non-animal origin), flour improver, mineral salts (electrolytic iron and zinc oxide) and vitamins (vitamin B3, vitamin B6, vitamin B1, vitamin B2, vitamin A and folic acid)	980	9.1	40	4.2	2.4	6.4	337	17.13
Gluten-free brown bread A	Tapioca flour, sorghum flour, rice flour, psyllium husk, potato starch, sugar, egg powder, maize starch, fibre, vegetable oil (sunflower seed), emulsifier (methocel), yeast, preservative (citric acid), salt	1030	4.5	41.9	1.4	4.3	10.3	542	171.72
Gluten-free brown bread B	Water, maize starch, golden linseed flour, gluten-free flour (contains: legume flour, vegetable flour, whole flaxseed meal, millet flour, buckwheat flour, flavouring), rice flour, potato starch, vegetable fat (palm fruit), sugar, free range egg, yeast, emulsifier, modified starch, salt, psyllium husk, cultured dextrose, preservatives: calcium propionate, potassium sorbate	1085	4.3	28	1.9	11.5	6.8	365	138.64

*Price at the time of purchase

Table 4.5: Ingredients, nutritional information (per 100 g) and price (per kg) of gluten-free commercial seeded bread

	Ingredients	**Energy (kJ)**	**Protein (g)**	**Carbohydrate (g)**	**Total sugar (g)**	**Total fat (g)**	**Dietary fibre (g)**	**Total sodium (mg)**	**Price per kg (ZAR)***
Control seeded bread	White bread flour (gluten), water, wheat bran (gluten), crushed wheat (4%) (gluten), linseed (2%), de-hulled soybean cuts (2%), yeast, oat groats (1%) (gluten), sugar, sunflower seeds (1%), sesame seeds (1%), salt, wheat gluten, acidity regulator, preservative (calcium propionate), emulsifiers (vegetable origin), flavour enhancer, soybean flour, minerals (electrolytic iron, zinc oxide) and vitamins (vitamin B3, vitamin B6, vitamin B1, vitamin B2, vitamin A and folic acid), flour improvers, enzymes (non-animal origin). Contains: 11% mixed grains and seeds	863	9.6	31	3.8	2.6	9.1	337	22.49
Gluten-free seeded bread A	Rice flour, tapioca starch, sorghum flour, potato starch, rice bran, maize starch, egg powder, vegetable oil (sunflower seeds), sunflower seeds, sesame seeds, flax seeds, sugar, yeast, emulsifier (methocel), psyllium husk, fibre, preservative (citric acid), salt	965	4.6	30	2.3	10	9.2	364	162.34
Gluten-free seeded bread B	Water, maize starch, golden linseed flour, gluten-free flour (contains: legume flour, vegetable fibres, whole flaxseed meal, millet flour, buckwheat flour, flavouring), rice flour, vegetable fat (palm fruit), potato starch, seeds (10%) (contains: pumpkin seeds, sesame seeds, brown linseeds), sugar, free range egg, yeast, modified starch, emulsifier, salt, psyllium husk, cultured dextrose, preservatives: calcium propionate, potassium sorbate	1180	9.5	26	2.2	13.9	8.8	278	138.64

*Price at the time of purchase

Determination of texture

Table 4.6 shows the analysis of the texture profiles of the bread types. The profiles are expressed through measurements of maximum firmness (N), adhesive force (mN), elasticity (%), second peak force (N) and resilience (%).

GFB white had a maximum firmness that was significantly higher ($p<0.05$) than the control yet it showed the least resilience and lowest adhesive force with a large standard deviation. GFA white was intermediary and closer to GFB in terms of maximum firmness and resilience.

The brown breads of GFA and GFB had similar and significantly higher ($p<0.05$) maximum firmness and adhesive force values than the control. The control brown bread had the highest resilience and GFB the lowest.

The maximum firmness and resilience of the seeded breads were not statistically different ($p>0.05$). The control bread had the lowest adhesive force, although with a high standard deviation.

Table 4.6: The texture profile (crumb firmness, adhesive force, elasticity, second peak force and the resilience) of white, brown and seeded commercial gluten-free bread type slices.

Sample	Max firmness (N)	Adhesive force (mN)	Elasticity (%)	Peak force 2 (N)	Resilience (%)
Control white	$0.7^{c} \pm 0.1$	$-29.1^{ab} \pm 10.4$	$95.0^{a} \pm 34.6$	$0.7^{c} \pm 0.1$	$96.3^{a} \pm 1.3$
GFA white	$4.1^{b} \pm 2.0$	$-11.2^{a} \pm 7.2$	$95.2^{a} \pm 13.6$	$3.6^{b} \pm 1.6$	$88.8^{b} \pm 3.4$
GFB white	$5.6^{a} \pm 1.1$	$-40.3^{b} \pm 36.3$	$89.1^{a} \pm 26.9$	$4.6^{a} \pm 0.9$	$83.4^{c} \pm 5.3$
Control brown	$0.7^{b} \pm 0.3$	$-31.3^{a} \pm 18.8$	$78.7^{a} \pm 20.6$	$0.7^{b} \pm 0.2$	$96.5^{a} \pm 1.7$
GFA brown	$3.7^{a} \pm 2.0$	$-10.3^{b} \pm 6.4$	$88.4^{a} \pm 26.2$	$3.5^{a} \pm 1.9$	$92.8^{b} \pm 4.8$
GFB brown	$3.9^{a} \pm 1.0$	$-14.8^{b} \pm 23.7$	$85.0^{a} \pm 11.3$	$3.4^{a} \pm 0.8$	$86.0^{c} \pm 1.9$
Control seeded	$4.6^{a} \pm 1.0$	$-69.5^{b} \pm 45.3$	$86.5^{b} \pm 7.2$	$3.9^{a} \pm 0.9$	$86.9^{a} \pm 14.0$
GFA seeded	$5.2^{a} \pm 0.7$	$-13.1^{a} \pm 12.7$	$100.0^{a} \pm 21.9$	$4.5^{a} \pm 0.5$	$86.5^{a} \pm 2.0$
GFB seeded	$5.1^{a} \pm 1.0$	$-22.8^{a} \pm 17.2$	$84.2^{b} \pm 15.3$	$4.4^{a} \pm 0.8$	$85.2^{a} \pm 1.5$

Mean ± standard deviation. [abc] For each bread type (white, brown and seeded), mean values in a column that do not share a letter are significantly different ($p < 0.05$).

Determination of the density, specific volume and mass per slice

Table 4.7 shows the density (g/cm^3), specific volume (cm^3/g) and average mass per slice (g) of the gluten-free and wheat bread types.

The density and specific volume measurements were inversely proportional. GFB white had the highest density, however the lowest specific volume. GFA white had the lowest density and highest specific volume. The same pattern was observed for the brown breads, where GFB had the highest density but lowest specific volume and; GFA had the lowest density and highest specific volume. However, GFA brown and the control brown bread did not show a statistical difference for density and specific volume ($p>0.05$).

For the seeded bread, the density and specific volume of the control bread and GFB were not statistically different. They were also the most dense with the lowest specific volume.

Table 4.7: The density, specific volume and average mass per slice of commercial gluten-free and wheat bread types

Sample	Density (g/cm^3)	Specific volume (cm^3/g)	Average mass per slice (g)*
Control white	$0.30^b \pm 0.05$	$3.39^b \pm 0.54$	38.89 ± 0.00
GFA white	$0.27^c \pm 0.02$	$3.77^a \pm 0.32$	22.86 ± 0.00
GFB white	$0.34^a \pm 0.02$	$2.92^c \pm 0.21$	26.79 ± 0.00
Control brown	$0.30^b \pm 0.04$	$3.41^a \pm 0.47$	38.89 ± 0.00
GFA brown	$0.26^b \pm 0.05$	$3.89^a \pm 0.68$	22.86 ± 0.00
GFB brown	$0.37^a \pm 0.03$	$2.70^b \pm 0.22$	26.79 ± 0.00
Control seeded	$0.45^a \pm 0.05$	$2.26^b \pm 0.22$	53.33 ± 0.00
GFA seeded	$0.33^b \pm 0.04$	$3.08^a \pm 0.42$	26.67 ± 0.00
GFB seeded	$0.42^a \pm 0.04$	$2.42^b \pm 0.21$	26.79 ± 0.00

Mean ± standard deviation. ^{abc} For each bread type (white, brown and seeded), mean values in a column that do not share a letter are significantly different ($p < 0.05$).

*Average mass per slice (g) = Net loaf weight declared on label/ number of slices in loaf

Determination of the colour

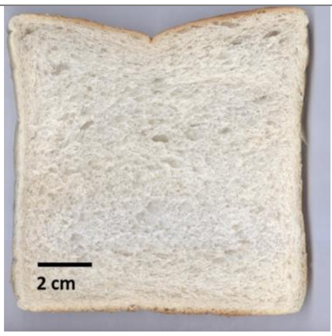
Table 4.8 displays the scanned images of the gluten-free and control wheat bread types as well as their colour measurements expressed by L* (black to white), a* (greenness to redness), b* (blueness to yellowness) and C* (colour intensity) values.

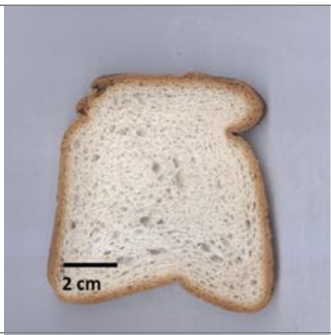
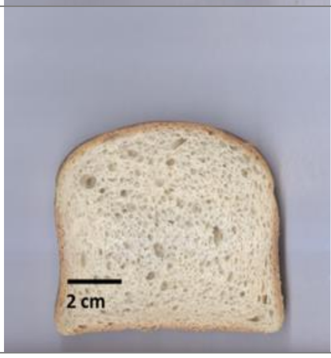
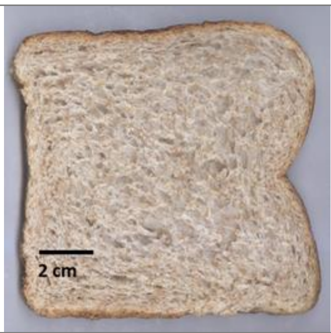
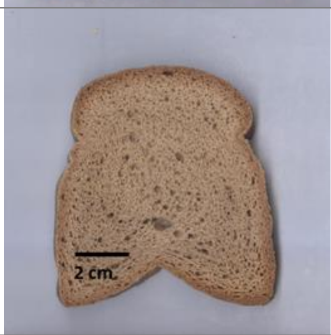
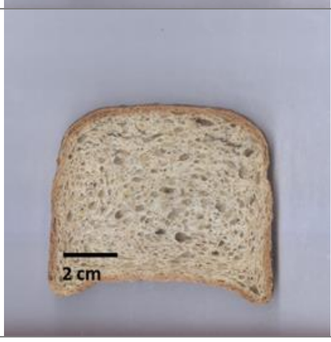
The white bread had L* values ranging from 67.7 to 77.0, which were generally higher than the brown and seeded bread and this indicates that they are indeed slanted more towards white than black. GFB white had the lowest L* ($p<0.05$). GFA white had the highest a* amongst the white bread. GFB white had the lowest a*, however, highest b* and C* ($p<0.05$). The colour intensity (C*) values were very similar to the b* values for all the white bread samples.

When looking at the brown bread images, GFA seems to be highest in brown colour, this was reflected in its low L* of 53.6, and high a*, b* and C* values compared to the other brown bread samples ($p<0.05$). GFB brown was intermediary in L*, b* and C*, although more closely related to the control than GFA. However, GFB's a* is the lowest of them all.

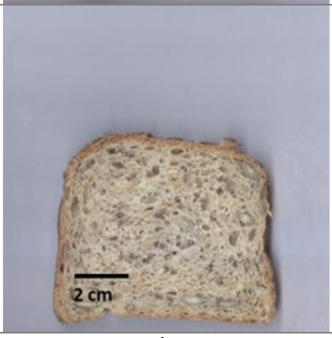
The seeded bread images appeared to be darker than their respective white and brown bread samples. GFB seeded had the highest L*, the lowest a* and was intermediary in its b* and C* amongst the seeded breads. GFA had the highest colour intensity, a* and b* but intermediary and closer to the control in its L*. The control bread appeared to be the darkest, hence it had the lowest L*. It was also lowest in b* and C* but intermediary in a*.

Table 4.8: Full slice image and quantitative colour measurements (L*, a*, b* and C*)* of the commercial gluten-free and wheat bread types

Samples	**Full slice image**	**L***	**a***	**b***	**C***
		White bread type			
Control white		$77.0^{a} \pm 1.9$	$-0.4^{b} \pm 0.1$	$10.7^{c} \pm 0.6$	$10.7^{c} \pm 0.6$

GFA white		74.3^{b} ± 1.2	0.2^{c} ± 0.1	11.4^{b} ± 0.6	11.4^{b} ± 0.6
GFB white		67.7^{c} ± 1.7	-0.9^{a} ± 0.1	14.5^{a} ± 0.7	14.5^{a} ± 0.7
Samples	**Full slice image**	**L***	**a***	**b***	**C***
		Brown bread type			
Control brown		67.9^{a} ± 1.8	2.9^{b} ± 0.5	14.9^{c} ± 1.1	15.2^{c} ± 1.2
GFA brown		53.6^{c} ± 1.0	7.2^{a} ± 0.4	25.7^{a} ± 0.6	26.7^{a} ± 0.6
GFB brown		63.3^{b} ± 1.5	0.4^{c} ± 0.4	17.8^{b} ± 0.6	17.9^{b} ± 0.6

Samples	**Full slice image**	**L***	**a***	**b***	**C***
		Seeded bread type			

Control seeded		51.9[b] ± 2.0	3.5[b] ± 0.9	15.8[c] ± 1.3	16.2[c] ± 1.5
GFA seeded		53.2[b] ± 1.2	7.2[a] ± 0.4	25.6[a] ± 0.7	26.6[a] ± 0.8
GFB seeded		61.4[a] ± 1.7	0.7[c] ± 0.3	17.6[b] ± 1.0	17.6[b] ± 1.0

Mean ± standard deviation. [abc] For each bread type (white, brown and seeded), mean values in a column that do not share a letter are significantly different (p < 0.05).

Where: L* = 0 (black) and L* = 100 (white), -a* = greenness, +a* = redness, -b* = blueness, +b* = yellowness and C* = colour intensity

Image analysis

Table 4.9 shows the image analysis results of the gluten-free and control bread types as expressed by cell quantity, area of cells, cell density and cell diameter.

All the control breads within each bread type had the highest cell quantity, with the control brown having the highest. This was also reflected in the cell density with the control bread having the cell density highest in all three bread types (p<0.05). The diameter of the cells was smallest for GFA within all the bread types, the same was noted for the area of cells and cell quantity. There was however large standard deviations in the cell quantities and cell densities of the samples, particularly in the control and GFB samples of all the bread types.

Table 4.9: Cell quantity, cell area, density and cell diameter of commercial gluten-free and wheat bread type

Sample	Cell quantity*	Area of cells (cm^2)	Cell density ($cells/cm^2$)	Cell diameter (cm)
Control white	$202^a \pm 120$	$0.004^a \pm 0.00$	$5.13^a \pm 3.06$	$0.07^a \pm 0.02$
GFA white	$47^b \pm 12$	$0.002^a \pm 0.00$	$1.20^b \pm 0.30$	$0.06^a \pm 0.01$
GFB white	$96^{ab} \pm 82$	$0.004^a \pm 0.00$	$2.43^{ab} \pm 2.08$	$0.07^a \pm 0.00$
Control brown	$310^a \pm 24$	$0.006^a \pm 0.00$	$7.88^a \pm 0.60$	$0.09^a \pm 0.01$
GFA brown	$82^b \pm 4$	$0.002^b \pm 0.00$	$2.08^b \pm 0.10$	$0.05^b \pm 0.01$
GFB brown	$71^b \pm 17$	$0.006^a \pm 0.00$	$1.81^b \pm 0.43$	$0.09^a \pm 0.02$
Control seeded	$185^a \pm 71$	$0.007^a \pm 0.00$	$4.71^a \pm 1.80$	$0.09^{ab} \pm 0.03$
GFA seeded	$86^b \pm 22$	$0.003^a \pm 0.00$	$2.18^b \pm 0.60$	$0.06^b \pm 0.05$
GFB seeded	$127^{ab} \pm 75$	$0.008^a \pm 0.01$	$3.24^{ab} \pm 1.90$	$0.10^a \pm 0.03$

Mean ± standard deviation. [abc] For each bread type (white, brown and seeded), mean values in a column that do not share a letter are significantly different ($p < 0.05$). *Cell quantity in a crumb area of 3.93 cm^2.

Descriptive sensory analysis

Figure 4.5 (a, b and c) shows the appearance attributes of the gluten-free and control bread types as evaluated by the descriptive sensory panel.

GFB white had the highest pore size compared to control white and GFA white. The pore quantity of GFB white was hence the lowest ($p<0.05$). The same trend was observed in the GFB brown samples. Also, the control brown and GFB brown samples contained a lot more specks than GFA brown ($p<0.05$).

Of the seeded bread, the control bread had the highest pore size and lowest pore quantity ($p<0.05$). GFA seeded had the highest pore quantity and lowest pore size. GFB was intermediary in pore size and quantity. The control seeded bread and GFB seeded were observed to contain much more seeds and specks than GFA ($p<0.05$).

Figure 4.6 (a, b and c) shows the aroma attributes of the gluten-free and control bread types as evaluated by the descriptive sensory panel.

As expected, the control bread in all bread types was perceived to have the highest wheat aroma. The yeast aroma within each bread type was however similar ($p>0.05$). For brown bread, GFA had the highest sweet aroma which was consistent in all the bread types. Brown and seeded GFA bread had the highest toasted aroma within the respective bread type categories. However, amongst the white breads, it was GFB which had the highest toasted aroma.

Figure 4.7 (a, b and c) shows the texture attributes of the gluten-free and control bread types as evaluated by the descriptive sensory panel.

When looking at the white bread samples (Figure 4.7a), GFB was the least smooth compared to GFA and the control, it also happened to be the firmest, driest and crumbliest bread ($p<0.05$). The samples were perceived to have similar densities, with GFA having a slightly lower density ($p>0.05$). The control white bread had the lowest firmness, dryness ($p<0.05$) and crumbliness. GFA white was perceived to be the most elastic ($p<0.05$).

In Figure 4.7b, it is seen that the densities of the samples were perceived to be similar. The control bread had the highest smoothness, however, the lowest firmness ($p<0.05$), dryness ($p<0.05$), elasticity ($p<0.05$) and crumbliness ($p>0.05$) compared to the gluten-free bread. GFA brown was also perceived to be the most elastic sample ($p<0.05$).

In Figure 4.7c, the control seeded bread was the least smooth, firm, dry and crumbly however, most elastic. GFA had the highest smoothness and dryness.

Figure 4.8 (a, b and c) shows the flavour attributes of the gluten-free and control bread types as evaluated by the descriptive sensory panel.

As expected, the control wheat breads had the highest wheat flavour amongst all three bread types ($p<0.05$). Among the white bread, GFB was perceived to have the most intense yeast, toasted and nutty flavours. Whereas, the control bread had the least intense yeast, toasted, coffee and nutty flavours.

Amongst the brown bread, the yeast and salt flavours of all the bread samples were perceived to be similar. GFA was significantly more intense in toasted and coffee flavour. GFB was perceived to have the most intense nutty flavour ($p<0.05$).

Amongst the seeded bread, the salt and yeast flavours of all the bread samples were perceived to be at a similar intensity. GFA had the most intense toasted and coffee flavour ($p<0.05$). GFB had the most intense nutty flavour and was intermediary in toasted flavour ($p<0.05$).

Figure 4.9 (a, b and c) shows the mouthfeel attributes of the gluten-free and control bread types as evaluated by the descriptive sensory panel.

The control white bread (Figure 4.9a) was the most soft, chewy and sticky ($p<0.05$). GFA was intermediary in all mouthfeel attributes and GFB was the least sticky, chewy, soft and most grainy and dry.

Figure 4.9b shows that the control brown bread was the most soft, chewy and sticky however, the least dry, grainy and seedy. GFB brown bread was the least soft, dry, chewy and sticky but the most grainy and seedy.

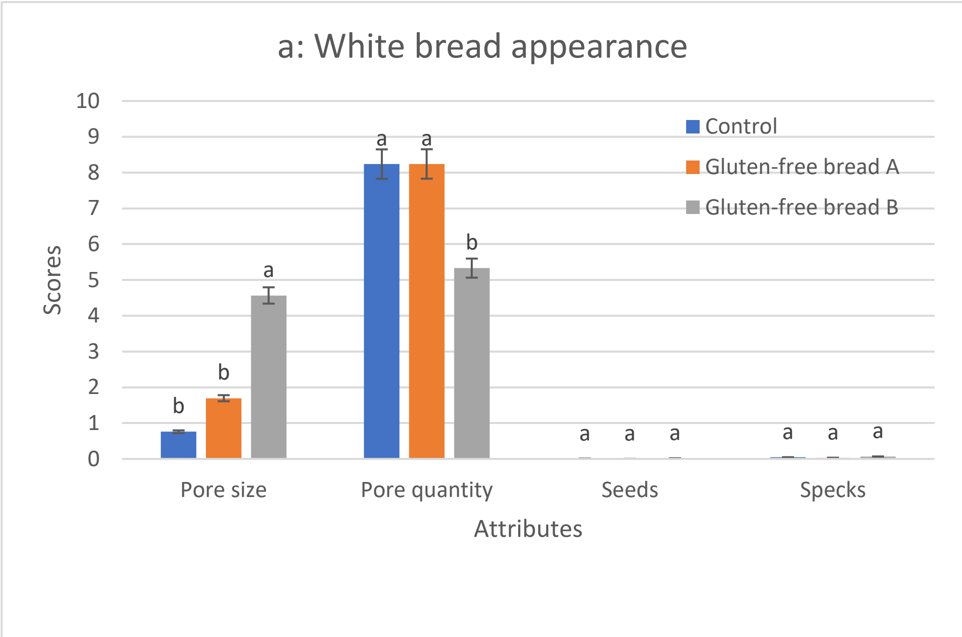
For the seeded bread (Figure 4.9c), the softness was similar for all three samples. The control seeded bread was highest in stickiness and chewiness. GFA was highest in dryness and intermediary in stickiness and chewiness.

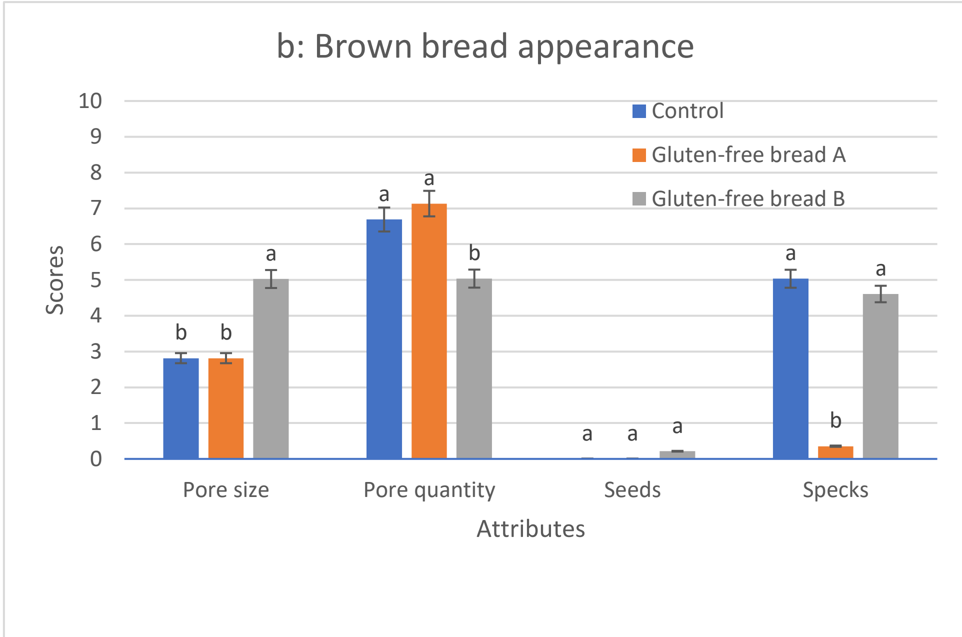
Figure 4.10 (a, b and c) shows the aftertaste attributes of the gluten-free and control bread types as evaluated by the descriptive sensory panel.

The control white bread (Figure 4.10a) was lowest in all aftertaste qualities except for wheat flavour, where it was the highest. GFB white had the highest sweet aftertaste.

For the brown bread (Figure 4.10b), GFA had the highest toasted aftertaste and lowest wheat aftertaste. The yeast aftertastes were similar. The control wheat bread had the highest wheat aftertaste and lowest toasted aftertaste.

Figure 4.10c shows that wheat seeded bread had the highest wheat and sweet aftertaste but the lowest toasted aftertaste. GFA seeded bread was highest in yeast and toasted aftertaste.





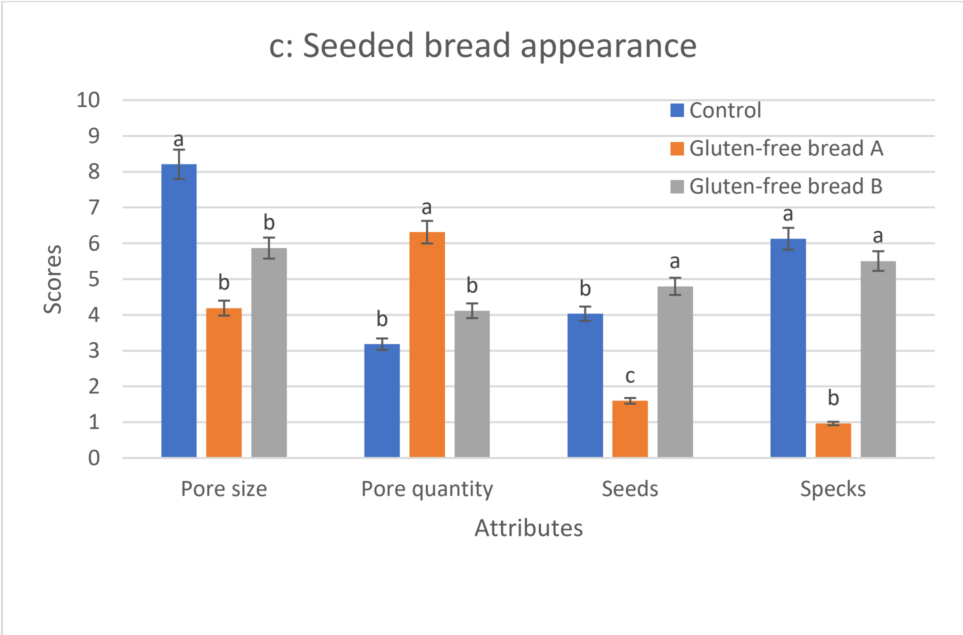
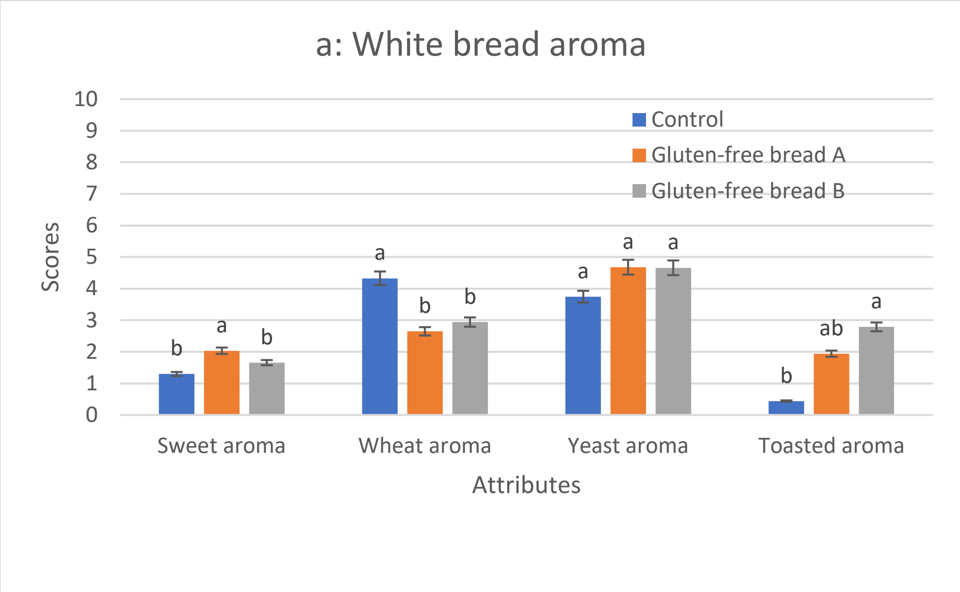
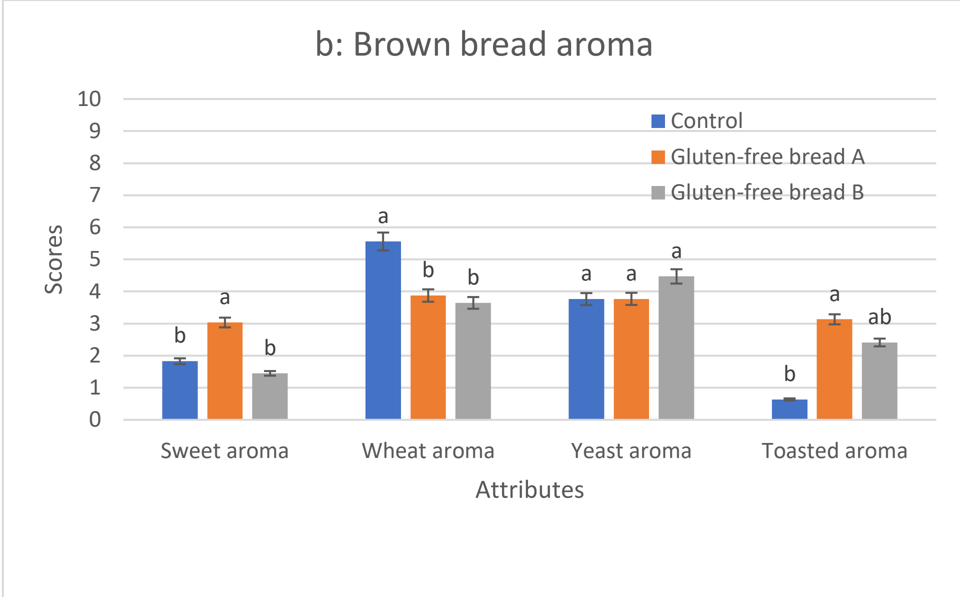


Figure 2.5a, b and c: Mean scores of a) white, b) brown and c) seeded commercial gluten-free and wheat bread appearance attributes as evaluated by descriptive sensory panel (n = 9). Where 0 = no presence of attribute and 10 = intense presence of attribute. Samples with different letters (a, b, c.) were significantly different for that attribute (p<0.05).





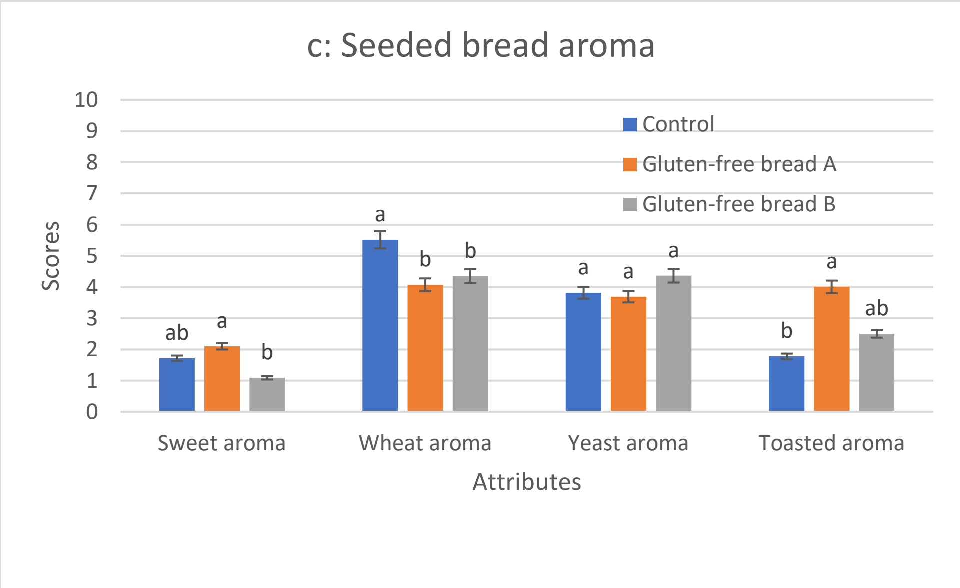
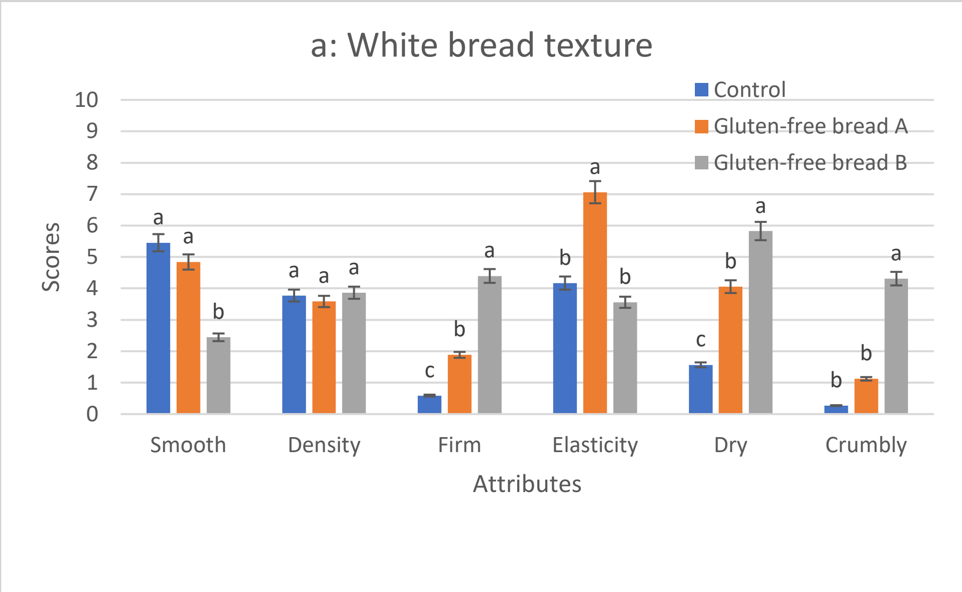
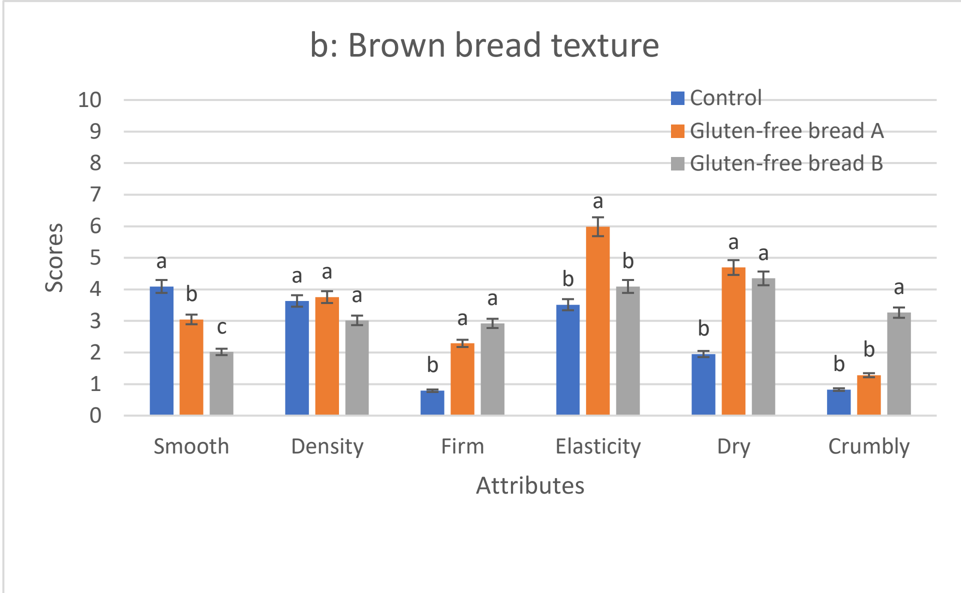


Figure 4.6a, b and c: Mean scores of a) white, b) brown and c) seeded commercial gluten-free and wheat bread aroma attributes as evaluated by descriptive sensory panel (n = 9). Where 0 = no presence of attribute and 10 = intense presence of attribute. Samples with different letters (a, b, c) were significantly different for that attribute (p<0.05).





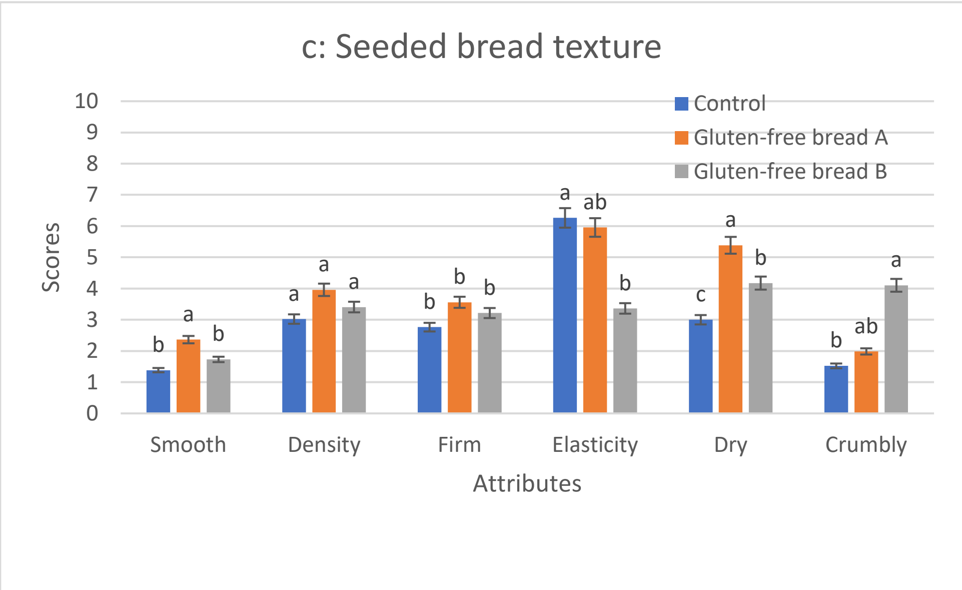
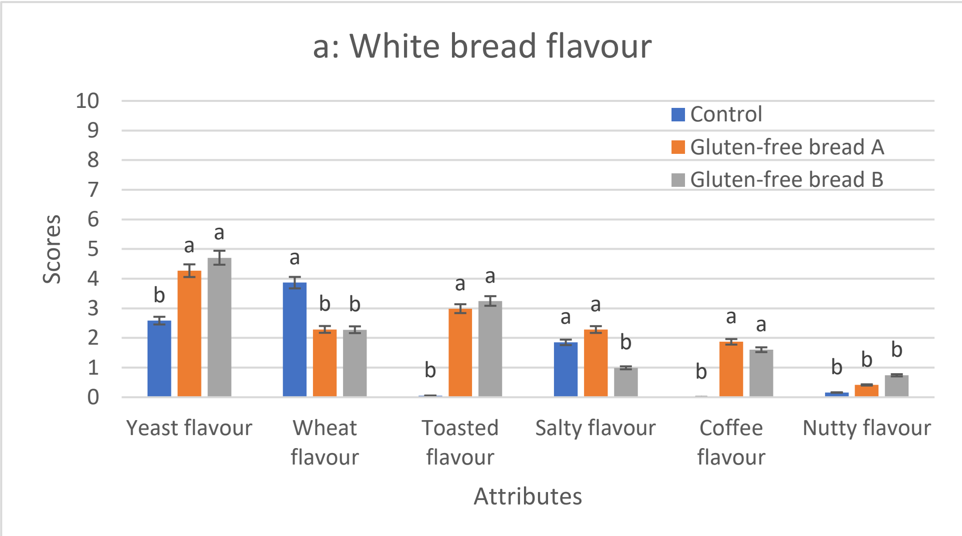
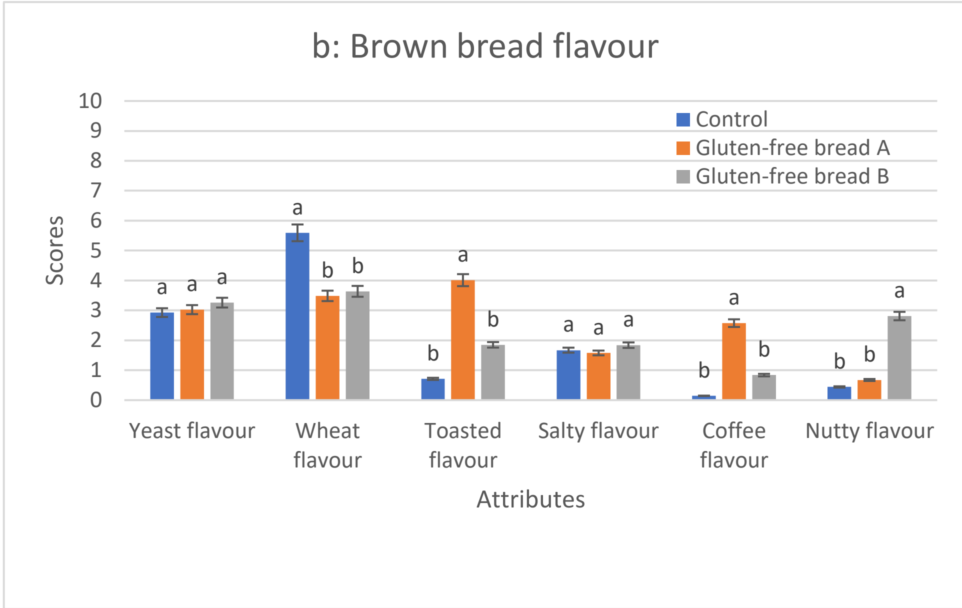


Figure 4.7a, b and c: Mean scores of a) white, b) brown and c) seeded commercial gluten-free and wheat bread texture attributes as evaluated by descriptive sensory panel (n = 9). Where 0 = no presence of attribute and 10 = intense presence of attribute. Samples with different letters (a, b, c.) were significantly different for that attribute (p<0.05). Where texture = how the sample felt in between the fingers.





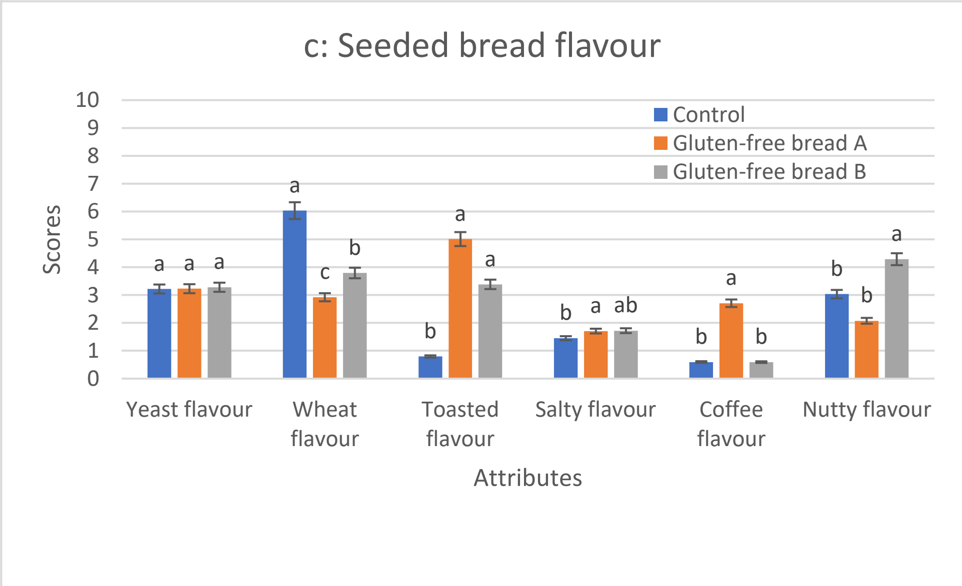
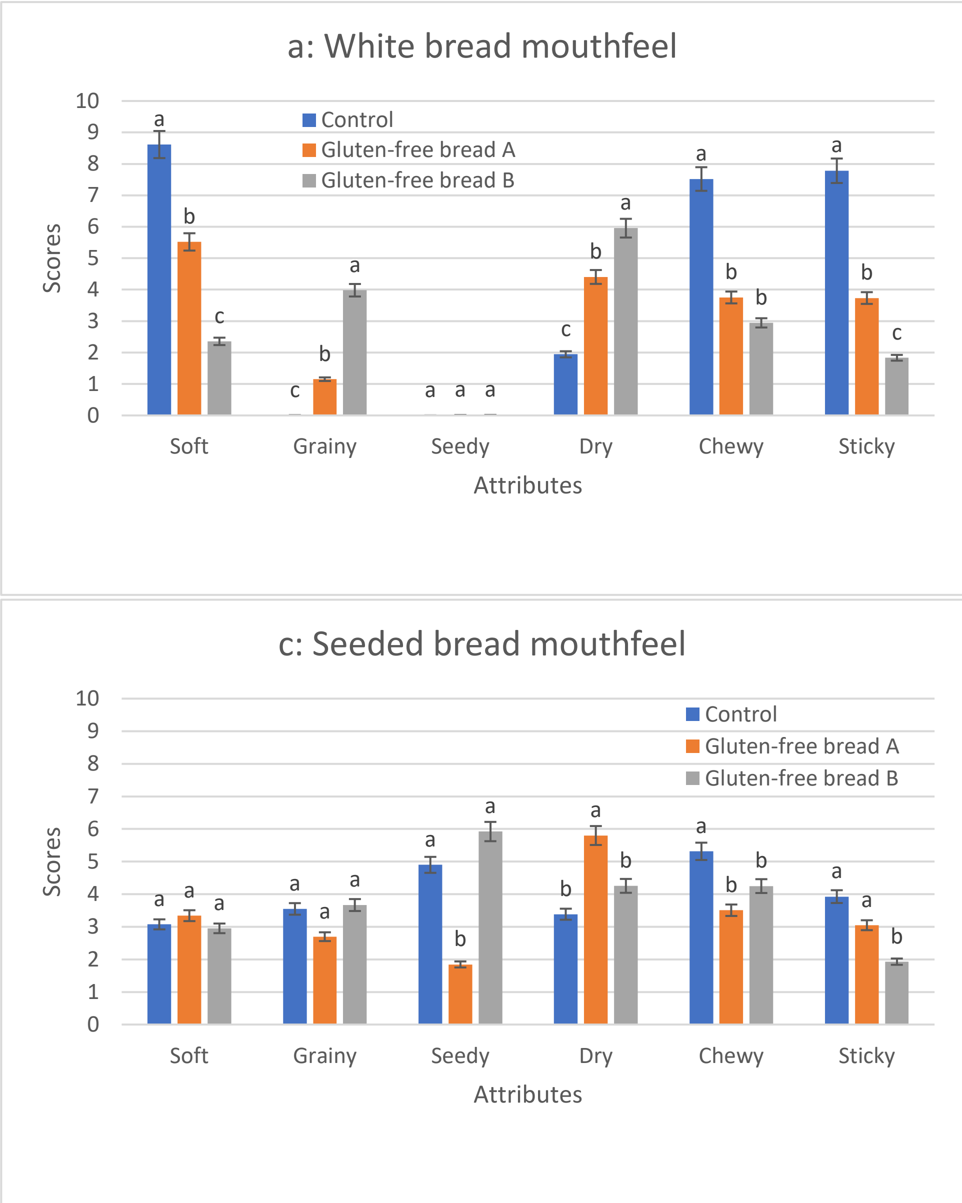


Figure 4.8a, b and c: Mean scores of a) white, b) brown and c) seeded commercial gluten-free and wheat bread flavour attributes as evaluated by descriptive sensory panel (n = 9). Where 0 = no presence of attribute and 10 = intense presence of attribute. Samples with different letters (a, b, c) were significantly different for that attribute (p<0.05).



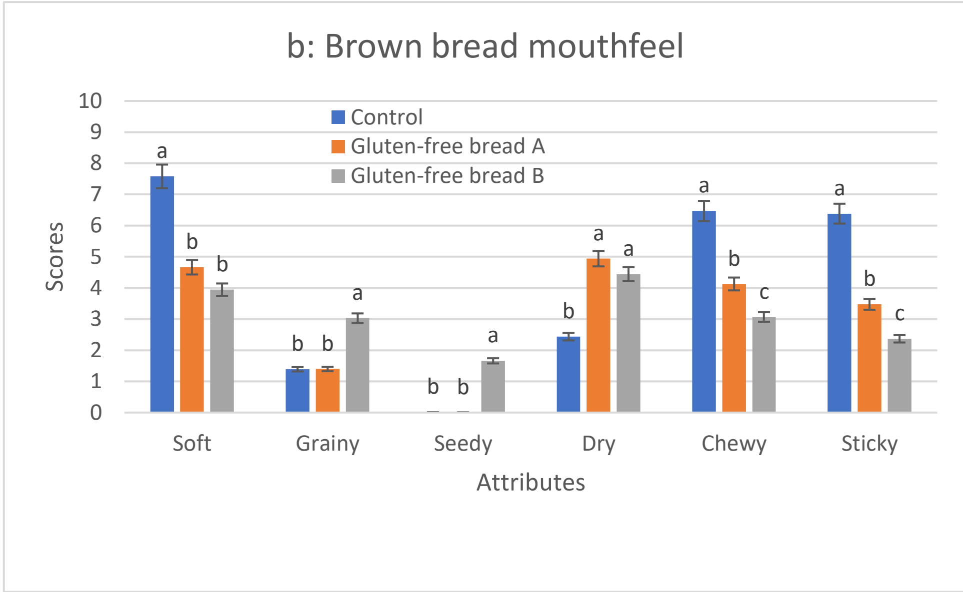
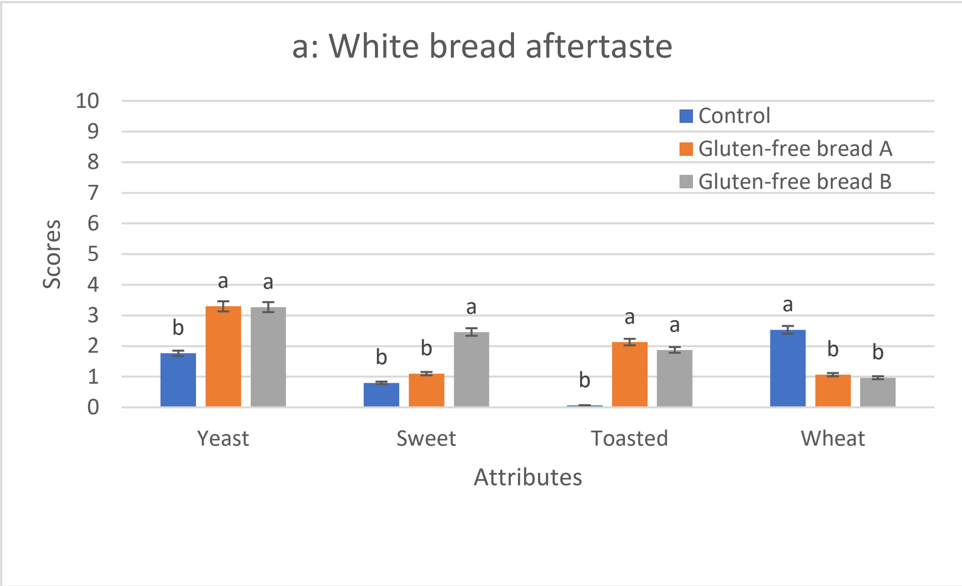
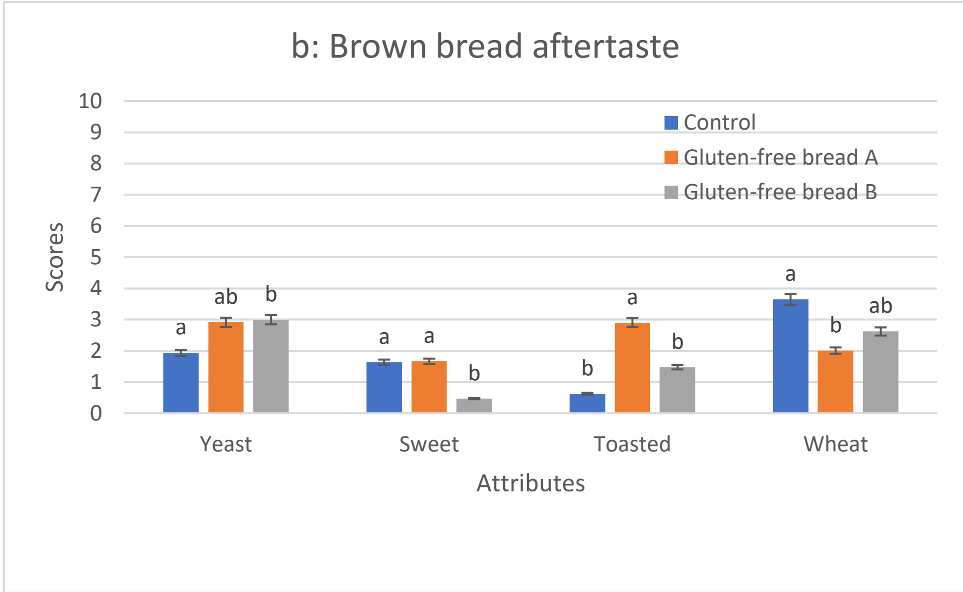


Figure 4.9a, b and c: Mean scores of a) white, b) brown and c) seeded commercial gluten-free and wheat bread mouthfeel attributes as evaluated by descriptive sensory panel (n = 9). Where 0 = no presence of attribute and 10 = intense presence of attribute. Samples with different letters (a, b, c) were significantly different for that attribute (p<0.05). Where mouthfeel = how the sample felt in the mouth.





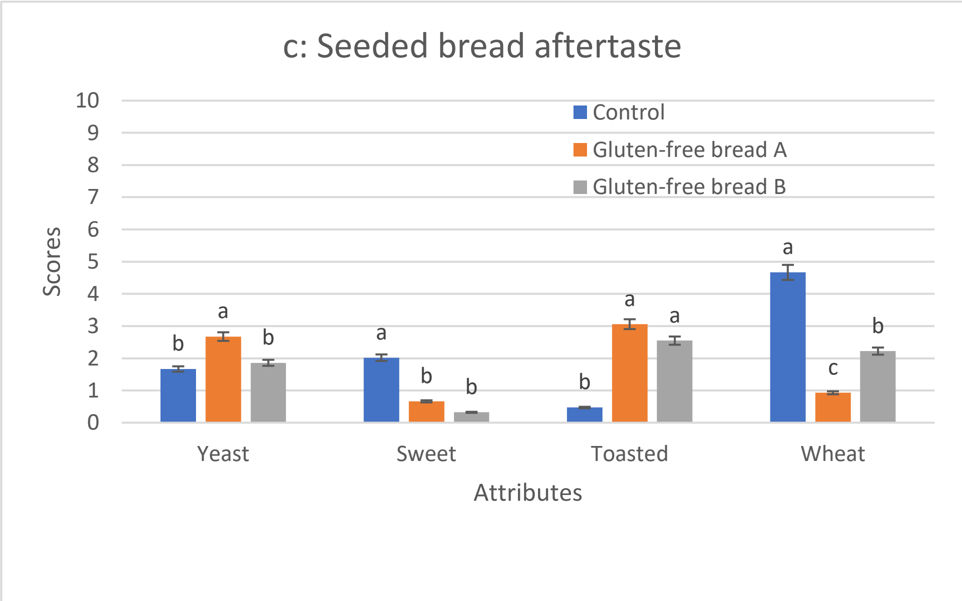


Figure 4.10a, b and c: Mean scores of a) white, b) brown and c) seeded commercial gluten-free and wheat bread aftertaste attributes as evaluated by descriptive sensory panel (n = 9). Where 0 = no presence of attribute and 10 = intense presence of attribute. Samples with different letters (a, b, c) were significantly different for that attribute (p<0.05). Where aftertaste = the taste which lingered in the mouth after swallowing.

Correlation (r^2) between descriptive sensory analysis and instrumental measurements for white, brown and seeded bread types

As seen from Table 4.10, there was a strong (r^2 >0.9) negative correlation between softness (descriptive) and firmness (instrumental) as well as resilience (instrumental) and firmness (descriptive and instrumental). There was also a high (r^2>0.85) positive correlation between firmness (descriptive) and firmness (instrumental), between dryness (descriptive) and firmness (instrumental), between softness (descriptive) and resilience (instrumental) and between stickiness (descriptive) and resilience (instrumental).

Table 4.10: Pearson correlation (r^2) between the descriptive sensory analysis and instrumental measurements pertaining to texture, density and specific volume for white, brown and seeded bread types

	Smooth DSP	Density DSP	Firm DSP	Elasticity DSP	Dry (to touch) DSP	Soft DSP	Dry (in mouth) DSP	Chewy DSP	Sticky DSP	Density (g/cm^3)	Max firmness (N)	Adhesive force (mN)	Elasticity (%)	Peak force 2 (N)	Resilience (%)	Specific volume cm^3/g
Smooth DSP	1.00															
Density DSP	0.54	1.00														
Firm DSP	-0.74	-0.02	1.00													
Elasticity DSP	0.13	0.00	-0.02	1.00												
Dry (to touch) DSP	-0.48	0.23	0.89	0.16	1.00											
Soft DSP	0.86	0.22	-0.96	-0.09	-0.81	1.00										
Dry (in mouth) DSP	-0.45	0.27	0.87	0.21	1.00	-0.79	1.00									
Chewy DSP	0.53	0.04	-0.84	-0.18	-0.94	0.81	-0.92	1.00								
Sticky DSP	0.75	0.19	-0.91	-0.04	-0.88	0.93	-0.86	0.93	1.00							
Density (g/cm^3)	-0.80	-0.67	0.44	-0.28	0.00	-0.56	-0.03	-0.07	-0.36	1.00						
Max firmness (N)	-0.69	-0.09	0.94	0.25	0.87	-0.96	0.86	-0.85	-0.93	0.39	1.00					
Adhesive force (mN)	0.37	0.39	-0.08	0.08	0.31	0.17	0.31	-0.33	-0.13	-0.67	-0.03	1.00				
Elasticity (%)	0.31	0.53	0.19	0.53	0.34	-0.07	0.39	-0.19	-0.02	-0.34	0.27	0.32	1.00			
Peak force 2 (N)	-0.69	-0.08	0.92	0.29	0.88	-0.95	0.87	-0.86	-0.93	0.36	1.00	0.02	0.28	1.00		
Resilience (%)	0.73	0.26	-0.93	-0.03	-0.77	0.93	-0.75	0.82	0.91	-0.55	-0.94	0.12	-0.15	-0.91	1.00	
Specific volume cm^3/g	0.78	0.62	-0.51	0.33	-0.08	0.59	-0.05	0.15	0.41	-0.98	-0.44	0.60	0.24	-0.40	0.63	1.00

Where DSP = descriptive sensory panel

4.1.6 Discussion

The bread types are not directly comparable. It is important to remember that the bread samples were manufactured in commercial facilities according to different recipes, mixing, proofing and baking parameters as well as ingredients and equipment. The intention was not to obtain insight on the reasons for the difference in properties but rather to obtain a baseline understanding of the characteristics of gluten-free bread available for consumers in the market. Furthermore, in an effort to control the effect of storage time (staling), the analyses (texture, density and descriptive sensory evaluation) of all the samples were conducted one day after purchasing/collection.

White bread:

The ingredients used to produce the gluten-free bread samples are similar to those noted by Allen and Orfila (2018), with the exception of millet flour. These include rice flour, psyllium husk, maize starch, potato starch and cassava starch (tapioca). Maize is the most consumed gluten-free crop in South Africa, however, the main grain crops that are indigenous to southern Africa are: pearl millet, sorghum, cowpea, bambara groundnuts and mung bean (DAFF, 2013). Amongst the white bread, it is only GFB which contains flour from one of these indigenous crops, viz., millet flour. The percentage inclusion is however unknown and also the type of millet. There are many millet types including pearl millet, finger millet, foxtail millet and proso millet (Shukla, Lalit, Sharma, Vats & Alam, 2015).

The inadequate and unbalanced nutritional value of gluten-free products has been highlighted by others (Thompson, 2009; Saturni *et al.*, 2010; Capriles, dos Santos & Arêas, 2016; Allen & Orfila, 2018). The GFA white bread was higher than the control in terms of energy, fibre and total sodium. However, the control bread as well as GFB had a higher and same amount of protein. GFB also had, comparatively, the highest fat and lowest sodium and fibre content. GFA displayed a similar energy content (1045 kJ/100g) as was reported in a study by Allen and Orfila (2018) for gluten-free white bread in the United Kingdom. The white bread in their study contained an energy content of 1043 kJ/100g. The high dietary fibre content of GFA could be attributed to the inclusion of psyllium husk (a plant fibre) as one of the major ingredients (4th on the ingredients list), unlike in GFB, where psyllium husk is amongst the last items listed (14th on the ingredient list). Psyllium husk is a plant material which is obtained from the ripe seeds of *Plantago psyllium* and is known to be a source of dietary fibre (Singh, 2007). The inclusion rate of psyllium husk in gluten-free bread formulations from previous studies has been about 2-3% (Mariotti, Lucisano, Ambrogina Pagani & Ng, 2009; Zandonadi, Botelho & Araújo, 2009). Cereal and root crop starches and flours are sources of energy. The energy content of the gluten-free bread was higher possibly due to the multiple sources of starch (maize, tapioca, rice and potato) used, as opposed to the control which only contained a flour, i.e. wheat flour. According to Montagnac, Davis and Tanumihardjo (2009), the amount of energy yielded by important staple crops is as follows: cassava root (1045 kJ/hectare) > maize grain (836 kJ/hectare) > rice grain (652 kJ/hectare) > wheat grain (460 kJ/hectare). Hence, the inclusion of high energy yielding crops (cassava, maize and rice) may have contributed to gluten-free bread containing more energy. GFB's protein content, which was the same as the control could be due to the inclusion of protein dense flours such as a legume (possibly soya) and buckwheat flour (Alvarez-Jubete *et al.*, 2010) in addition to eggs. As seen in Table 4.11, legume flours contain at least twice the protein content of wheat flour. Whereas, GFA bread only contained egg powder as a protein source.

Table 4.11: Protein content of some ingredients used in their powder/flour form in commercial gluten-free bread

Ingredient	Protein (%)	Reference
Buckwheat flour	12.0-13.0	Zhang, Zhou, Tang, Li, Tang, Shao, Xue and Wu (2012)
Wheat flour	12.0-14.0	Eggum, Kreft and Javornik (1980), De Francischi, Salgado and Leitao (1994), Ntuli, Bekele, Ntseliseng, Makotoko, Chatanga and Asita (2013)
Egg powder	45.2	Ndife, Ejikeme and Amaechi (2010)
Oil seed legume flours:		
Soybean flour	44.0	Igbabul, Adole and Sule (2013)
Grain legume flours:		
Chickpea	24.0	(Iqbal, Khalil, Ateeq & Khan, 2006)
Cowpea	24.7	(Iqbal *et al.*, 2006)
Lentil	26.1	(Iqbal *et al.*, 2006)
Green pea	24.9	(Iqbal *et al.*, 2006)
Mung bean	25.9	(Butt & Batool, 2010)

The GFA bread's high total sodium content was also detected as the highest by the sensory panel in terms of salt level. Sodium is added to bread to enhance flavour (Charlton, Macgregor, Vorster, Levitt & Steyn, 2007) and for dough functionality (Ambrosewicz-Walacik, Tańska, Rotkiewicz & Piętak, 2016). Therefore, the sodium chloride could have also contributed to the enhancement of the coffee and toasted flavours as, GFA was rated higher than GFB in coffee flavour and amongst the highest in toasted flavour. The toasted, coffee and nutty flavours were detected more in the gluten-free bread. Pico, Martínez, Bernal and Gómez (2017) determined that the evolution of the volatiles produced during the fermentation and baking of gluten-free bread which contained maize starch as the carbohydrate source. Furfuryl alcohol and butyrolactone were detected as volatile compounds which were characterised by "sweet, caramel" and "burnt, sweet" flavours, respectively. These compounds were also noted to be elicited during fermentation and Maillard reactions (butyrolactone) (Pico *et al.*, 2017). This is possibly one of the reasons why the toasted and coffee flavours were mostly detected in the gluten-free bread and very low in the wheat bread. Maize starch also occurs as the second ingredient on both the gluten-free bread samples' ingredient lists. According to Bredie, Mottram, Hassell and Guy (1998), toasted, nutty and burnt-like flavours in maize products are yielded by high temperature baking/extrusion conditions. GFB was distinctly unique in that it was perceived to have a more intense nutty flavour. GFB contains flaxseed flour, which has been described to impart a nutty flavour in gluten-free baked goods (Watson, Stone, Bauer & Bunning, 2009). Furthermore, it is important to note that these evaluations were done on the crumb sections of the bread. Pico *et al.* (2017) noted that the crucial odourants which contribute to stronger aromas of gluten-free bread are more likely to come from the crust than the crumb. The flavour and aroma results presented here are therefore not a complete reflection of the flavour of the full slice including the crust.

The instrumental texture results show that the gluten-free bread had a much higher firmness than the control, GFB being the firmest. These results correspond to the descriptive sensory texture results, where GFB was perceived as the highest in firmness, followed by GFA. GFB bread was the most firm, dry (to fingers and in-mouth) and crumbly. Gluten-free bread was also previously associated with having a firm and crumbly texture (Schober *et al.*, 2005; Onyango *et al.*, 2010; Torbica *et al.*, 2010), which had a negative effect on consumer acceptability as it is interpreted as stale or bread that is not fresh (Amigo, del Olmo Alvarez, Engelsen, Lundkvist & Engelsen, 2016). The control bread had the lowest firmness (instrumental and sensory analysis) and was perceived to have the softest mouthfeel. Among other things, firmness has been shown to be associated with crumb structure and specific volume. GFB had the highest density and lowest specific volume, and was also perceived as the firmest by the sensory panel and texture instrument ($r^2 = 0.94$). Bourekoua *et al.* (2016) evaluated the effect of hydrothermal treatment of rice and maize flour on gluten-free bread making. Onyango *et al.* (2009) investigated the effect of hydrocolloids on the creep-recovery of cassava starch and sorghum-based gluten-free bread. They both found that the softer the breadcrumbs, the higher the specific volume. However, the same trend was not seen for GFA and the control. The specific volume of GFA was higher than that of the control, however, the control was softer than GFA in both instrumental and panel texture measurements. The reason for this is not clear and could be corroborated by many other factors, it is however likely related to the different crumb structures of the bread.

In terms of crumb colour, the control white sample had the highest L*, indicating that it was the whitest sample and it also had the highest cell quantity and cell density. This was in agreement with the results of Zghal, Scanlon and Sapirstein (1999) who studied the extent to which bread crumb density can be predicted by digital image analysis. The authors noted that bread crumb whiteness was highly associated with having a large quantity of small cells. GFB had the lowest L* (darker bread), it also had a higher protein content than GFA. This was likely due to the inclusion of multiple protein containing ingredients. Gallagher, Gormley and Arendt (2003) and Matos and Rosell (2013) noted the same for gluten-free bread samples and attributed it to the participation of the amino acids of the protein sources to Maillard browning as well as caramelisation. In terms of b* value, GFB was the highest. This could be due to its egg content which probably yielded a yellowish colour in the formulation (Matos & Rosell, 2013).

The crumb of GFA and the control white breads were perceived by the panel to have similar cell sizes and cell quantities. These samples had a lower cell size than GFB and, a higher cell quantity. A high cell quantity was also observed in white wheat bread which was evaluated by Hager *et al.* (2012) who were investigating the properties of bread made from commercial gluten-free flours in comparison to wheat equivalents. This high cell quantity was attributed to the lack of bran particles in white bread which would otherwise have penetrated the gas cells causing coalescence. In addition to a high cell quantity, the control bread also had the highest cell density, thereby implying a thin lamella area. A lamella makes up the solid area of bread, and a thin lamella is associated with a soft texture (Hager *et al.*, 2012). Hence, the control bread was perceived as softer than the gluten-free bread.

Brown bread:

The base carbohydrate-rich ingredients of the GFA brown bread were cassava starch (tapioca), sorghum flour, rice flour, psyllium husk and potato starch. The addition of sorghum flour is what differentiated the GFA brown formulation from the GFA white formulation. The sorghum flour was probably added to impart a brown colour to differentiate the bread as brown. Onyango *et al.* (2009) noted a chocolate-brown colour in gluten-free bread samples baked with sorghum. Sorghum and cassava starch (tapioca) are also the only climate-smart crops used in the formulation. On the other hand, GFB bread contained maize starch, golden linseed flour, a blend of gluten-free flours (which according to the label contained legume flour, vegetable flour, whole flaxseed meal, millet flour, buckwheat flour and flavouring), rice flour and potato starch. The specific ingredients used in the legume flour and vegetable flour are not declared on the packaging, this is possibly problematic as it is not described as required according to the South African regulations relating to the labelling and advertising of foodstuffs (DAFF, 2012). This could be a risk to a consumer who may be allergic to one of the undeclared ingredients (e.g., the legume or vegetable flour may be soya based and soya is a known allergen). Unlike the white GFB sample, the brown GFB bread contained golden linseed flour in addition. According to Xu, Hall III and Manthey (2014), golden linseed flour, is a very good source of dietary fibre [contains 28% dietary fibre (on a dry basis)] and lignans [a source of biologically active components found in plant foods such as broccoli and linseed (Touré & Xueming, 2010)]. Both are beneficial to human health as they have shown potential to reduce the risk of cancer. The control brown bread was made up of the same ingredients as the control white bread, except, brown wheat flour is used instead of white wheat flour and, there is no sugar added. Wheat flour as defined by South African regulation is “all milled, dry and uncooked wheat products with an ash content of more than 0.60% on a moisture-free basis but excludes crushed wheat, pearled wheat, semolina, wheat flour with an ash content of less than 0.60% on a moisture-free basis and self-raising flour” (DOH, 2005). According to Charlton *et al.* (2007), brown bread flour is composed of about 87.5% of standard wheat bread flour plus 12.5% wheat bran. The presence of bran in the control brown bread was perceived as specks by the panel. This perception of specks in the control brown bread was higher than in GFA and GFB. Thus, the main difference between the white and brown wheat bread samples discussed in this work is increased fibre content resulting in a more brown colour for the brown type.

GFA contained the highest amount of dietary fibre of the three brown bread samples. This is likely due to the inclusion of psyllium husk at a higher quantity than what was in GFB. Psyllium husk is declared as one of the first few ingredients (4th) in GFA bread unlike in GFB, where it is mentioned as the 13th ingredient. Among other functional advantages such as improving loaf volume, psyllium husk is added to gluten-free bread formulations to enhance the fibre content (Mariotti *et al.*, 2009; Fratelli, Muniz, Santos & Capriles, 2018). The high fibre content was also reflected in the a* value which was higher than in the other samples, meaning GFA had a more red colour. The same was found by Angioloni and Collar (2009) when studying the bread crumb quality of commercial whole and white wheat pan breads. They noted that bread that was more fibrous was inclined to have a red colour. GFB brown bread had the lowest amount of protein and the highest energy and total fat content among the samples, which is not ideal from a nutrition perspective. GFB brown contained a higher number of starch containing ingredients (e.g., maize starch, potato starch, millet flour) than GFA brown which probably contributed to GFB's high energy content and probably the fat content too due to some of the grains being milled whole (e.g. whole flaxeed meal). The mouthfeel of GFB bread was also perceived by the panel as bread with many seeds compared to GFA and the control brown bread samples. The germ of grains has a higher lipid content than the endosperm, therefore, grains that are milled whole tend to have a higher fat content (Jain & Bal, 1997). The control wheat brown bread had the highest protein content, this could be attributed to the inclusion of soybean flour in the formulation. As seen in Table 4.11, the protein content of wheat flour alone can range from 12 to 14% (Eggum *et al.*, 1980; De Francischi *et al.*, 1994; Ntuli *et al.*, 2013), whereas, soybean flour contains about 44% protein (Igbabul *et al.*, 2013). Soybean is a source of protein and it contains the essential amino acid lysine, which is deficient in most cereal proteins (Mateos-Aparicio, Cuenca, Villanueva-Suárez & Zapata-Revilla, 2008). The sum of the wheat protein and soybean flour proteins thereby increases the protein quality of the control wheat bread. The highest protein source in the GFA brown sample was egg powder which has a protein content of 45.2%. In GFB brown, the protein content was due to egg powder and the legume flours which potentially have a protein content that ranges from 45% and 24 to 26%, respectively (Table 4.11).

The instrumental texture measurement revealed that the brown wheat control bread was the least firm of the three samples, with the lowest adhesive force, however, the most resilient. A low adhesive force has been related to low stickiness in bread dough (Collar, Santos & Rosell, 2007). A strong negative correlation was also found between resilience and firmness ($r^2 = -0.93$). GFB was slightly firmer than GFA, and it was the least resilient sample of the three. Resilience measures the capacity of the bread to revert back to its original form after deformation in terms of speed and force (Yadav, Aggarwal, Yadav & Yadav, 2016). Low resilience also indicates a loss of elasticity, which is often related to firm and crumbly bread (Onyango, Mutungi, Unbehend & Lindhauer, 2011; Ekpa, Palacios-Rojas, Rosales, Renzetti, Fogliano & Linnemann, 2020). The firmness observed by the panel had a high and positive correlation with the instrumental texture results ($r^2 = 0.94$). The control was perceived by the panel to be the least firm of the three samples, and GFB was perceived to be the firmest and crumbliest of the three samples. When relating this to the image analysis results, the control had the highest cell quantity and cell density whereas, GFB and GFA had the lowest cell quantity and cell density (GFB being the lowest). GFB also had a lower specific volume than the control, it was also perceived to have cells that are larger and fewer than GFA and the control . A low cell quantity, cell density and specific volume often indicate a greater presence of the surrounding matrix (lamella) in between the gas cells – which is associated with a dense and firm crumb (Hager *et al.*, 2012).

The high number of gas cells are also reflected in the L* colour values of the control sample as it had the highest L*, followed by GFB then GFA. A high cell quantity is associated with crumb whiteness (Zghal *et al.*, 1999). GFA had the highest a*, b* and C* values, meaning its colour was most slanted towards red and yellow, and its colour was the purest solid brown colour – as seen from its image. The panel agreed with this as they perceived GFA to have the lowest number of specks. GFA was perceived to have a sweet and toasted aroma as well as a toasted and coffee flavour. In addition to the types of ingredients used, the extent of caramelisation and Maillard reactions that take place during baking contribute to the flavour and aroma of bread (Purlis, 2010). Seeing as caramelisation is associated with yielding sweet, caramel-like notes under high heat and the presence of reducing sugars – a higher extent of caramelisation may have taken place during the baking of GFA. The control was perceived to be soft, chewy and sticky, indicating that it was quite cohesive. Cohesiveness in bread is desirable as it contributes to the formation of a bolus during chewing, instead of crumbling in the mouth (Matos & Rosell, 2012). This potentially enhances the ease of oral processing and the swallowing of bread (Jourdren, Panouille, Saint-Eve, Deleris, Forest, Lejeune & Souchon, 2016; Gao, Wang, Dong & Zhou, 2018).

Seeded bread:

The carbohydrate sources in the wheat control seeded bread, according to the information of the label, were white bread flour followed by wheat bran, crushed wheat, linseeds and then oat groats [cleaned and dehulled oat grains that take long to cook (Welch, Brown & Leggett, 2000)]. The seeds included were sunflower seeds and sesame seeds. None of the crops used are climate-smart or indigenous to Southern Africa. GFA seeded bread contained rice flour followed by cassava starch (tapioca), sorghum flour, potato starch, rice bran and maize starch, in that order, as carbohydrate sources. The seeds included were sunflower seeds, sesame seeds and flax seeds. Cassava is considered a climate smart crop, however, it is not indigenous to Southern Africa (Mupakati & Tanyanyiwa, 2017). Sorghum is the only crop fulfilling the climate-smart and indigenous categories. The GFB seeded bread contained the following carbohydrate sources: maize starch followed by golden linseed flour, a gluten-free flour mix (containing an unidentified legume flour, unidentified vegetable fibres, whole flaxseed meal, millet flour, buckwheat flour and flavouring), rice flour then potato starch. The seeds included were pumpkin seeds, sesame seeds and brown linseeds. Millet flour is the only ingredient used in this bread that is climate-smart and indigenous to Southern Africa.

GFB seeded bread had the highest fat content, the lowest dietary fibre and an intermediary protein content of 9.5 g/100 g which is similar to the control bread's 9.6 g/100 g. GFB and GFA both contained vegetable oil (potentially sunflower oil) as an ingredient; however, vegetable oil is the 5th and 8th ingredient by mass on the label for GFB and GFA, respectively. This could be an indication that GFB contained more vegetable oil than GFA, and hence a higher fat content. GFA had the lowest protein content, however, the highest dietary fibre (0.54% more than the control) – and similar to the seeded gluten-free bread analysed by Allen and Orfila (2018). The source of protein included in the GFA formulation with the lowest protein content was egg powder. Whereas, GFB contained egg as well as an unidentified legume flour and buckwheat flour – these are considered rich sources of protein (Table 4.11) (Alvarez-Jubete *et al.*, 2010) which contributed to the overall protein content of GFB seeded bread. The wheat-based control bread contained the highest protein content and the lowest total fat content. There is no indication of an oil or fat used in the control bread's ingredient list, also the control contains soybean flour, which is a good source of protein (Mateos-Aparicio *et al.*, 2008).

Although the control seeded bread was the least firm by instrumental texture analysis of the three bread samples, GFA and GFB were not much firmer. A similar trend was noted by the sensory panel where, only a slight difference in firmness among the three seeded bread products was perceived. These results are also in line with the findings of cell densities and cell quantities measured by image analysis. The control had the highest cell density and cell quantity followed by GFB and then GFA. A high cell quantity and density is related to low crumb firmness (Hager *et al.*, 2012). However, of all the control bread types (white, brown and seeded), the control seeded bread was much firmer than the other bread types. Ming-Yin *et al.* (2012) also noted increased firmness in steamed wheat bread with an increase in wheat bran, possibly due to wheat bran being rigid or the reduction of free water in the system. Wheat bran tends to absorb more water compared to wheat flour, adding to the increased firmness if water quantity remains constant (Boita, Oro, Bressiani, Santetti, Bertolin & Gutkoski, 2016). There was also a large variation in the image analysis data, which meant that there was a large variation in the crumb structures among bread samples within each bread type. This can be attributed to the product heterogeneity found even in commercially produced products as noted by Angioloni and Collar (2009). Also, the inclusion of large and small seeds may have disrupted the matrix unevenly. Therefore, the extent of gas cell formation, specifically the amount and size of gas cells formed cannot be fully controlled possibly due to cell rupture.

The GFA seeded bread sample had the lowest density and hence the highest specific volume amongst the three seeded bread samples. According to Iglesias-Puig and Haros (2013), the presence of seeds (chia in their research) in wheat doughs disrupted the gluten network, which would otherwise have facilitated the gas cell growth and stability, thereby inhibiting the increase in specific volume. Steffolani, De la Hera, Pérez and Gómez (2014) observed the same in gluten-free bread containing chia seeds. GFB and the control bread were also perceived to have the most seeds by the panel. This could be the reason for the high density and low specific volume of the control and GFB seeded breads.

GFB seeded bread had the highest L* value followed by the control and GFA which had similar L* values. GFA contained sorghum flour, which has been shown to impart a chocolate brown colour in the baked crumb of gluten-free bread made from sorghum and cassava starch (Onyango *et al.*, 2009). The high L* value of GFB could also be due to the types of ingredients used in the making of GFB seeded bread. Miñarro, Albanell, Aguilar, Guamis and Capellas (2012) who studied the effect of legume flours on gluten-free bread, stated that the colour change in bread crumb is more affected by the protein source(s) added than by Maillard or caramelisation reactions which occur. This is because it is only the crust that reaches temperatures suitable for browning reactions, not the crumb.

The GFB seeded sample, like the white and brown GFB samples, was perceived to be the crumbliest and to have a distinct nutty flavour. This was likely due to the reason discussed for the other GFB bread types, i.e., the inclusion of flaxseed flour which imparts a nutty flavour. Similar to the other GFA bread types, the GFA seeded bread was perceived to have a toasted flavour and to be dry. A reason for the dryness may be due to its higher protein content. Proteins are known to bind significant amounts of water, hence reducing moisture migration to the crust of the bread (Gallagher *et al.*, 2003).

Concerning all bread types:

The price per kg of gluten-free bread ranged from being 517 to 903% more than that of the control wheat bread. It also appeared that GFA was generally more expensive than GFB. The bakery which produces GFA is smaller than that of GFB. The GFB bakery can probably therefore produce at a lower cost due to the advantage brought about by economies of scale. Brown bread was the most expensive bread type amongst the gluten-free bread types, it was however the cheapest amongst the control bread types. The relatively low price per kg of the control wheat bread is likely due to the fact that wheat flour for breadmaking is subsidised in South Africa (Mncube, 2014). This is with the exception of white and probably seeded wheat bread which are inclusive of value added tax (Mncube, 2014). White and seeded wheat bread are still, however, much cheaper than gluten-free bread. The high price of gluten-free bread, in the southern African context, could be due to the relatively low local production (and hence low availability) of alternative grains, such as sorghum, cassava and the millets (Chivenge *et al.*, 2015), which are used in the production of gluten-free bread. The scarcity of these alternative crops as well as the cost of the unique ingredients (e.g., psyllium husk) and additives used in combination with gluten-free flour possibly make gluten-free bread production more expensive. Gluten-free bread is also currently considered a premium product which is targeted at the health-conscious elite in southern Africa (Shepherd, 2016). The willingness-to-pay for gluten-free bread made from indigenous CSFC amongst consumers would need to be determined.

CSFC can be described as crops which have some resilience to climate change (Amin, Mubeen, Hammad & Nasim, 2015) and are more efficient in using resources to achieve optimal and sustainable effects on the agricultural ecosystem and the surrounding environment (Faurès, Bartley, Bazza, Burke, Hoogeveen, Soto & Steduto, 2013). In terms of the current inclusion of indigenous CSFC in commercial gluten-free bread, this study found that only millet flour (in all the GFB bread types) as well as sorghum flour and cassava starch (in the brown and seeded GFA types) were used. The increased inclusion of indigenous crops in the production of gluten-free bread could stimulate much needed opportunities along the value chain for the indigenous crops. The production yield of indigenous crops is however relatively lower than that of maize (Hillocks, 2014). Also, the fact that indigenous climate-smart crops are gluten-free poses many challenges to the sensory quality of the resulting bread product, e.g., the bread tends to be dense, crumbly and it has strong flavours that are not typical of bread. However, indigenous crops are unique in that they are climate smart, require little fertilisers, irrigation, pesticides to survive and could possibly offer better nutrition (Chivenge *et al.*, 2015).

Lastly, apart from sensory quality that is close to or on par with wheat bread, the development of bread from climate-smart crops should prioritise the nutritional quality. Interventions such as fortification may be implemented as a means to compensate for the relatively low nutritional value of baked products that would be produced from gluten-free climate-smart crops. The fortification of commercial wheat bread is mandatory in South Africa, therefore, implementing the same for gluten-free bread is likely to be feasible.

4.1.7 Limitations of the study

Although careful consideration was taken to ensure that the analyses were conducted using scientific methods and principles, a few limitations have been acknowledged.

The products evaluated were commercial products. Therefore, their characteristics were described based on scientific observation. This is unlike a situation where the parameters and ingredients used in the production of the breads was controlled by the researchers. Also, an effort was made to sample the products in such a way that typical batch differences are represented. However, the products may present different results in another study due to their commercial nature. Commercial products are continuously being optimised and hence the formulations may be different in future. Also, the researcher had no control over the process or conditions of manufacture on the specific days.

In real-life application, bread is consumed in full slices. The panel only evaluated a disk-shaped portion of the crumb of the bread and not the full slice which includes the crust. The area/ size differences of the slices would have been a major factor in describing the bread. The crusts were also excluded, a factor that will always be considered by consumers, possibly in terms of appearance, flavour and texture. A recommendation for future studies would be to serve square-shaped portions where one of the sides includes the crust from the top of the bread slice.

Lastly, in thresholding the images for image analysis using the ImageJ software, the default thresholding option was used. This method is effective in approximating the different properties of bread. However, it was later learnt that using the Otsu's thresholding method could have provided a more reliable representation of the crumb structure of bread (Scheuer *et al.*, 2015).

4.1.8 Conclusions

Here, the physical and sensory properties of commercially available gluten-free bread products were characterised by instrumental methods and a human panel. The results were compared within bread type (white, brown and seeded). It was also clear that although the two gluten-free bread samples were different from each other, the difference between the control samples and the gluten-free samples was even larger. For white bread, it was concluded that in order for the white gluten-free bread to display similar characteristics to white wheat bread it should: be less firm, dry, crumbly and grainy. It should also be whiter in colour, have a higher cell quantity, cell density, have a more soft texture and a more chewy and sticky mouthfeel. For gluten-free brown bread to be similar to brown wheat bread it should: be whiter in colour, be less firm, have a higher cell quantity and cell density, it should contain more fibre specks and should have a more soft, chewy and sticky mouthfeel. It should however have a less toasted, nutty and coffee aroma and flavour, it should also be less dry, crumbly, grainy and seedy. The seeded gluten-free bread was not very different to the control in textural properties. However, for gluten-free seeded bread to be more similar to seeded wheat bread it should: be less white in colour, have a lower toasted and coffee flavour and aroma, it should also be less dry and crumbly. Furthermore, the gluten-free seeded bread should contain more seeds, be more sticky and chewy. Lastly, it would be ideal if a wheat flavourant would be added in all the gluten-free bread types because wheat was a prominent flavour and aroma which was detected in all the wheat bread types. A wheat flavourant would perhaps give the gluten-free bread a more familiar and hence more acceptable flavour and aroma.

In terms of the use of CSFC in the commercial gluten-free breads, the following was concluded. Millet flour was the only CSFC indigenous to Southern Africa which was used among all the white gluten-free bread samples. GFA brown was the only sample containing an indigenous CSFC being sorghum flour. For the seeded gluten-free bread, sorghum flour was used in GFA and millet in GFB. Therefore, a higher inclusion of flours and starches produced from CSFC, as opposed to crops like rice, is preferably needed in future developments of gluten-free bread.

The next important step would be to determine the acceptability of the commercial gluten-free bread. This will assist in determining the favourable and unfavourable sensory properties of the bread compared to wheat bread. Thereby informing the development of gluten-free bread made from CSFC that is acceptable to consumers.

4.2 Perception of the sensory properties of gluten-free bread as influenced by the health and taste attitudes of millennial consumers

4.2.1 Abstract

Introduction: The drivers of liking and disliking for commercial gluten-free bread have not been studied in South Africa. Determining the acceptability of gluten-free bread is important as it may be useful in bringing insight for the development of bread using alternative indigenous and sustainable crops such as sorghum and the millets, which also happen to be gluten-free. Food choices made by consumers, however, are affected by various factors such as health and taste related considerations. The health and taste attitudes questionnaire was developed to measure the impact health and taste predispositions people have on food choice and consumption. This questionnaire has not yet been explored in Africa. **Objective:** The objective of this work was to determine the health and taste attitudes of a selected group of millennial consumers (n=354). It was also to determine whether the health and taste attitudes of millennial consumers' (n=173) have an effect on the acceptability of the sensory properties of commercial gluten-free bread. Another objective was to determine the general perceptions millennial consumers' have about gluten-free bread. **Results:** The health and taste attitudes questionnaire presented itself to be reliable in measuring the health and taste attitudes of the millennial consumers. The attitudes of the selected group of 173 millennial consumers did not have a significant effect on their rating of the acceptability of the sensory properties of gluten-free and wheat brown bread. However, most of the participants had the perception that gluten-free bread is healthier than wheat bread. The sensory properties of the control wheat bread were the most preferred across all health and taste attitude groups in both informed and uninformed conditions. However, information about the gluten-free/wheat containing nature of the bread had a negative effect only on the acceptability of the smell of gluten-free bread. The interaction of health and taste attitudes and the samples was significant for the acceptability of the appearance and taste of the bread samples. **Conclusions:** The health and taste attitudes of the participants did not have a significant effect on their acceptability ratings for gluten-free bread. Participants preferred the sensory properties of wheat bread which they are more familiar with regardless of their perception that gluten-free bread was healthier. Gluten-free bread is perceived as healthier than wheat bread. However, the sensory properties of bread remain the main determinant for choice.

4.2.2 Introduction

The choices consumers make on food often vary and are likely based on different reasons (Costell *et al.*, 2010). Two important factors affecting food choice have been identified to be health aspects and taste aspects (Roininen *et al.*, 1999). Health aspects refer to a consumer's perception of the effect a particular food choice has on their health. Taste refers to the hedonic benefit perceived based on the sensory properties when choosing and consuming a product. In an effort to measure the relative extent and importance of these two constructs (health and taste) in consumers when it comes to food choice, Roininen *et al.* (1999) developed a health and taste attitudes questionnaire. The two health and taste sub-groups of this questionnaire each contained three factors: (1) general health interest, (2) light product interest and (3) natural product interest for the health subscale and; (1) craving for sweet foods, (2) using food as a reward and (3) pleasure for the taste subscale. Each of these factors had six to eight items/statements. These statements were rated on a 7-point Likert scale ranging from "strongly disagree to strongly agree". The Roininen *et al.* (1999) health and taste attitudes questionnaire has been used worldwide in countries such as Taiwan (Chen, 2013), Serbia (Grubor *et al.*, 2015), Italy (Saba *et al.*, 2019), Finland, The Netherlands and Britain (Roininen *et al.*, 2001) but not yet in Africa. The questionnaire was therefore employed in this study to determine the health and taste attitudes of a selected group of millennial consumers in South Africa.

Attitudes of consumers are formed by three factors: 1) the affective factor which is defined by feelings, 2) cognition, which refers to thoughts or beliefs and, 3) behaviour in the form actions (Pickens, 2005). The millennial generation, or "Generation Y" generally consists of people who were born between 1980 and 2000 (Lu *et al.*, 2013). This generation is much larger than "Generation X" – the preceding generation (Nowak *et al.*, 2006) and it accounts for about 35.47% of the South African population (StatsSA, 2017). It is therefore a significant market group – justifying them as the consumer group for the proposed study. Millennials are generally described to be market savvy when it comes to purchases (Nowak *et al.*, 2006), they have also been reported to be slightly more health conscious (Kuhns & Saksena, 2016) and have an affinity for green consumerism (Muposhi *et al.*, 2015). South African millennials, specifically, are more educated than the previous generation (StatsSA, 2020), are quite brand conscious (Botha, 2016) and are more technologically advanced compared to the preceding generation (Padayachee, 2017). Their education and capability to use technology, and hence access the internet, probably implies that their health and taste attitudes are likely to be affected by their access to information.

There are currently two main commercial gluten-free bread brands in South Africa. The bread products are largely based on maize, cassava and rice flours and starches – none of which are indigenous to southern Africa. Also, the acceptability of the sensory properties of the commercial gluten-free bread produced in South Africa has not been described or documented. At the same time, it is also known that drivers of liking go beyond the sensory properties of food products (King & Meiselman, 2010; Meiselman, 2013; Meiselman, 2016). Other factors such as a consumer's state of wellness, past experiences with the product as well as their inherent attitudes towards it are also some important factors to consider.

This study had two aims, each of them were covered in two phases. The first aim was to determine the orientation of a selected group of millennial consumers in South Africa towards the health and hedonic characteristics of food as measured using the Health and Taste Attitudes questionnaire (Roininen *et al.*, 1999). The second aim was to determine millennial consumers' acceptance of the sensory properties of gluten-free bread as influenced by their health and taste attitudes towards food. This study also measured the knowledge the consumers have on gluten-free bread. This could help determine whether consumers need more education or not in terms of the meaning of gluten-free and its implications on food and consumers' health. This study could also give insight on the tools which could be used to market gluten-free bread made from climate-smart crops. This could include marketing such bread by highlighting the economic sustainability of the crops from which the flour is derived and the fact that the products are made from indigenous and climate smart crops, instead of merely stating that they are gluten-free. Information on the drivers of liking or disliking of commercial gluten-free bread obtained from this study could inform the development of bread products which are made from gluten-free climate-smart crops that are indigenous to southern Africa.

4.2.3 Phase 1: Health and taste attitudes of a selected group of millennial consumers'

4.2.3.1 Research questions:

1. What is the factor structure of the health and taste attitude questionnaire when applied to a selected group of African millennial consumers?
2. How reliable are the health and taste factors of the health and taste attitude questionnaire when applied in this study?
3. What is the distribution of the participants between high and low health and taste attitudes?

4.2.3.2 Materials and methods

4.2.3.2.1 Subjects

The subjects were millennial consumers (born between 1980 and 2000) registered on a University of Pretoria consumer database to which consumers interested in food evaluation studies voluntarily signed up to. An invitation link to the study was emailed to the consumers, by clicking on the link, the consumers consented to participate in the study. The link then led them to a questionnaire to complete.

4.2.3.2.2 Procedure

The health and taste attitudes of the consumers where measured using the Health and Taste Attitudes (HTA) questionnaire which was developed by Roininen *et al.* (1999). The questionnaire is used to determine the inherent attitudes consumers have towards the health and taste aspects pertaining to food. The health scale consists of three factors which are: general health interest (8 items), light product interest (6 items) and natural product interest (6 items) (Table 4.12). The taste scale consists of three factors namely: craving for sweet foods (6 items), using food as a reward (6 items) and pleasure (6 items) (Table 4.13). Half of the statements in each of the factors were negatively worded, the scores for these statements were hence reverse coded prior to analysis as recommended by Roininen *et al.* (1999). All of the items were used in English with no changes or translations from the original paper.

The participants rated the items from all three health factors and all three taste factors on a seven-point Likert -type scale ranging from (1) strongly disagree to (7) strongly agree (Table 4.14). The items from all 6 factors were presented in a balanced random order to minimise order effects, thereby increasing the validity of the results. At the end of the questionnaire, a set of questions relating to demographics, bread consumption, gluten awareness and gluten intolerances were asked. Respondents were asked to indicate their gender, highest education level (grade 12, higher certificate, diploma, bachelor's degree/BTech or postgraduate degree), whether they had heard of gluten or not, which bread type (white, brown or seeded) they consume the most and whether they have an intolerance to gluten or not. They were also asked to give an awareness response (true or false) to the statement "*gluten-free breads are healthier than gluten-containing breads*" – as was asked in a study done on the perceptions of the gluten-free concept by Dunn *et al.* (2014). Respondents who indicated that they do not eat bread or have an intolerance to gluten or wheat allergy were not invited for the follow-up sit-in evaluation of the bread.

Table 4.12: Factors of the health attitudes sub-scales with their item numbers and statements*

Item	Statement
	General health interest
1	I am very particular about the healthiness of food
2	I always follow a healthy and balanced diet
3	It is important for me that my diet is low in fat
4	It is important for me that my daily diet contains a lot of vitamins and minerals
5R	I eat what I like, and I do not worry much about the healthiness of food
6R	I do not avoid foods, even if they may raise my cholesterol
7R	The healthiness of food has little impact on my food choices
8R	The healthiness of snacks makes no difference to me
	Light product interest
1R	In my opinion, the use of light products does not improve one's health
2R	I do not think that light products are healthier that conventional products
3	I believe that eating light products keeps one's cholesterol level under control
4R	In my opinion, light products don't help to drop cholesterol levels
5	I believe that eating light products keeps one's body in good shape
6	In my opinion, by eating light products, one can eat more without getting too many calories
	Natural product interest
1R	I do not care about additives in my daily diet I try to eat foods that do not contain additives
2R	In my opinion, organically grown foods are not better for my health than those grown conventionally
3R	In my opinion, artificially flavoured foods are not harmful for my health
4	I try to eat foods that do not contain additives
5	I would like to eat only organically grown vegetables
6	I do not eat processed foods, because I do not know what they contain

*Negatively worded statements have a “R” after the item number

Table 4.13: Factors of the taste attitudes sub-scales with their item numbers and statements*

Item	Statement
	Craving for sweet foods
1R	In my opinion it is strange that some people have cravings for chocolate
2R	In my opinion it is strange that some people have cravings for sweets
3R	In my opinion it is strange that some people have cravings for ice-cream
4	I often have cravings for sweets
5	I often have cravings for chocolate
6	I often have cravings for ice-cream
	Using food as a reward
1	I reward myself by buying something really tasty
2	I indulge myself by buying something really delicious
3	When I am feeling down I want to treat myself with something really delicious
4R	I avoid rewarding myself with food
5R	In my opinion, comforting myself by eating is self-deception
6R	I try to avoid eating delicious food when I am feeling down
	Pleasure
1R	I do not believe that food should always be a source of pleasure
2R	The appearance of food makes no difference to me
3	It is important for me to eat delicious food on weekdays as well as weekends
4	When I eat, I concentrate on enjoying the taste of food
5	I finish my meal even when I do not like the taste of a food
6R	An essential part of my weekend is eating delicious food

*Negatively worded statements have a “R” after the item number

Table 4.14: Seven-point Likert-type rating scale used in the Health and Taste Attitudes Questionnaire

Disagree strongly	1
Disagree moderately	2
Disagree slightly	3
Neither agree nor disagree	4
Agree slightly	5
Agree moderately	6
Agree strongly	7

4.2.3.3 Statistical analyses

The mean scores for each factor (general health interest, light product interest, natural product interest, craving for sweet foods, using food as a reward and pleasure) from each respondent were determined. The median (50th percentile) score of each factor was used as the cut-off point between high and low health/taste attitude groups. The distribution of respondents who believed that gluten-free bread is healthier than gluten-containing bread and those who do not was compared using binomial distribution. A Pearson correlation (2-tailed) was conducted for the six health and taste attitude factor' mean scores. The internal consistency (reliability) of the health and taste attitude factors was determined by calculating the coefficient alpha of each factor. The validity of the health and taste attitude factors was determined through exploratory factor analysis using the Varimax (orthogonal) with Kaiser Normalisation rotation method. This method was chosen over a non-orthogonal one because none of the component correlation matrix values exceeded |0.32| (Brown, 2009). Also, the rotated component matrix was expressed with the absolute factor values below 0.3 excluded (Samuels, 2017). Extraction was based on Eigen values greater than 1 (Yong & Pearce, 2013). The statistical analyses were conducted using SPSS version 25 (IBM Corporation ®, New York, USA).

4.2.3.4 Results

The health and taste attitudes questionnaire was completed online via Compusense Cloud and independently by 354 millennial consumers.

Gender, gluten-free awareness, most consumed bread type and health and taste attitudes (by factor) distribution

As shown in Table 4.15, most of the respondents were female (66.6%) and most respondents (56.1%) thought that gluten-free bread is healthier than gluten-containing bread ($p<0.05$).

Table 4.15: Gender distribution, highest qualification and most consumed bread type and health perception of gluten-free bread (n=354)

		Frequency	Percentage (%)
Gender	Female	236*	66.6
	Male	118	33.3
Gluten-free breads are healthier than gluten containing breads	True	198*	56.1
	False	155	43.9
Most consumed bread type	White	99	30.9
	Brown	159	49.7
	Seeded	62	19.4
Highest qualification	Grade 12/ Matric	243	68.6
	Higher certificate	8	2.3
	Diploma	5	1.4
	Bachelor's degree/ BTech	59	16.7
	Postgraduate degree	39	11.0

*significant at $p<0.05$

Table 4.16: Distribution of the respondents into the six health and taste attitudes factors between high and low (n = 354)

Sub-scale	Factors	Category	Frequency	Percentage (%)
Health attitudes	General health interest	High	170	48.0
		Low	184*	52.0
	Light product interest	High	163	46.0
		Low	191*	54.0
	Natural product interest	High	155	43.8
		Low	199*	56.2
Taste attitudes	Craving for sweet foods	High	163	46.0
		Low	191*	54.0
	Using food as a reward	High	153	43.2
		Low	201*	56.8
	Pleasure	High	173	48.9
		Low	181*	51.1
	Corrected pleasure**	High	194*	54.8
		Low	160	45.2

*Significant at $p<0.05$. **Pleasure factor with item 5 deleted (see table 4.17)

Reliability and validity of the health and taste attitudes questionnaire

Table 4.17 shows the coefficient alpha values for all health and taste attitudes factors. The general health interest factor had the highest alpha (0.83) followed by craving for sweet foods (0.78). Pleasure had a coefficient alpha of 0.51 which increased to 0.54 after item 5 (*I finish my meal even when I do not like the taste of a food*) was deleted. Looking at the mean scores, craving for sweet foods was scored the highest and light product interest was scored the lowest.

Table 4.18 shows the correlations between the scores for health and taste attitude factors. All the factors representing taste attitudes were significantly correlated to each other ($p<0.01$). In terms of the health sub-scale, natural product interest was significantly correlated with general health interest and light product interest ($p<0.01$). Light product interest and general health interest presented a significant correlation ($p<0.05$). The three taste factors (craving for sweet foods, using food as a reward and pleasure) were negatively correlated with the general health interest and natural product interest factors and, as expected, very poorly correlated with the light product interest factor.

Table 4.19 shows the factor loadings of the health sub-scale factors by means of a rotated component matrix. The 4 negatively worded items (5, 6, 7, 8) of the general health interest items along with item 3 loaded together on component 1, with item 5 having the highest factor loading. Items 1, 2 and 4 of general health interest loaded together on component 3. The light product interest items loaded together on component 2, with item 3 having the highest factor loading. Items 1, 2, 3 and 5 of the natural product interest factor had the highest factor loadings on component 4, whereas items 4 and 6 were better fitted to component 3. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.85, which is satisfactory. Bartlett's Test of Sphericity was significant ($p<0.0001$) and the four extracted components had a cumulative percentage of 54% explaining variance.

Table 4.20 shows the factor loadings of the taste sub-scale factors by means of a rotated component matrix. The craving for sweet food items loaded together on component 1, with item 3 having the highest factor loading. Items 1, 2, 3 and 4 of the using food as a reward items loaded together on component 2, however, item 5 and 6 were better fitted in component 3. For the pleasure factor: item 1 loaded well on component 3, items 3 and 6 of the pleasure factor loaded together on component 4 and items 2, 4 and 5 loaded well on component 5. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.80, which is satisfactory. Bartlett's Test of Sphericity was significant ($p<0.0001$) and the five extracted components had a cumulative percentage of 57.5% explaining variance.

Table 4.17: Internal consistency (coefficient alpha) as an indication of reliability and mean scores of the six health and taste attitude scale factors (n=354)

Sub-scale	Factor	Coefficient alpha	Number of items	Mean scores**	Median score
Health	General health interest	0.83	8	4.52 ± 1.20	4.63
	Light product interest	0.77	6	4.13 ± 1.08	4.17
	Natural product interest	0.74	6	4.26 ± 1.17	4.50
Taste	Craving for sweet foods	0.78	6	5.22 ± 1.28	5.50
	Using food as a reward	0.76	6	5.03 ± 1.11	5.17
	Pleasure	0.51	6	4.98 ± 0.95	5.00
	Corrected pleasure*	0.54	6	4.28 ± 0.83	4.30

*Pleasure factor with item 5 deleted

**Where 1 = disagree strongly and, 7 = agree strongly

Table 4.18: Correlation table for the six factors of the health and taste attitudes questionnaire

	General health interest	Light product interest	Natural product interest	Craving for sweet foods	Using food as a reward	Pleasure
General health interest	1.000					
Light product interest	0.122*	1.000				
Natural product interest	0.512**	0.213**	1.000			
Craving for sweet foods	-0.131*	0.092	-0.074	1.000		
Using food as a reward	-0.316**	0.053	-0.163**	0.389**	1.000	
Pleasure	-0.088	0.011	0.006	0.207**	0.336**	1.00

**Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed)

Table 4.19: Factor loadings of the health sub-scales of the health and taste attitudes questionnaire*

		F1	F2	F3	F4	h^2
GENERAL HEALTH INTEREST						
1	I am very particular about the healthiness of food	0.53	0.05	0.55	0.10	0.60
2	I always follow a healthy and balanced diet	0.38	-0.09	0.68	-0.06	0.62
3	It is important for me that my diet is low in fat	0.48	0.31	0.16	0.04	0.36
4	It is important for me that my daily diet contains a lot of vitamins and minerals	0.34	0.04	0.62	0.00	0.50
5R	I eat what I like, and I do not worry much about the healthiness of food	0.73	0.00	0.26	0.12	0.62
6R	I do not avoid foods, even if they may raise my cholesterol	0.68	0.03	0.03	0.27	0.54
7R	The healthiness of food has little impact on my food choices	0.70	0.04	0.20	0.07	0.54
8R	The healthiness of snacks makes no difference to me	0.71	0.00	0.17	0.03	0.54
LIGHT PRODUCT INTEREST						
1R	In my opinion, the use of light products does not improve one's health	0.14	0.62	-0.10	0.18	0.45
2R	I do not think that light products are healthier that conventional products	0.14	0.66	-0.10	0.16	0.49
3	I believe that eating light products keeps one's cholesterol level under control	-0.06	0.79	0.06	0.10	0.64
4R	In my opinion, light products don't help to drop cholesterol levels	0.01	0.68	-0.03	0.18	0.50
5	I believe that eating light products keeps one's body in good shape	0.09	0.72	0.02	0.00	0.53
6	In my opinion, by eating light products, one can eat more without getting too many calories	-0.14	0.57	0.22	-0.19	0.43
NATURAL PRODUCT INTEREST						
1R	I do not care about additives in my daily diet I try to eat foods that do not contain additives	0.35	-0.08	0.37	0.54	0.56
2R	In my opinion, organically grown foods are not better for my health than those grown conventionally	0.12	0.21	-0.08	0.75	0.62
3R	In my opinion, artificially flavoured foods are not harmful for my health	0.11	0.11	0.11	0.75	0.60
4	I try to eat foods that do not contain additives	0.18	0.03	0.67	0.39	0.64
5	I would like to eat only organically grown vegetables	0.04	0.13	0.29	0.58	0.44
6	I do not eat processed foods, because I do not know what they contain	0.07	0.01	0.71	0.19	0.55
Percentage variance explained by each component (%)		25.58	14.68	7.54	6.08	53.88

* Negatively worded statements have a “R” after the item number. Communalities are represented by h^2.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.85. Bartlett's Test of Sphericity: $p<0.0001$

Table 4.20: Factor loadings of the taste sub-scales of the health and taste attitudes questionnaire*

CRAVING FOR SWEET FOODS		**F1**	**F2**	**F3**	**F4**	**F5**	**h²**
1R	In my opinion it is strange that some people have cravings for chocolate	0.71	0.03	0.23	-0.06	-0.02	0.56
2R	In my opinion it is strange that some people have cravings for sweets	0.76	0.08	0.11	0.00	-0.01	0.60
3R	In my opinion it is strange that some people have cravings for ice-cream	0.78	0.03	0.18	-0.11	0.10	0.66
4	I often have cravings for sweets	0.55	0.36	-0.28	0.29	0.01	0.61
5	I often have cravings for chocolate	0.58	0.42	-0.11	0.27	-0.06	0.60
6	I often have cravings for ice-cream	0.67	0.20	-0.09	0.10	0.10	0.52
USING FOOD AS A REWARD							
1	I reward myself by buying something really tasty	0.11	0.80	0.18	0.14	-0.01	0.70
2	I indulge myself by buying something really delicious	0.15	0.78	0.04	0.11	0.06	0.65
3	When I am feeling down I want to treat myself with something really delicious	0.22	0.70	0.16	0.08	-0.00	0.57
4R	I avoid rewarding myself with food	0.06	0.65	0.39	0.00	0.04	0.58
5R	In my opinion, comforting myself by eating is self-deception	0.11	0.07	0.58	0.24	-0.14	0.43
6R	I try to avoid eating delicious food when I am feeling down	0.03	0.37	0.63	-0.07	0.01	0.54
PLEASURE							
1R	I do not believe that food should always be a source of pleasure	0.09	0.17	0.57	0.19	0.16	0.42
2R	The appearance of food makes no difference to me	0.08	0.02	0.19	-0.02	0.70	0.53
3	It is important for me to eat delicious food on weekdays as well as weekends	0.07	-0.03	0.33	0.75	0.04	0.69
4	When I eat, I concentrate on enjoying the taste of food	-0.08	0.21	-0.06	0.32	0.62	0.54
5R	I finish my meal even when I do not like the taste of a food	0.07	-0.10	-0.11	-0.01	0.70	0.52
6	An essential part of my weekend is eating delicious food	-0.01	0.30	0.06	0.73	0.12	0.64

Percentage variance explained (%)	24.98	11.37	8.37	6.82	5.94	57.48

* Negatively worded statements have a "R" after the item number. Communalities are represented by h^2.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.80. Bartlett's Test of Sphericity: p<0.0001

4.2.3.5 Discussion of results

Distribution of consumers according to their health and taste attitudes:

Considering that the split between high health/taste and low health/taste attitudes amongst the 354 subjects was established using the 50th percentile (Sabbe, Verbeke, Deliza, Matta & Van Damme, 2009), an even distribution was expected. However, most of the subjects had a low general health, natural product and light product interest. Light product interest reflects the extent to which the respondent values eating "light" foods (reduced-fat foods) for the purpose of maintaining good health and physical appearance (Roininen *et al.*, 1999). Therefore, it appears as though most of the participants in this study did not necessarily view consuming light products (as evaluated by this particular scale for measuring light product interest) as particularly important. Most of the subjects had a high pleasure interest for the corrected pleasure factor which represents a high taste attitude. Taste has been reported to be one of the most important factors consumers consider when it comes to the food they consume (Roininen *et al.*, 1999; Zandstra *et al.*, 2001; Costell *et al.*, 2010). The mean scores of the taste factors ranged from 4.98 to 5.22, which is higher than the mean score range for the health scale factors (4.13 to 4.52). This may be an indication of taste attitude more dominant than health attitude amongst the subjects.

When looking at the distribution of the participants amongst the three taste factors, most of the subjects were classified as low in craving for sweet foods (54.0%), using food as a reward (56.8%) and pleasure (51.1%). This was unexpected considering that most of the respondents were female (66.7%). Roininen *et al.* (1999) found that females were more inclined to crave sweet foods and eating for pleasure – however, the researchers found no gender differences for using food as a reward. After the pleasure factor was corrected by removing item 5, as it had low reliability (coefficient alpha of 0.51 to 0.54), more people were classified as high for the corrected pleasure factor (54.8%). Item 5 (*I finish my meal even when I do not like the taste of a food*) may have been interpreted in various ways by the subjects.

Reliability and validity of the health and taste attitudes scales:

Coefficient alpha determines the internal consistency of the items of the scale and the closer the alpha value is to one, the more reliable the scale is (Gliem & Gliem, 2003). George and Mallery (2003) suggested that a coefficient alpha value that is below 0.5 is unacceptable. Based on this, all of the health and taste attitudes factors measured in this study had acceptable coefficient alpha values with the pleasure factor having the lowest coefficient alpha of 0.51 (Table 10). Similar to (Chen, 2013), it is was found that after deleting item 5 of the pleasure factor, the coefficient alpha increased. In this case the coefficient alpha increased from a borderline satisfactory 0.51 to a more acceptable 0.54. The light product interest, natural product interest, craving for sweet foods and using food as a reward factors had higher coefficient alpha's than those measured in the UK and the Netherlands by Roininen *et al.* (2001) (Table 4.21). This means that these four factors were more reliable in measuring their respective constructs in this study compared to the study done by Roininen *et al.* (2001). Grubor *et al.* (2015) reported relatively high coefficient alpha values for all the health and taste attitudes factors when applied in Serbia (Table 4.21), they attributed this to the strong and similar attitudes Serbian consumers have towards the health and taste attitude aspects of food. The coefficient alphas from the general health interest and light product interest factors were fairly in line with those from the UK and Finland, respectively. The coefficient alpha for craving for sweet foods in South Africa was in line with that from the UK. (Roininen *et al.*, 2001) This indicates that these factors were similarly consistent in both studies (Table 4.21).

Table 4.21: Coefficient alpha values of the Health and Taste Attitudes factors as applied by authors in various countries

Factor	**South Africa (this study)**	**Finland**	**United Kingdom**	**The Netherlands**	**Serbia**	**Belgium**
	(n = 354)	(n = 467)	(n = 361)	(n = 477)	(n = 300)	(n = 86)
General health interest	0.83	0.87	0.84	0.80	0.947	0.84
Light product interest	0.77	0.78	0.66	0.70	0.933	ND
Natural product interest	0.74	0.76	0.65	0.69	0.934	ND
Craving for sweet foods	0.78	0.84	0.77	0.74	0.935	ND
Using food as a reward	0.76	0.74	0.67	0.67	0.968	ND
Pleasure	0.51 (0.54)*	0.63	0.39	0.54	0.964	ND
Reference	N/A (current study)	(Roininen *et al.*, 2001)	(Roininen *et al.*, 2001)	(Roininen *et al.*, 2001)	(Grubor *et al.*, 2015)	(Sabbe *et al.*, 2009)

*Corrected pleasure coefficient alpha after deleting item 5; ND = no data.

The significant correlation between all three of the taste factors was also reported by Roininen *et al.* (1999). This shows that the three factors of the taste attitude scale complement each other in measuring the taste attitude of a person. Natural product interest had a strong correlation with general health interest and light product interest, the same was found by Roininen *et al.* (1999) and Zandstra *et al.* (2001). However, unlike in Roininen *et al.* (1999), general health interest and light product interest did not have a high correlation. This may be a reflection that participants who are concerned about the nutrition and health impact of food may not necessarily be concerned about consuming light products to stay in shape as the items suggest.

The cumulative variance explained by the components extracted in the three health factors was 53.88%. This was higher than what was obtained when the questionnaire was applied in Finland (45%), United Kingdom (36.2%) and The Netherlands (34.4%) (Roininen *et al.*, 2001), but lower than what was found in Serbia (71.11%) (Grubor *et al.*, 2015). The exploratory factor analysis revealed that the light product interest factor was stable as all of its items loaded well on component 2. A similar pattern was found by Saba *et al.* (2019) in a study of the health attitudes of 1224 Italian consumers. However, unlike in the studies by Saba *et al.* (2019) and Grubor *et al.* (2015), the general health interest factor of this study had items with high loadings in two separate components. General health interest therefore formed two constructs, one had all the negative (R) items (items 5, 6, 7, 8 along with item 3) which imply little or no care for one's health, except item 3 which also showed the lowest communality in the entire questionnaire. The other construct contains items (items 1, 2 and 4) which alluded to one being meticulous about the healthfulness of a diet. Item 5 of the general health interest factor (which reads: "*I eat what I like, and I do not worry about healthiness of food*") had the highest factor loading and this may mean that this item best represented the general health interest of the subjects in this research. This may be an indication that the subjects have a clear understanding that what they eat may affect their health. For natural product interest, items 4 and 6 which refer to processed foods and foods containing additives had high loadings on component 3 – thereby forming a separate construct specific to an interest in whether food is processed or contains additives or not. Similar results were noted by Roininen *et al.* (2001) in their study of the health attitudes of Finnish (n=467), British (n=361) and Dutch (n=477) consumers. The light product interest factor therefore presented the highest validity amongst the health factors.

In terms of the taste factors, the cumulative variance explained by the components extracted in the three health factors was 51.54%. This was higher than what was obtained when the questionnaire was applied in Finland (45%), United Kingdom (36.2%) and The Netherlands

(34.4%) (Roininen *et al.*, 2001). Craving for sweet foods was stable in that all items loaded well together on component 1, the same stability was also noted by Grubor *et al.* (2015) in Serbia and Roininen *et al.* (2001) when the factor was applied in Finland. However, it is interesting to note that in the research done by Talvia, Räsänen, Lagström, Angle, Hakanen, Aromaa, Sillanmäki, Saarinen and Simell (2011) and Saba *et al.* (2019), craving for sweet foods formed two separate constructs based on items relating personal craving and others relating to other people's cravings. Similar to Great Britain (Roininen *et al.*, 2001), items 1, 2, 3 and 4 of the 'using food as a reward' factor in this study loaded well on component 2 but items 5 and 6 were better fitted on component 3. These two items related to emotional eating. Emotional eating is when emotional states and situations affect food intake (Geliebter & Aversa, 2003). The pleasure factor however, seemed to yield three constructs – this may also be the reason for the relatively low coefficient alpha it presented. Item 1 of pleasure loaded well on component 3 with the 2 emotional eating items from the 'using food as a reward' factor. This item addresses one's standpoint on whether food should be a source of pleasure or not, which may have also been interpreted as a form of emotional eating by the subjects. Items 3 and 6 of the pleasure factor loaded well on component 4, these items refer to eating delicious foods specifically on weekends. Items 2, 4 and 5 loaded well on component 5, these items deal with the sensory appeal or sensory benefit perceived from the consumption of food. Item 5 had the lowest coefficient alpha and it was also the item which presented the highest number of negative loadings in other components. This is an indication that item 5 may have represented something other than pleasure. Responses to item 5 ("*I finish my meal even when I do not like the taste of food*") may have been affected by other inherent values (e.g., food waste consciousness) and not necessarily the motivation to obtain pleasure from food. Item 5 also loaded poorly and presented the lowest communality for Great Britain (Roininen *et al.*, 2001).

4.2.3.6 Conclusions

The health and taste attitudes of a selected group of millennial subjects were determined using the health and taste attitudes questionnaire. All three health factors and all three taste factors were satisfactory in terms of reliability. Factor analysis revealed that the light product interest factor was valid compared to general health interest and natural product interest. Craving for sweet foods was the most stable factor for determining taste attitude. Using food as a reward yielded two separate constructs, one had an emotional eating theme. The pleasure factor showed the lowest validity in that its items loaded on three separate components.

Most of the subjects were female, which might show that females are probably more interested to participate in food studies. Most of the subjects were classified as having a low interest for the health interest factors. Most of the subjects were also classified as having a low interest for craving for sweet foods and using food as a reward, however, high for corrected pleasure (item 5 deleted). Therefore, this group of millennial consumers is likely to be driven by taste more than health considerations when it comes to food choice or liking of gluten-free bread specifically.

4.2.4 Phase 2: Millennial consumers' acceptance of the sensory properties of gluten-free bread as influenced by health and taste attitudes

4.2.4.1 Research questions

1. Do the health and taste attitudes of consumers' have an effect on the acceptability of the sensory properties of gluten-free bread?
2. Does information about the gluten-status of the gluten-free bread samples have an effect on the acceptability of the sensory properties of the bread samples?
3. Is there an interaction between health and taste attitudes and information when it comes to the acceptance of the sensory properties of gluten-free bread?
4. What general perceptions do consumers' have on gluten-free bread compared to wheat bread?

4.2.4.2 Materials and methods

4.2.4.2.1 Subjects

The participants of this study were recruited from the group of 354 subjects used in phase 1 and are therefore a sub-set of 173 recruits. The 173 recruits were people who (1) completed the health and taste attitudes questionnaire, (2) qualified to be invited for the sensory evaluation based on not having any wheat or gluten intolerances and (3) voluntarily scheduled themselves for the sensory evaluation and attended. Each of these participants were also classified into one of the four health and taste attitude groups according to their health (general health interest) and taste (pleasure with item 5 deleted) attitudes (Figure 4.14). In this study, only the General Health Interest factor was used to represent health attitude and the Pleasure factor represented taste attitude for classifying the respondents into having either a low or high health/taste attitude. This decision was based on face validity as determined by the researchers (Dickson-Spillmann, Siegrist & Keller, 2011; Taherdoost, 2016). The items of these two factors were identified to be most relevant and appropriate for this study. A total of 56 sensory evaluation appointments were made available for respondents from each health and taste attitude classification group. The number of people from each group that participated in the sensory evaluation is shown in Figure 4.14.

4.2.4.2.2 Products

The same three brown bread samples profiled in Chapter 4.1 were evaluated in this part of the study. Two of the samples were gluten-free (GFA and GFB) and the control sample was a commercial brown wheat bread. The sensory evaluation was conducted on the brown bread as it was found to be the most consumed bread type amongst the respondents (Table 4.24). The samples were presented as disk-shaped portions of the crumb area of the bread slice. These were packaged in transparent 120 mm x 180 mm Ziplock bags.

4.2.4.2.3 Procedure

The acceptance tests were conducted in a Sensory Laboratory (Figure 4.11) over three consecutive days. The laboratory used has 16 individual booths, the evaluations were done under white day light conditions and the room temperature was ±21 °C. Filtered water was provided to each participant for pallet cleansing. On each day (1 to 3 October 2019), four one-hour sessions (scheduled from 08:30 am to 12:30 pm) were held and each participant received a store-voucher worth 25 ZAR after their evaluation as a token of appreciation. Compusense Cloud (Compusense Inc., Guelph, Canada) software was used to produce the sample codes, presentation orders and to collect the rating data and comments for each sample from each participant.

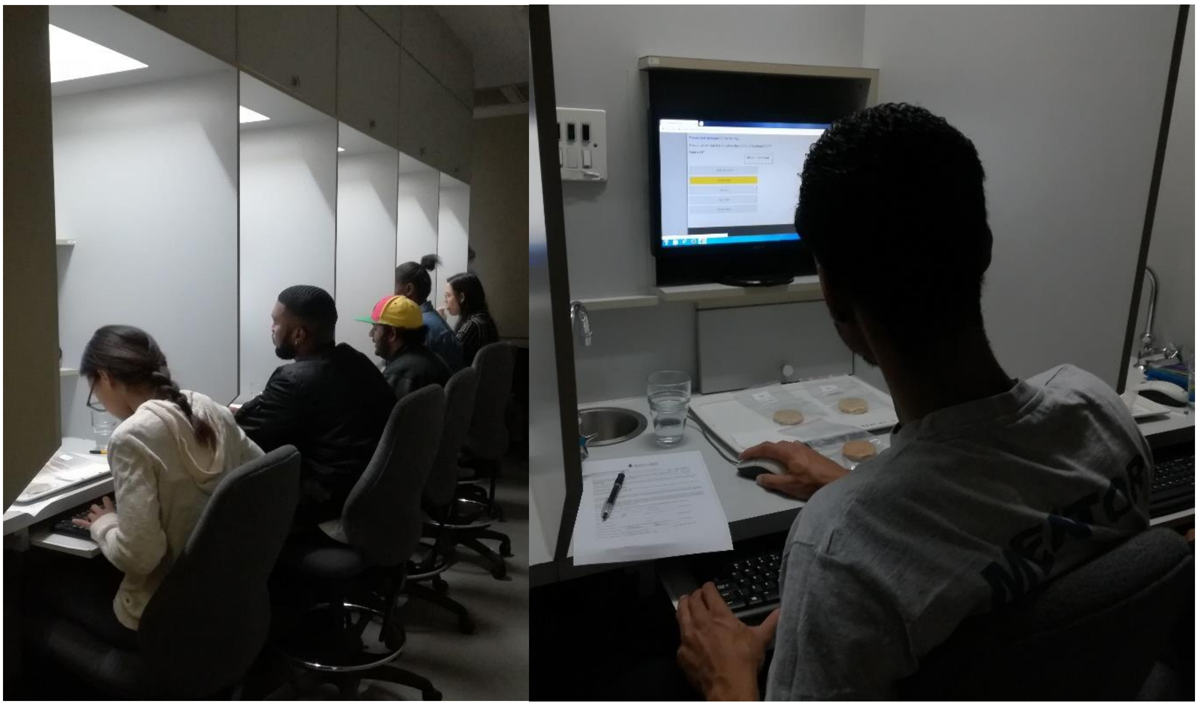


Figure 4.11: Image of participants seated in the Sensory Laboratory in their individual booths during the evaluation (left). Image of a participant giving a response on the screen (right).

The process was a three-part evaluation whereby the panellists had one hour to complete. The three sections were conducted as follows:

Section 1:

In the first section, using a five-point Likert type scale (Table 4.22), the participants rated the acceptability of the look (appearance), smell (aroma), taste (flavour) and texture attributes of disk-shaped samples of each of the three breads, blind-coded with 3-digit numbers (figure 4.12). The sample serving positions varied from panellist to panellist according to a Williams latin square design. A rating of 1 (dislike very much) to 3 (not sure) connected the participant to a comment section where they were asked to indicate their reason for disliking the particular sample for the evaluated attribute. A rating from 4 (like a little) to 5 (like very much) connected the participant to a comment section where they were asked to indicate the reason for liking the sample for the evaluated attribute in question. This section was the uninformed section where the participants had no information on the nature of the bread samples that they were evaluating.

Figure 4.12: Image of blind-coded bread crumb samples as served simultaneously to participants for sensory evaluation in the Sensory Science Preparation Laboratory

Section 2:

In the second section, samples of the three brown bread types (GFA, GFB and wheat control) were labelled with randomly selected 3-digit blind-codes (different to those from the first section) as well as labels identifying them as either “gluten-free bread” or “wheat bread” (figure 4.13). The participants were therefore informed as to whether the bread samples evaluated were gluten-free or wheat bread. The samples were all served at the same time with sample set positions varying from panellist to panellist according to a Williams latin square design. The participants were again requested to rate the acceptability of the look, smell, taste and texture of the bread samples using a five-point Likert type scale (Table 4.22). The participants were then given the option to give overall/general comments on each of the samples after evaluating them.

Figure 4.13: Image of blind-coded and labelled bread crumb samples as served simultaneously to panellists for sensory evaluation in the Sensory Science Preparation Laboratory

Table 4.22: Five-point Likert-type rating scale used in the sensory evaluation of the brown bread samples

Dislike very much	1
Dislike a little	2
Not sure	3
Like a little	4
Like very much	5

Section 3:

The third section tasked the participants to associate characteristics (Check-All-That-Apply, CATA) that apply to gluten-free bread and wheat bread from a list of 24 options provided (Table 4.23). This list was used to associate characteristics for gluten-free bread, thereafter, the list was presented again for wheat bread. The options used for the CATA list were generated from responses from a pilot study. The three sections of the sensory evaluation were pilot tested with a group of 24 millennial students using the same samples and testing conditions used in this study. The comments which were made frequently in the pilot study along with other characteristics suggested by the researchers were included in the CATA list of options.

Table 4.23: List of characteristics used as CATA options to describe gluten-free and wheat brown bread

	Characteristics
1	Affordable
2	For people with allergies
3	For people with coeliac disease
4	Healthy
5	Tasty/delicious
6	Contributes to weight loss
7	Many options available
8	Easy to find
9	Filling
10	Appealing
11	Natural
12	Organic
13	Processed
14	Convenient
15	Source of fibre
16	Source of protein
17	Source of fat
18	Salty
19	Foreign taste
20	Bitter taste
21	Sweet taste
22	Leaves you feeling bloated
23	Made with flour from indigenous crops
24	Made with flour from sustainable crops

4.2.4.3 Statistical analyses

SPSS version 25 (IBM Corporation ®, New York, USA) was used for the statistical analysis of the health and taste attitudes of the respondents. The mean scores for each factor (general health interest and pleasure) from each respondent were determined. The median (50^{th}

percentile) score of each factor was used as the cut-off point between high and low health/ taste attitude groups. The distribution between male and female respondents was compared using binomial distribution. The distribution between respondents who believed that gluten-free bread is healthier than gluten-containing bread and those who do not was also compared using binomial distribution.

The main and interaction effects of the health and taste attitude groups, samples and information (knowing the gluten-free/wheat status of the samples) were determined through a type III, three-way analysis of variance (ANOVA). Fisher's Least Significant Difference (LSD) test at $p<0.05$ was used to compare means. The comments were grouped according to the health and taste attitude groups, refined using the coding method (Linneberg & Korsgaard, 2019) and presented as word clouds using www.wordclouds.com. The differences in perceptions of the participants about gluten-free and wheat bread (association test by CATA) was determined using Cochran's Q test and compared at $p<0.05$. These statistical tests (three-way ANOVA and CATA) were done using XLStat software (version 2020.1.3) (Addinsoft, Long Island, New York, USA).

4.2.4.4 Results

Distribution of respondents based on their health and taste attitude classification

Of the 354 subjects who completed the health and taste attitudes questionnaire (phase 1), only 283 qualified to be invited for the sensory evaluation based on indicating that they do not have any wheat or gluten intolerances. Of the 283 who were invited, 173 attended and, the results presented and discussed in this phase of the research are from this subset of 173 participants. In this phase of the research, only the general health interest factor was considered for classifying the participants into having either a high or low health attitude. The corrected pleasure factor (pleasure factor where item 5 was not included) was used for classifying participants according to either high or low taste attitude. As seen in Figure 4.14, most respondents (56%) had a high taste attitude. The split between high health and low health was however even. The high health, low taste group had the lowest number of respondents (21%) and high health, high taste had the most (28%).

As shown in Table 4.24, most of the respondents were female (71.1%) and most respondents (55.5%) thought that gluten-free bread is healthier than gluten-containing bread.

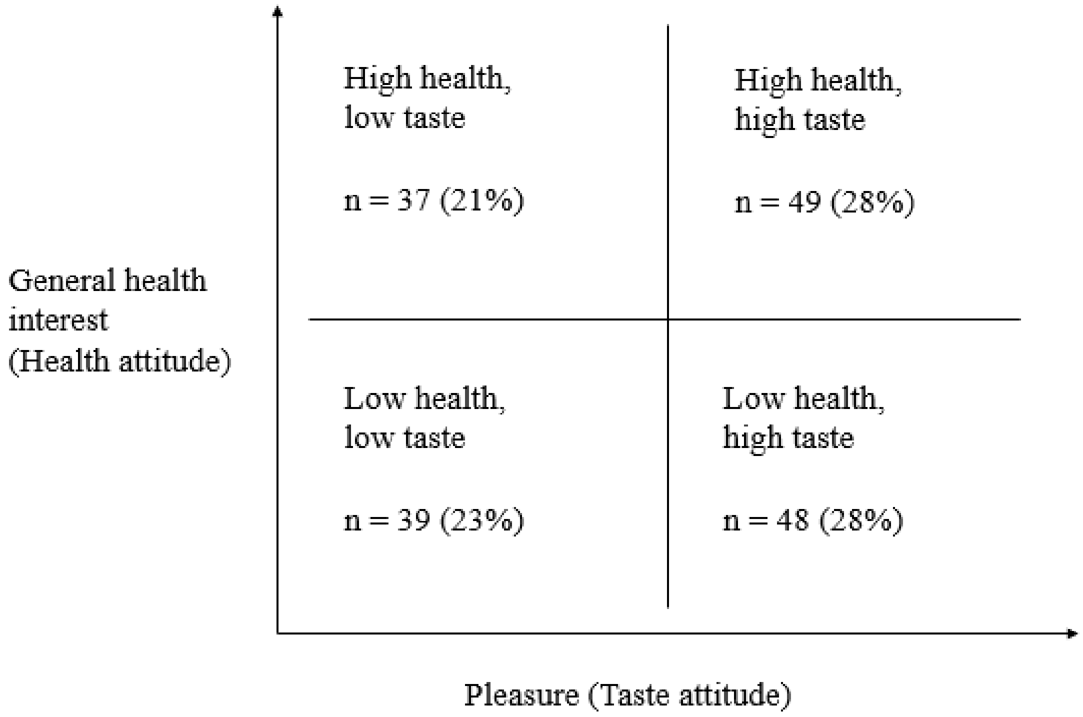


Figure 4.14: Distribution and classification of respondents based on their health and taste attitudes (n=173)

Table 4.24: Gender distribution, highest qualification and most consumed bread type and health perception of gluten-free bread (n=173)

		Frequency	**Percentage (%)**
Gender	Female	123*	71.1
	Male	50	28.9
Gluten-free breads are healthier than gluten containing breads	True	96*	55.5
	False	77	44.5
Most consumed bread type	White	48	27.7
	Brown	97	56.1
	Seeded	28	16.2
Highest qualification	Grade 12/ Matric	120	69.4
	Higher certificate	4	2.3
	Diploma	2	1.2
	Bachelor’s degree/ BTech	32	18.5
	Postgraduate degree	15	8.7

*p<0.05

Main and interaction effects

Table 4.25 shows the main effects and interaction effects of health and taste attitude group, samples and information (gluten-free/wheat status of the bread) on the sensory properties (appearance, smell, taste and texture) of the bread samples. The sample effect was significant for all attributes and the effect of information was only significant for smell. With interaction effects, the interaction of health and taste attitude group X sample was only significant for appearance ($p = 0.052$) and taste ($p = 0.037$). There was no other significant interaction or main effects.

Table 4.25: ANOVA table for the main effect and interaction effects of health and taste attitude groups, samples and information about gluten-free/wheat bread status of bread on the sensory attributes (appearance, smell, taste and texture) as evaluated by consumers (n=173).

		Appearance				**Smell**				**Taste**				**Texture**			
Source	**DF**	**Sum of squares**	**Mean squares**	**F**	**p-value**	**Sum of squares**	**Mean squares**	**F**	**p-value**	**Sum of squares**	**Mean squares**	**F**	**p-value**	**Sum of squares**	**Mean squares**	**F**	**p-value**
HTA group	3	3.658	1.219	0.778	0.506	7.824	2.608	1.825	0.141	0.669	0.223	0.126	0.945	8.945	2.982	1.507	0.211
Sample	2	27.878	13.939	8.891	**0.000**	270.135	135.068	94.516	**<0.0001**	239.140	119.570	67.668	**<0.0001**	234.481	117.241	59.277	**<0.0001**
Info	1	1.588	1.588	1.013	0.314	21.756	21.756	15.224	**0.000**	2.270	2.270	1.284	0.257	2.404	2.404	1.216	0.270
HTA group*Sample	6	19.634	3.272	2.087	**0.052**	11.266	1.878	1.314	0.248	23.826	3.971	2.247	**0.037**	15.909	2.651	1.341	0.236
HTA group*Info	3	0.207	0.069	0.044	0.988	0.490	0.163	0.114	0.952	1.097	0.366	0.207	0.892	1.356	0.452	0.229	0.877
Sample*Info	2	4.354	2.177	1.388	0.250	7.530	3.765	2.635	0.072	1.512	0.756	0.428	0.652	0.185	0.092	0.047	0.954
HTA group*Sample*Info	6	1.736	0.289	0.185	0.981	2.317	0.386	0.270	0.951	0.546	0.091	0.051	0.999	1.907	0.318	0.161	0.987

Where * = interaction. The p-values highlighted in bold were significant at $p<0.05$. HTA = health and taste attitude, DF = degrees of freedom and F = F statistic

The effect of the samples on acceptance

Table 4.26 shows the main effect of sample (control, GFA or GFB) on the acceptance of the sensory properties of the bread. The sensory attributes of the control sample were significantly more acceptable than that of GFA and GFB.

Table 4.26: Main effect of sample (control, GFA or GFB) on the acceptance of the sensory properties of gluten-free and wheat brown bread

	Appearance	Smell	Taste	Texture
Control	3.9^{a}	4.0^{a}	4.1^{a}	3.9^{a}
GFA	3.5^{b}	3.8^{b}	3.1^{b}	2.7^{c}
GFB	3.6^{b}	2.8^{c}	3.0^{b}	3.2^{b}
p-value	0.000	<0.0001	<0.0001	<0.0001

Means with different superscripts are significantly different for the attribute. Where 1 = dislike very much, 5 = like very much

The effect of information on hedonic ratings

Table 4.27 shows the main effect of information (knowing the gluten-free or wheat bread status) on the acceptance of the sensory properties of gluten-free and wheat brown bread. Information only had a significant negative effect on the acceptability of the smell of the samples by the participants.

Figure 4.15 shows the mean hedonic ratings for the smell of gluten-free brown bread samples as affected by information about the gluten-free/wheat bread status. The liking of the smell of the two gluten-free samples was negatively and significantly affected by the information ($p<0.05$). Liking of the smell of the control sample was not significantly affected ($p>0.05$).

Table 4.27: The effect of information (knowing the gluten-free or wheat bread status) on the acceptability of the sensory properties of gluten-free and wheat brown bread

	Appearance	Smell	Taste	Texture
No info	3.6^{a}	3.7^{a}	3.3^{a}	3.2^{a}
Info	3.7^{a}	3.4^{b}	3.4^{a}	3.3^{a}
p-value	0.314	0.000	0.257	0.270

Means with different superscripts are significantly different for the attribute. Where 1 = dislike very much, 5 = like very much

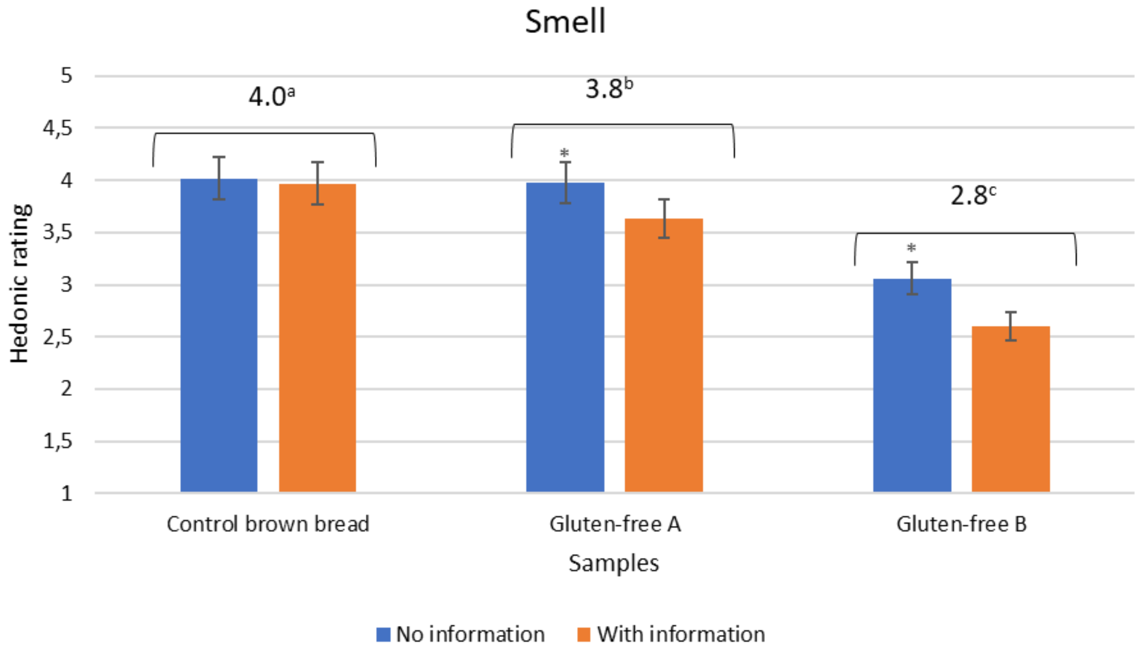


Figure 4.15: Mean hedonic ratings of the smell of commercial brown wheat and two gluten-free samples as evaluated by all millennial participants (n=173). Where 1 = dislike very much and 5 = like very much. An asterisk (*) indicated a significant difference in the mean hedonic rating of the sample, as affected by information (p<0.05), where information meant that the sample was identified as either gluten-free or wheat bread. Means with different superscripts are significantly different for the sample.

Effect of consumers' health and taste attitudes on the acceptability of the sensory properties of brown gluten-free samples

Table 4.28 shows the mean liking scores of the sensory properties of the gluten-free samples as affected by the interaction between the health and taste attitude group X samples. The liking scores of the appearance of the samples (control, GFA and GFB) did not differ significantly for those in the HTHH (high taste, high health) group. The liking scores of the appearance of the GFA and GFB were significantly lower than for the control sample for consumers in the HTLH (high taste, low health) group. The liking scores of the appearance of GFA and GFB were significantly lower than the control sample for those in the LTHH (low taste, high health) group. The liking scores of the appearance of all the samples did not differ significantly for consumers on the LTLH (low taste, low health) group.

For HTHH consumers, the taste of wheat bread was preferred followed by that of GFA and then GFB having the lowest mean liking score. The liking scores of the taste of GFA and GFB were significantly lower than the control sample for those in the HTLH, LTHH and LTLH groups.

The effect of the interaction between health and taste attitude groups and samples was not significant for the appearance and taste liking scores of the bread samples. The sample effect was significant in terms of smell and texture with the control sample having the highest ratings.

Table 4.28: Mean scores of the acceptability of the sensory properties of the gluten-free samples as affected by the interaction between health and taste attitudes and sample (n=173)

	Appearance	Smell	Smell sample mean	Taste	Texture	Texture sample mean
HTHH*Control	3.8^{abc}	3.9^{abc}	4.0	3.9^{b}	3.8^{b}	3.9
HTLH*Control	3.9^{ab}	3.9^{abc}		4.3^{a}	3.9^{ab}	
LTHH*Control	4.1^{a}	4.1^{a}		4.1^{ab}	4.3^{a}	
LTLH*Control	3.8^{abc}	4.0^{abc}		3.9^{b}	3.6^{bc}	
HTHH*GFA	3.7^{abc}	3.8^{bc}	3.8	3.3^{c}	2.8^{ef}	2.7
HTLH*GFA	3.3^{d}	3.7^{c}		2.9^{cd}	2.7^{f}	
LTHH*GFA	3.6^{bcd}	3.8^{bc}		3.2^{cd}	2.8^{ef}	
LTLH*GFA	3.5^{cd}	4.1^{ab}		3.1^{cd}	2.6^{f}	
HTHH*GFB	3.6^{bcd}	2.7^{e}	2.8	2.8^{d}	3.1^{de}	3.2
HTLH*GFB	3.5^{cd}	3.0^{de}		2.9^{d}	3.0^{def}	
LTHH*GFB	3.3^{d}	2.7^{e}		2.9^{cd}	3.2^{de}	
LTLH*GFB	3.8^{abc}	3.0^{d}		3.2^{cd}	3.3^{cd}	
p-value	0.052	0.248	<0.0001	0.037	0.236	<0.0001
			Significant sample effect			Significant sample effect

Means scores with different superscript letters (abc) significantly different, across all health and taste attitude groups and samples (p<0.05). Where HTHH = high health, high taste; HTLH = high taste, low health; LTHH = low taste, high health and LTLH = low taste, low health. Where 1 = dislike very much and 5 = like very much

Reasons for liking and disliking the sensory properties of the control and gluten-free bread samples in uninformed conditions by consumers from the four health and taste attitude groups

Figure 4.16 shows the word cloud analyses of the reasons for disliking the sensory properties of the control brown wheat bread by consumers in the different health and taste attitudes groups when they did not have knowledge of the gluten-free/wheat bread nature of the samples. The words used most frequently by each group to describe reasons for dislike were: “bland, chewy and normal" by the HHLT group; "familiar and bland" by the LHLT group; "unappealing and normal" by the LHHT group and "regular" by the HHHT group.

Figure 4.17 shows the word cloud analyses of the reasons for liking the sensory properties of the control brown wheat bread by consumers in the different health and taste attitudes groups when they did not have knowledge of the gluten-free/wheat bread nature of the samples. The words used most frequently by each group to describe reasons for liking were: "soft, fresh and familiar" by the HHLT group; "familiar" by the LHLT group; "soft and normal" by the LHHT group and "regular, soft and normal" by the HHHT group.

Figure 4.18 shows the word cloud analyses of the reasons for disliking the sensory properties of sample GFA gluten-free brown bread by consumers in the different health and taste attitudes groups when they did not have knowledge of the gluten-free/wheat bread nature of the samples. The words used most frequently by each group to describe reasons for disliking were: "dry, stale and hard" by the HHLT group; "dry, sponge-like and hard" by the LHLT group and "dry, spongy, and rough" by the LHHT and HHHT groups.

Figure 4.19 shows the word cloud analyses of the reasons for liking the sensory properties of sample GFA gluten-free brown bread by consumers in the different health and taste attitudes groups when they did not have knowledge of the gluten-free/wheat bread nature of the samples. The words used most frequently by each group to describe reasons for liking were: "healthy and normal" by the HHLT group; "sweet, soft and different" by the LHLT group; "soft, sweet and fresh" by the LHHT group and "fresh, sweet, normal and spongy" by the HHHT group.

Figure 4.20 shows the word cloud analyses of the reasons for disliking the sensory properties of sample GFB gluten-free brown bread by consumers in the different health and taste attitudes groups when they did not have knowledge of the gluten-free/wheat bread nature of the samples. The words used most frequently by each group to describe reasons for disliking were: "hard, dry, stale and not fresh" by the HHLT group; "dry, unexpected, sour and crumbly" by the LHLT group; "gritty, dry, bland and weird" by the LHHT group and "porous, hard and dry" by the HHHT group.

Figure 4.21 shows the word cloud analyses of the reasons for liking the sensory properties of sample GFB gluten-free brown bread by consumers in the different health and taste attitudes groups when they did not have knowledge of the gluten-free/wheat bread nature of the samples. The words used most frequently by each group to describe reasons for liking were: "healthy and grainy" by the HHLT group; "fresh, normal and spongy" by the LHLT group; "fresh, seedy and different" by the LHHT group and "light, grainy and fresh" by the HHHT group.

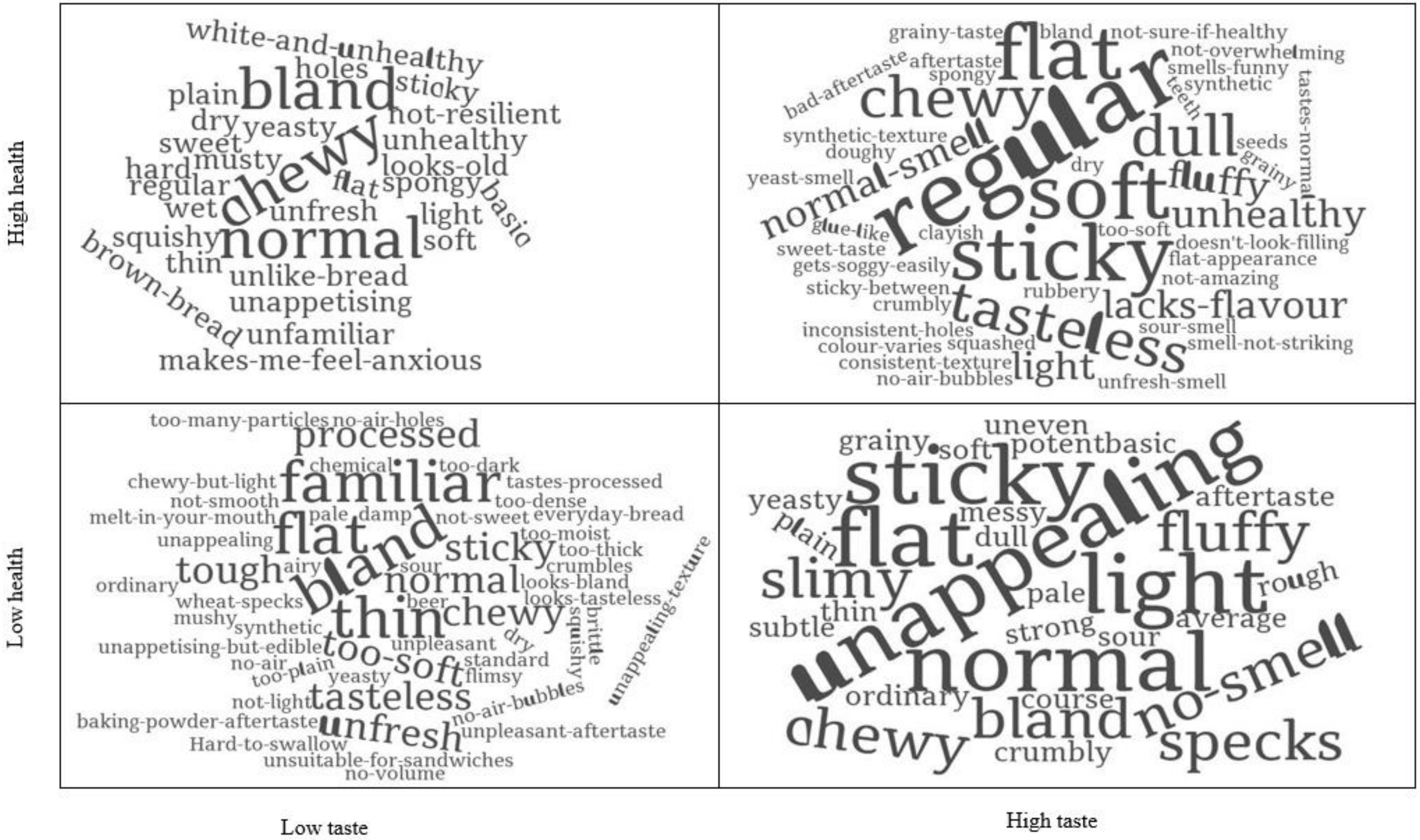


Figure 4.16: Word cloud analyses of the reasons for disliking the sensory properties of the control brown wheat bread by consumers (N=173) in the different health and taste attitudes groups when they did not have knowledge of the gluten-free/wheat bread nature of the samples. The size of the words are related to the frequency of use- the larger a word, the more frequently it was used by the consumers. n(LHLT) = 39; n(LHHT) = 48; n(HHLT) = 37; n=(HHHT) = 49

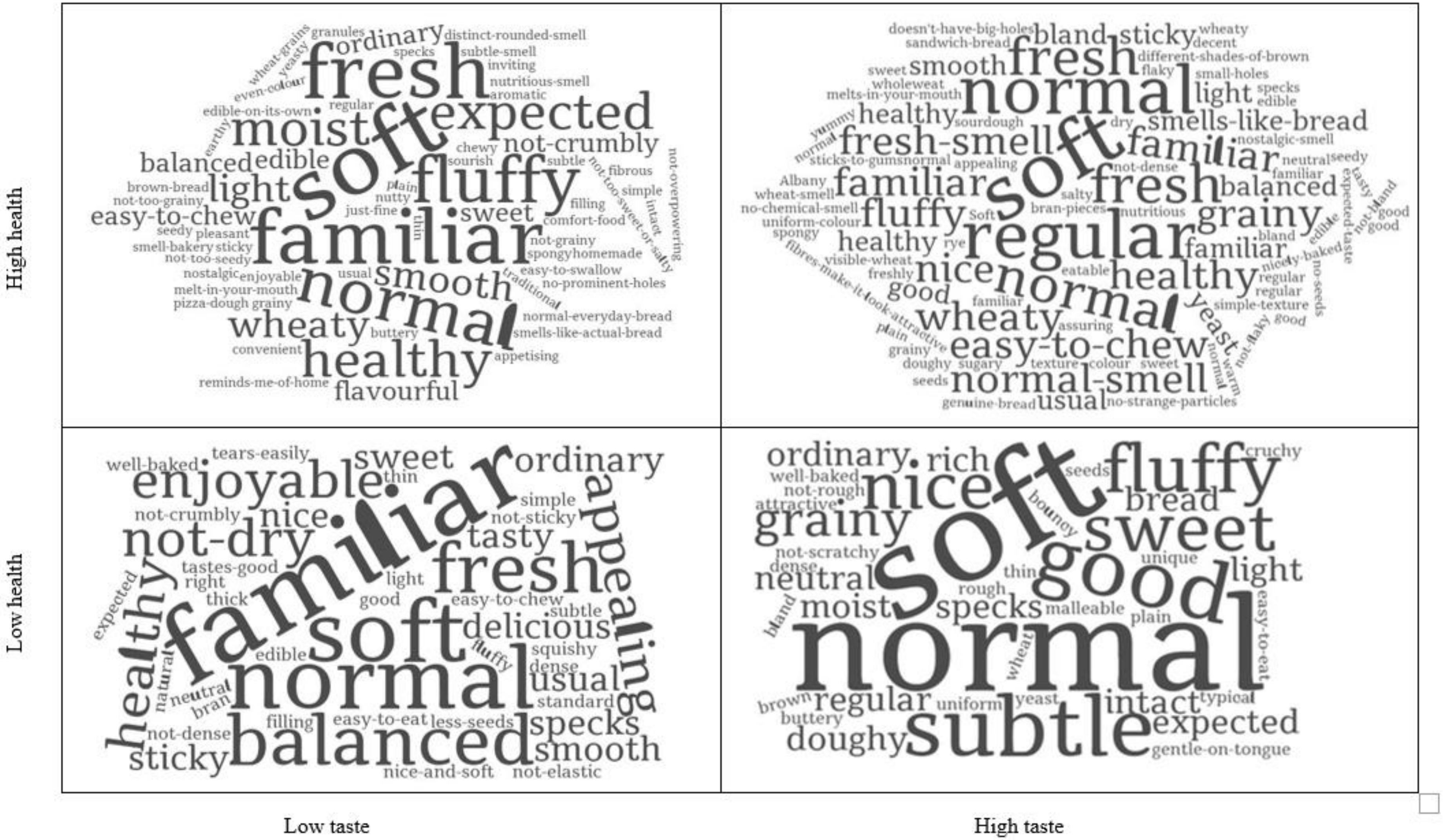


Figure 4.17: Word cloud analyses of the reasons for liking the sensory properties of the control brown wheat bread by consumers (N=173) in the different health and taste attitudes groups when they did not have knowledge of the gluten-free/wheat bread nature of the samples. The size of the words are related to the frequency of use- the larger a word, the more frequently it was used by the consumers. n(LHLT) = 39; n(LHHT) = 48; n(HHLT) = 37; n=(HHHT) = 49

Figure 4.18: Word cloud analyses of the reasons for disliking the sensory properties of sample GFA gluten-free brown bread by consumers (N=173) in the different health and taste attitudes groups when they did not have knowledge of the gluten-free/wheat bread nature of the samples. The size of the words are related to the frequency of use- the larger a word, the more frequently it was used by the consumers. n(LHLT) = 39; n(LHHT) = 48; n(HHLT) = 37; n=(HHHT) = 49

Figure 4.19: Word cloud analyses of the reasons for liking the sensory properties of sample GFA gluten-free brown bread by consumers (N=173) in the different health and taste attitudes groups when they did not have knowledge of the gluten-free/wheat bread nature of the samples. The size of the words are related to the frequency of use- the larger a word, the more frequently it was used by the consumers. n(LHLT) = 39; n(LHHT) = 48; n(HHLT) = 37; n=(HHHT) = 49

Figure 4.20: Word cloud analyses of the reasons for disliking the sensory properties of sample GFB gluten-free brown bread by consumers (N=173) in the different health and taste attitudes groups when they did not have knowledge of the gluten-free/wheat bread nature of the samples. The size of the words are related to the frequency of use- the larger a word, the more frequently it was used by the consumers. n(LHLT) = 39; n(LHHT) = 48; n(HHLT) = 37; n=(HHHT) = 49

Figure 4.21: Word cloud analyses of the reasons for liking the sensory properties of sample GFB gluten-free brown bread by consumers (N=173) in the different health and taste attitudes groups when they did not have knowledge of the gluten-free/wheat bread nature of the samples. The size of the words are related to the frequency of use- the larger a word, the more frequently it was used by the consumers. n(LHLT) = 39; n(LHHT) = 48; n(HHLT) = 37; n=(HHHT) = 49

Comments on the sensory properties of the bread samples in informed conditions (samples identified as either gluten-free or wheat bread) by consumers from the four health and taste attitude groups

Figure 4.22 shows the word cloud analyses of the general comments on the sensory properties of the control wheat brown bread by consumers in the different health and taste attitudes groups when they had knowledge of the gluten-free/wheat bread nature of the samples. The words used most frequently by each group to describe the control sample were: “normal, soft and familiar” by the HHLT group; “bland, soft, tasty and familiar” by the LHLT group; “soft, familiar, normal and nice” by the LHHT group and “familiar and soft” by the HHHT group.

Figure 4.23 shows the word cloud analyses of the general comments on the sensory properties of sample GFA gluten-free brown bread by consumers in the different health and taste attitudes groups when they had knowledge of the gluten-free/wheat bread nature of the samples. The words used most frequently by each group to describe sample GFA were: “dry” by the HHLT and HHHT groups; “sandy, dry, spongy and rough” by the LHLT group and “crumbly, dry and rough” by the LHHT group.

Figure 4.24 shows the word cloud analyses of the general comments on the sensory properties of sample GFB gluten-free brown bread by consumers in the different health and taste attitudes groups when they had knowledge of the gluten-free/wheat bread nature of the samples. The words used most frequently by each group to describe sample GFB were: “weird, grainy, hard, dry, rough and unappealing” by the HHLT group; “crumbly and dry” by the LHLT group; “bad-taste, healthy, tasteless, grainy and dry” by the LHHT group and “off-smell, bad and dry” by the HHHT group.

Figure 4.22: Word cloud analyses of the general comments on the sensory properties of the control wheat brown bread by consumers (N=173) in the different health and taste attitudes groups when they had knowledge of the gluten-free/wheat bread nature of the samples. The size of the words are related to the frequency of use- the larger a word, the more frequently it was used by the consumers. n(LHLT) = 39; n(LHHT) = 48; n(HHLT) = 37; n=(HHHT) = 49

Figure 4.23: Word cloud analyses of the general comments on the sensory properties of sample GFA gluten-free brown bread by consumers (N=173) in the different health and taste attitudes groups when they had knowledge of the gluten-free/wheat bread nature of the samples. The size of the words are related to the frequency of use- the larger a word, the more frequently it was used by the consumers. n(LHLT) = 39; n(LHHT) = 48; n(HHLT) = 37; n=(HHHT) = 49

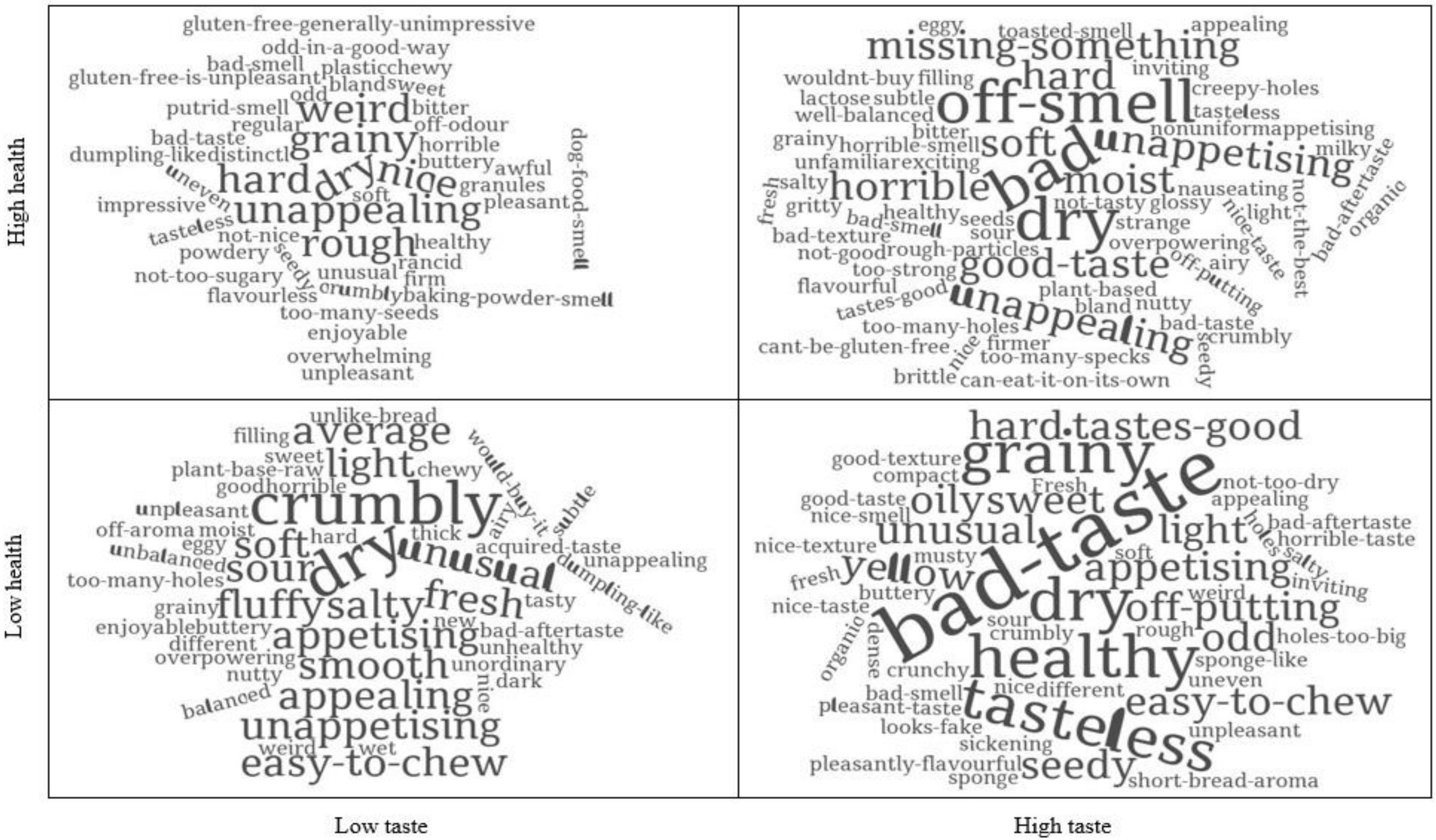


Figure 4.24: Word cloud analyses of the general comments on the sensory properties of sample GFB gluten-free brown bread by consumers (N=173) in the different health and taste attitudes groups when they had knowledge of the gluten-free/wheat bread nature of the samples. The size of the words are related to the frequency of use- the larger a word, the more frequently it was used by the consumers. n(LHLT) = 39; n(LHHT) = 48; n(HHLT) = 37; n=(HHHT) = 49

Perceptions that the participants have of the characteristics of gluten-free and wheat bread

Table 4.29 shows the comparison of the characteristics associated with gluten-free and wheat bread as selected by consumers (n = 173) from a check-all-that-apply (CATA) list. The characteristics were sorted in descending order of frequency of checking in terms of gluten-free bread, from the most to the least checked characteristic. Significantly more participants thought that gluten-free bread compared to wheat bread was more: for people with allergies, for people with coeliac disease, healthy, natural, organic and had a foreign and bitter taste compared to wheat bread ($p<0.05$). However, significantly more participants thought that wheat bread compared to gluten-free bread was more: affordable, tasty, convenient, filling, appealing, processed, fibrous, fatty, sweet, makes you feel bloated and is made from flour from sustainable crops ($p<0.05$).

Table 4.29: Comparison of the characteristics associated with gluten-free and wheat bread as selected by consumers (N=173) from a check-all-that-apply (CATA) list.

Characteristics	Gluten-free (%)	Wheat bread (%)
Healthy*	75.1	31.8
For people with allergies*	71.1	3.5
Contributes to weight loss*	55.5	8.1
Foreign taste*	54.9	2.9
Source of fibre*	47.4	68.2
Natural*	45.1	27.7
Organic*	43.4	17.9
For people with coeliac disease*	32.4	2.3
Filling*	31.2	54.9
Bitter taste*	24.9	2.9
Appealing*	23.7	48.6
Processed*	23.7	52
Tasty/delicious*	22.5	62.4
Source of protein^{NS}	19.7	18.5
Made with flour from sustainable crops*	17.3	30.6
Salty^{NS}	14.5	13.3
Sweet taste*	13.3	36.4

Made with flour from indigenous crops^{NS}	12.7	16.8
Many options available*	11	56.6
Easy to find*	6.4	85
Convenient*	5.2	74
Affordable*	4	83.8
Leaves you feeling bloated*	4	31.2
Source of fat*	3.5	15

*Significant difference (p<0.05) according to Cochran's Q test.

NS, no significant difference (p>0.05).

4.2.4.5 Discussion of results

The general health interest factor was considered for classifying the participants into having either a high or a low health attitude and the pleasure factor was used for classifying participants according to taste attitudes. This was done based on face validity, these two factors were considered most relevant for this study by the researchers. It was decided that the factors which were left out would not be useful in the context of gluten-free bread. For example, natural product interest has an item referring to organically grown vegetables and light product interest has two items which deal with cholesterol – both are not useful for relating the health and taste attitudes of participants to gluten-free bread. Sabbe *et al.* (2009) did something similar by using only the general health interest items in a study. The study aimed to focus only on the health-related attitudes and beliefs in determining the effect of health claims and food neophobia on the acceptance of fruit juices with different concentrations of acai by Belgian consumers. Cox, Melo, Zabaras and Delahunty (2012) also used only three of the six factors (general health interest, pleasure and using food as a reward) to determine the effect of taste, information and attitudes on the acceptance of Brassica vegetables amongst Australian consumers.

Compared to white and seeded bread, brown bread was the most consumed amongst the participants. Brown wheat bread is amongst the most purchased and consumed products in South Africa (Labadarios *et al.*, 2005). It is also cheaper compared to white and seeded bread types due to the inclusion of value added tax on the price of white bread (Mncube, 2014) and probably seeded bread too. This is likely to be one of the reasons why brown bread is the most consumed.

Information had a negative impact of the acceptability of the smell of the gluten-free bread. This may have been because the wheat bread label as well as the appearance of the wheat bread were more familiar to the participants than that of the gluten-free samples. Some studies have shown that the sensory properties of familiar grain products are more preferred than the unfamiliar alternative (Vázquez-Araújo *et al.*, 2012; Cayres *et al.*, 2020). Also, smelling an aroma prepares one's body for ingestion, it is also important in the anticipation phase of eating (Boesveldt & de Graaf, 2017). Therefore, the unfamiliar smell of the gluten-free samples may have been undesirable to the consumers considering that they could anticipate the taste based on the aroma. Information did not however have a significant impact on the acceptability of the appearance, taste and texture of any of the samples. Participants were therefore consistent in their perception of the taste of the bread samples regardless of whether it was gluten-free or wheat bread in informed conditions. This supports the notion that many consumers often consume food for taste rather than the perceived health benefits (Sabbe *et al.*, 2009), considering that most of the participants in this study thought that gluten-free bread is healthier than gluten-containing bread.

The participants had a clear preference for the sensory properties of the control sample in both informed and uninformed conditions. However, amongst the gluten-free bread, participants seemed to prefer the smell of GFA compared to GFB. The smell of the brown GFA sample was described to have a toasted and coffee aroma by the descriptive panel (research chapter 4.1), this may have been drivers of liking. Participants also preferred the texture of GFB compared to that of GFA regardless of information. The texture of the brown GFB sample was more similar to the control wheat bread in terms of elasticity compared to GFA according to the descriptive sensory panel (research chapter 4.1).

The effect of the interaction between health and taste attitude and samples was only significant for the appearance and taste sensory attributes. However, differences in acceptance (although not significant) of the gluten-free samples amongst the four health and taste attitude groups are discussed:

Information affected the participants with a high health and high taste attitude (HTHH) differently compared to the other groups. Their liking of the smell of the gluten-free samples was negatively affected by information. The smell of GFB in particular was frequently described to have an "off-smell" by this group. This means that despite their high health attitude, their high taste attitude may not have allowed them to tolerate the unfamiliar smell of the GFB sample. This group also liked the taste of GFA more than the other groups. The brown GFA sample was described to have a toasted and sweet coffee flavour by the descriptive panel

(Research chapter 4.1). This may be what this group may have liked about it. Bernstein and Rose (2015) also found that a large number of consumers (From Lincoln, USA), in a study of the preference of commercial whole wheat breads, liked breads that are sweet.

Participants with a high taste and low health attitude (HTLH) had a higher preference for the taste of the control sample compared to the other groups. The words “normal” and “soft” were the most frequent comments on reasons for liking. Familiarity seemed to be important for this group. Consumers tend to dislike products they are not familiar with (Gosine & McSweeney, 2019). This group was also negatively influenced by information when it came to the liking of the smell of GFB. GFB was described by the descriptive sensory panel to have the most intense nutty flavour (chapter 4.1), which is a driver of disliking in bread made with non-wheat alternative grains (Gosine & McSweeney, 2019). GFB was overall the least liked sample in terms of smell and taste by all groups in both informed and uninformed conditions. This group (HTLH) might have preferred the more familiar control bread considering that taste is important to them. They may also have associated gluten-free bread with having unacceptable sensory properties and were therefore probably unwilling to compromise taste when a “healthy” gluten-free alternative was presented (Sabbe *et al.*, 2009).

Although most of the comments for GFB from all groups were negative, some participants from the low taste, high health (LTHH) group described GFB as “nice”, “regular” and “impressive.” Also, participants frequently described GFB as being “healthy”. This may imply that these participants are indeed concerned with their health. However, despite their high health attitude, this group still showed higher liking for the sensory properties of wheat bread compared to both the gluten-free samples. This may have been because drivers of liking are mostly defined by the sensory properties of a product, followed by the health aspects (Vázquez-Araújo *et al.*, 2012). However, this group may be more willing to compromise the familiar and more desirable sensory properties of wheat bread for gluten-free bread compared to other groups. This is likely due to their perception that gluten-free bread is healthier than wheat bread, which is also an important factor for choice.

Information had a negative effect on the liking of the smell of both gluten-free samples by the low taste, low health group. Some of the frequent comments on GFB by this group were “appealing”, “easy to chew” and “normal.” These comments were rather positive compared to other groups. This shows that some participants from this group were not interested in the taste of the gluten-free bread, neither were they averse towards it.

General perceptions participants had on gluten-free bread:

The participants were of the view that gluten-free bread was more of a speciality bread meant for people with allergies, for weight loss purposes and for enhancing one's health. This agrees with Dunn *et al.* (2014) who found that students from the University of Florida (USA) may have unfounded perceptions about health benefits and potential positive impact a gluten-free diet has on one's health. Participants of this study were also under the impression that gluten-free bread is natural, organic and less processed compared to wheat bread. This shows that the participants seem to believe that gluten is an unnatural or man-made ingredient added to bread (Chambers & Castro, 2018). This shows a need for more consumer education when it comes to gluten and this need was also highlighted by Vázquez-Araújo *et al.* (2012). The participants however viewed wheat bread to be more acceptable and accessible to them. Participants also showed that they are not quite aware of the origins of the crops used to produce gluten-free and wheat bread. Of the few participants who selected the "made with flour from sustainable crops" option, most of them associated this statement with wheat bread. In the current context of South Africa, wheat cannot be considered sustainable because it needs to be imported. Therefore, consumers need more education in this regard, they also need to be made more aware of what gluten is, its purpose in bread and its effect on human health.

4.2.4.6 Limitations of the study

Although careful consideration was taken to ensure that the analyses were conducted using scientific methods and principles, a few limitations have been acknowledged.

The classification of consumers into the different health and taste attitude groups was based on a single tool, i.e., the health and taste attitudes scales. This is limiting because there may be other health and taste factors which consumers consider (in the South African context) which may not have been part of the health and taste attitudes scales which were used. Also, the unequal number of negatively worded (2) and positively worded (3) items on the pleasure scale after the deletion of item 5 (negatively worded) may have compromised bias response balance (Sauro & Lewis, 2011).

The bread samples evaluated did not represent the full slice or loaf that would be purchased in store. The participants only evaluated a disk-shaped portion of the crumb of the bread and not the full slice which includes the crust. The area/ size differences of the slices would have been a driver of liking or disliking in terms appearance. The crusts were also excluded, a factor that will always be considered by consumers, possibly in terms of appearance, flavour and texture.

4.2.4.7 Conclusions

In this work, millennial consumers' acceptance of the sensory properties of gluten-free bread as influenced by their health and taste attitudes towards food was determined. The effect of the participants' health and taste attitudes on the acceptability of the sensory properties of gluten-free bread was not significant. Knowing the gluten-free status of the gluten-free samples had a negative effect on the acceptability of the smell of the samples. The effect of the interaction between health and taste attitudes and information on the acceptability of the sensory properties of gluten-free/wheat brown bread was not significant.

Participants had the general perception that gluten-free bread provides overall health benefits and it is more natural and organic than wheat bread. Gluten-free bread was also indicated to be bitter and less tasty than wheat bread. Participants thought that wheat bread was more accessible, tasty, convenient and affordable than gluten-free bread. Consumer education on crops used and those which could potentially be used for breadmaking is needed amongst consumers. More participants believed that wheat bread is made from sustainable crops, which is not the case in the context of South Africa.

5.0 GENERAL DISCUSSION

This chapter is an overview of the overall findings as well as a critique of the project design and materials and methods used in this study. The appropriateness of the methods is discussed, the shortfalls and advantages are also highlighted. The chapter ends with concluding remarks which highlight the overall knowledge contributions of this study.

5.1 Overview of main findings

Table 5.1 summarises the physical and descriptive sensory characterisation results of the commercial bread samples. The samples (control, GFA and GFB) had different characteristics across all bread types (white, brown and seeded). The results show that the gluten-free bread samples were firmer, crumblier and drier than their corresponding wheat bread controls. The gluten-free bread samples also had lower resilience and had a lower cell quantity than their wheat control counterparts. These different characteristics between gluten-free bread and wheat bread are part of the reason why the sensory properties of gluten-free bread are not as appreciated as those of wheat bread. These differences are mainly due to the absence of gluten in the gluten-free samples. Developing gluten-free bread with sensory properties that are more similar to that of wheat bread is challenging (Naqash *et al.*, 2017). However, consumers are likely to be more accepting of gluten-free bread that has similar sensory properties to wheat bread. As discussed in chapter 4, previous studies have demonstrated that the sensory properties of familiar grain products (e.g., bread) are more preferred by consumers than the unfamiliar alternatives (Vázquez-Araújo *et al.*, 2012; Cayres *et al.*, 2020).

Figure 5.1 outlines the findings from the acceptability of the sensory properties of commercial gluten-free brown bread as affected by the health and taste attitudes of the participants and by knowing the gluten-free or wheat bread status of the sample. Interestingly, health and taste attitudes did not have a significant impact on the acceptability of the sensory properties of the samples. The interaction of health and taste attitude group and samples was significant for the acceptance of the appearance and taste of the bread. Knowing the gluten-free or wheat status of the bread only had a significant impact on the acceptability of the smell of the samples. As predicted, the familiarity of the sensory properties of the brown wheat bread were an important driver of liking for the consumers. Therefore, despite the fact that the participants are of the view that gluten-free brown bread provides health benefits, its sensory properties were not as acceptable as those of wheat brown bread.

Table 5.3: Summary of findings on the physical and descriptive sensory characterisation of white, brown and seeded commercial gluten-free samples

Analyses	Parameter	White bread samples			Brown bread samples			Seeded bread samples		
		Control	GFA	GFB	Control	GFA	GFB	Control	GFA	GFB
Texture	Firmness (N)	0.7[c]	4.1[b]	5.6[a]	0.7[b]	3.7[a]	3.9[a]	4.6[a]	5.2[a]	5.1[a]
	Adhesive force (mN)	-29.1[ab]	-11.2[a]	-40.3[b]	-31.3[a]	-10.3[b]	-14.8[b]	-69.5[b]	-13.1[a]	-22.8[a]
	Resilience (%)	96.3[a]	88.8[b]	83.4[c]	96.5[a]	92.8[b]	86.0[c]	86.9[a]	86.5[a]	85.2[a]
Colour	L*	77.0[a]	74.3[b]	67.7[c]	67.9[a]	53.6[c]	63.3[b]	51.9[b]	53.2[b]	61.4[a]
	a*	-0.4[b]	0.2[c]	-0.9[a]	2.9[b]	7.2[a]	0.4[c]	3.5[b]	7.2[a]	0.7[c]
	b*	10.7[c]	11.4[b]	14.5[a]	14.9[c]	25.7[a]	17.8[b]	15.8[c]	25.6[a]	17.6[b]
	C*	10.7[c]	11.4[b]	14.5[a]	15.2[c]	26.7[a]	17.9[b]	16.2[c]	26.6[a]	17.6[b]
Image analysis	Cell quantity	202[a]	47[b]	96[ab]	310[a]	82[b]	71[b]	185[a]	86[b]	127[ab]
	Cell area (cm^2)	0.004[a]	0.002[a]	0.004[a]	0.006[a]	0.002[b]	0.006[a]	0.007[a]	0.003[a]	0.008[a]
	Cell density (cells/cm^2)	5.13[a]	1.20[b]	2.43[ab]	7.88[a]	2.08[b]	1.81[b]	4.71[a]	2.18[b]	3.24[ab]
	Cell diameter (cm)	0.07[a]	0.06[a]	0.07[a]	0.09[a]	0.05[b]	0.09[a]	0.09[ab]	0.06[b]	0.10[a]
Density (g/cm^3)		0.30[b]	0.27[c]	0.34[a]	0.30[b]	0.26[b]	0.37[a]	0.45[a]	0.33[b]	0.42[a]
Specific volume (cm^3/g)		3.39[b]	3.77[a]	2.92[c]	3.41[a]	3.89[a]	2.70[b]	2.26[b]	3.08[a]	2.42[b]
Descriptive sensory	Appearance	GFB had the largest pores and lowest pore quantity			GFA had the lowest appearance of specks. GFB had the largest pores and lowest pore quantity			GFA had the highest pore quantity and lowest appearance of seeds and specks		
	Aroma	GFA was most intense in sweet aroma			GFA was the most intense in sweet and toasted aromas			GFA was the most intense in sweet and toasted aromas		
	Texture	GFB had the firmest, driest and crumbliest texture			GFB had the crumbliest texture			GFA had the driest texture. GFB was the crumbliest and least elastic		
	Flavour	GFB and GFA had the most intense toasted and coffee flavours			GFA had the most intense toasted and coffee flavour. GFB had a nutty flavour			GFA had the most intense toasted and coffee flavours. GFB had the most intense nutty flavour		
	Mouthfeel	GFB was the most grainy and dry			GFB was the grainiest and most seedy			GFA was the driest and least seedy		
	Aftertaste	GFA had the most intense sweet aftertaste			GFA had the most intense toasted aftertaste			GFA had the most intense yeasty and toasted aftertaste		

[abc] For each bread type (white, brown and seeded bread samples), mean values in a row that do not share a letter are significantly different ($p < 0.05$)

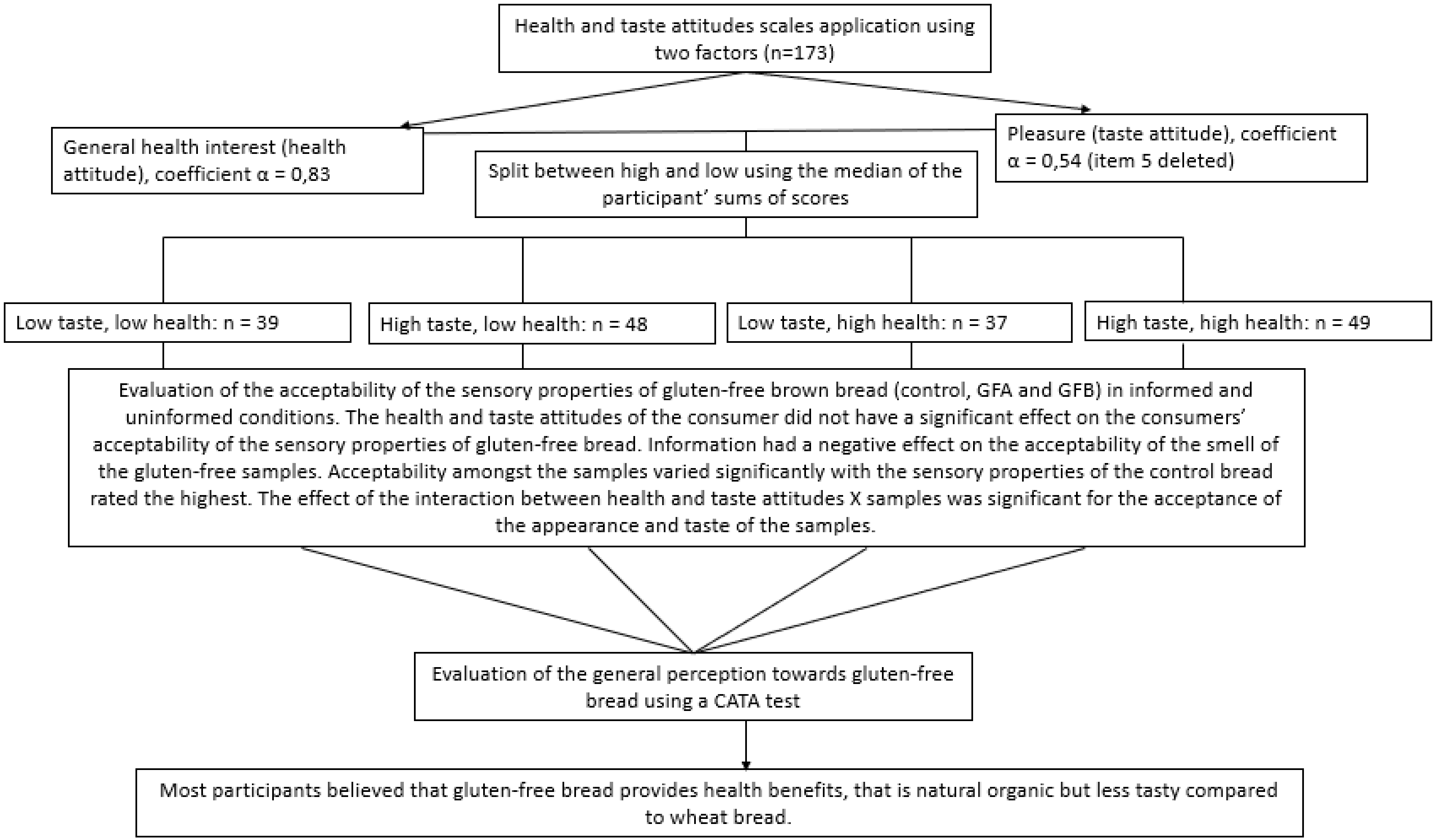


Figure 5.3: Summary of the study of the acceptability of the sensory properties of commercial gluten-free brown bread according to the health and taste attitudes of the participants in informed and uninformed conditions. Where GFA = gluten-free A and GFB = gluten-free B.

5.2 Review of methodology applied

Here, methods which were used to produce and analyse the results in this study are discussed and critiqued.

5.2.1 Texture profile analysis

The measurement of the texture of bread is often done using a combination of parameters, by an instrument, in an effort to determine the quality during dough formation, proofing and storage effects (GåMbaro *et al.*, 2002). These parameters include: hardness (N), brittleness (N), cohesiveness, adhesiveness (J), gumminess (N), chewiness (J), elasticity (m) and stringiness (m) (Trinh & Glasgow, 2012) and together, they provide information on the mastication properties of a solid/ semi-solid product like bread or cheese. In this research only hardness, adhesive force, elasticity and resilience were determined. The brittleness of the gluten-free bread samples is probably the extent of irreversible structural collapse (Ahlborn, Pike, Hendrix, Hess & Huber, 2005), the more brittle the bread is, the more stale it may be to the consumer (Rozylo, Dziki, Gawlik-Dziki, Cacak-Pietrzak, Mis & Rudy, 2015). Determining brittleness by instrument might have been useful to consistently measure the crumbliness of the gluten-free samples, which was only measured by the descriptive sensory panel. However, several studies demonstrated that the brittleness of bread can be reflected by other parameters such as low cohesiveness, crumb hardness and low elasticity (Moore, Schober, Dockery & Arendt, 2004; McCarthy, Gallagher, Gormley, Schober & Arendt, 2005; Matos & Rosell, 2012).

5.2.2 Colour

The colour of bread is important as it contributes to the quality and it contributes to consumer preference (Zanoni, Peri & Bruno, 1995). The colour of the crumb and crust reflect the efficacy and consistency of the baking process (e.g. Maillard reactions). Colour can also be used to predict other bread characteristics such as the effects of the various added ingredients e.g. fibre. In this research, the L* a* b* and C* colour systems were used to determine the colour of the bread samples. There are other colour parameters such as the total colour difference (ΔE*), which indicates the difference between the initial and final colour of a food item after storage or treatment (Pathare *et al.*, 2013). However, due to the samples having been commercial bread and therefore not baked by the researcher, the difference in colour before and after baking could not be determined. The effect of storage was also not an objective of this study and was therefore not determined.

Furthermore, in real-life, bread is consumed in full slices. The panellists and consumers only evaluated a disk-shaped portion of the crumb of the bread and not the full slice which includes the crust. The crust colour differences of the slices may have been a major factor in describing the bread. The crust colour may have also had an effect on the acceptance of the appearance, smell and flavour and texture of the bread samples.

5.2.3 Image analysis

Image analysis, with image analysis software, allows one to study the crumb structure of bread. This is useful as the crumb structure affects the perceived texture and appearance of the bread. This crumb structure can be reflected through parameters such as cell quantity, cell density, cell diameter, cell area and circularity (Scheuer *et al.*, 2015). For image analysis software to effectively process an image, the image needs to undergo thresholding. This is a process where an image is processed into a binary format. The default thresholding option was used for bread images using the ImageJ image analysis software. This method is effective in approximating the different properties of bread. However, it was later learnt that using the Otsu's thresholding method could have provided a more reliable representation of the crumb structure of bread. Unlike the default algorithm, Otsu's thresholding method is an adaptive method for converting an image to a binary image, it measures pixels that occur both in the foreground or background (Scheuer *et al.*, 2015).

5.2.4 Density and specific volume

The volume of a bread loaf is a measurable quality parameter. Volume is useful in indicating the extent of aeration, gas retention, effectiveness of processing conditions and texture of the crumb. One of the most common methods used by researchers to determine volume is rapeseed displacement (Keskin, Sumnu & Sahin, 2004; Gómez, Oliete, Pando, Ronda & Caballero, 2008; Siddiq, Nasir, Ravi, Butt, Dolan & Harte, 2009; Ahmad, Butt, Ahmed, Riaz, Sabir, Farooq & Rehman, 2014). This is where the bread loaf displaces the volume of seeds to the extent or equivalence of its own volume (Sahi, Little & Ananingsih, 2006). The rapeseed displacement method was not used in this research because the samples were sliced, ready to eat commercial bread products. There was therefore no baseline dough for determining and comparing the extent of aeration or quality of ingredients used for example. The volume of all of the samples was determined by multiplying the length, width and height of a square piece of the bread extracted from the crumb. The extracted piece was weighed in order to determine density (g/cm^3). Although this method has not been widely used for bread, it was successfully employed by Feili *et al.* (2013) who determined the volume of high fibre bread incorporated with jackfruit rind flour.

5.2.5 Descriptive sensory evaluation

Descriptive sensory evaluation is a sensory profiling method where trained human subjects objectively quantify the qualitative aspects (appearance, aroma, flavour, texture and aftertaste) of a food product (Lawless & Heymann, 2010a). The terms used to judge the products are developed and agreed upon prior the evaluation by the panellists during the training process (Murray *et al.*, 2001). This was a useful tool in this research which gave guidance in interpreting results obtained from the physical analyses and acceptance tests. There are however some questionable aspects about descriptive sensory evaluation which were reviewed by Murray *et al.* (2001). One of them are that humans tend to be limited in their capacity to distinguish between complex aroma, flavour or colour profiles – often only one layer (out of many) of the sensory characteristic is detected, thereby giving a narrow or limited representation of the product's sensory profile. This could have been mitigated by incorporating methods such as temporal dominance of sensations (Pineau, Schlich, Cordelle, Mathonnière, Issanchou, Imbert, Rogeaux, Etiévant & Köster, 2009) or the temporal check-all-that-apply sensory method (Makame, Cronje, Emmambux & De Kock, 2019) which could have revealed the various sensory attributes perceived in succession or simultaneously during the course of tasting. The panellists however had reference samples for each descriptive term which were also available to them during the evaluation. This assisted in ensuring that the attributes that were evaluated were at least judged in a balanced and consistent manner.

5.2.6 Health and taste attitudes questionnaire

The health and taste attitudes questionnaire was developed and validated by Roininen *et al.* (1999) with the aim of determining the health and taste aspects affecting food choice. They came up with three health related factors and three taste related factors. The health and taste attitude scale has been shown to be useful in characterising and segmenting people according to their health and taste attitudes and also for predicting food choice (Roininen *et al.*, 2001; Zandstra *et al.*, 2001; Grubor *et al.*, 2015). The pleasure factor has however been criticised for having low reliability (Roininen *et al.*, 2001; Saba *et al.*, 2019), it also presented the lowest reliability (coefficient alpha) in this study. However, deleting item 5 (*I finish my meal even when I do not like the taste of food*) from the pleasure factor increased its coefficient alpha value, thereby increasing its reliability. Chen (2013) also deleted item 5 of the pleasure scale for the sake of improving its reliability. Furthermore, in the same way that Sabbe *et al.* (2009)

only included the general health interest factor in their study of the effect of health claims on the acceptance of fruit juices. The pleasure factor was also found to be the most relevant for segmenting the participants according to their taste attitudes, especially pertaining to gluten-free bread.

The health and taste attitudes questionnaire was developed over 20 years ago and the statements were based on responses from Finnish consumers aged 18 to 81 years. This may have been a limitation for this study considering the different contexts. Health and taste attitudes may have shifted between 1999 and now (2020). Emerging factors such as the shift towards plant-based diets (which are increasingly becoming popular) may have an effect on the health and taste attitudes of millennials in 2020. Motivating factors for adopting a plant-based diet include: improved health, sustainable eating habits, concerns about animal cruelty, positive taste experiences and perceived convenience (Graça, Godinho & Truninger, 2019). The perceived cost of a healthy diet by consumers in South Africa may also play a role in defining their health and taste attitudes. According to Temple and Steyn (2011), most South Africans gravitate to unhealthy food choices because of the apparent high cost and inaccessibility of healthier food. The age range of the consumers in this study was also smaller (millennials; born between 1980 and 2000) compared to the age range used in the study by Roininen *et al.* (1999) (18 to 81 years). Furthermore, the geographical difference should also be considered (Finland vs. South Africa). The health and taste attitudes of South Africans may not necessarily be defined by the same statements used in the health and taste attitudes questionnaire by Roininen *et al.* (1999). Therefore, a more country specific questionnaire may need to be developed and validated for future studies.

5.2.7 Acceptability of the sensory properties of gluten-free bread

Acceptability testing involves evaluating if consumers like or dislike a product or find it more acceptable than another product based on its sensory properties (Lawless & Heymann, 2010a). One of the most widely used scales for evaluation is the 9-point hedonic scale which ranges from 1(dislike extremely) to 9 (like extremely) (Wichchukit & O'Mahony, 2015). However, in this study, a 5-point hedonic scale was used. The 5-point scale has been described to be more appropriate for children than adult consumers due to its simplicity (Homann, Ayieko, Konyole & Roos, 2017). The 5-point hedonic scale also has relatively little room for participants to express the full range of their hedonic perception (Lim, 2011). This could misrepresent the consumer’s real perception of the sensory of the products being evaluated, whereas with a longer scale, participants would have been able to discriminate between the samples more clearly. Be that as it may, the 5-point hedonic scale may have been appropriate for this study in that it was simple and easy to understand for consumers, especially since most of them had no experience with sensory evaluation. A user-friendly test is important as it simplifies the consumer's task of evaluating, rating and providing comments on the product (Milde, Ramallo & Puppo, 2012).

The consumers were asked to rate the acceptability of the appearance, smell, taste and texture of the bread samples; however, overall liking was not determined. Exclusion of the overall liking question may not have been much of a disadvantage because consumers pay most attention to the taste and least attention to the odour of a product when considering overall liking (Andersen, Brockhoff & Hyldig, 2018), both of which were included in the evaluation. Furthermore, in an effort to promote test completion with minimal fatigue, the test duration was made as short as possible. As described in chapter 4, the three bread samples were served simultaneously during the uninformed (3-digit code labelling) and informed (3-digit code with gluten-free/wheat bread label) evaluations. This may have been risky as it relied on the consumer to match the correct sample to the corresponding three-digit code presented on the questionnaire (Lawless & Heymann, 2010a) (e.g. mistakenly evaluation sample 123 when the question is pertaining to sample 321). Therefore, it may have been less risky to serve the samples monadically. However, all samples were clearly marked and none of the 173 participants indicated any form of confusion during the evaluation.

5.2.8 Check-all-that-apply evaluation

Check-all-that-apply (CATA) evaluations have been described as a simpler way to determine factors such as preconceived perceptions about a product and its sensory drivers of liking and disliking, as compared to open-ended questions which need to be coded (Schonlau, Gweon & Wenemark, 2019). Another advantage of a CATA evaluation is that it can provide more holistic perceptions consumers have of a product compared to a 5, 7 or 9 point hedonic scale (Meyners & Castura, 2014). For instance, instead of just including sensory attributes, one can include purchase intention, emotional and general perception statements. In this study, CATA was used to determine the general perceptions consumers have towards gluten-free bread and wheat bread. Bechoff, Chijioke, Westby and Tomlins (2018) applied a CATA test to determine 123 Nigerian consumers' general feelings of biofortified cassava products (fufu and eba). They found that the consumers perceived some of the biofortified cassava samples to, amongst other things, be good for children's health and good for eyesight. However, not all of the biofortified (and hence yellow in colour) products were associated with higher nutrition and health. This revealed to the researchers that the consumers required more education. In the same light, the CATA test results from this study showed that consumers have unsubstantiated beliefs about supposed health benefits one can obtain from consuming gluten-free bread. This showed that consumers need more education on what gluten-free means and entails. This goes to show how effective a CATA test can be when applied to measure general perception and not only sensory perception, with regards to the different type of information it can provide.

5.2.9 Statistical analysis

Roininen *et al.* (1999) used the 33rd and 66th percentiles as cut-off points for dividing the scores obtained in their application of the health and taste attitude scale on 1005 Finnish adults. The consumers were hence segmented into low, moderate and high groups according to their health and taste attitudes. This segmentation method may be beneficial in that it provided a clear distinction between consumers who have a high health/taste attitude and those with a low health/taste attitude. In this work, the 50th percentile was used to segment the participants between high and low. Those who may have had a moderate health/taste attitude were included in either the high or low group, depending on the relation of the score to the median. This may have therefore blurred the distinction between high and low health and taste attitude groups. The effect of the health and taste attitude group may have been significant if the "moderate" participants were excluded in the analysis. However, due to the limited number of participants, all data responses had to be considered. Further motivation to use the 50th percentile was the work done by Chen (2013) and Sabbe *et al.* (2009) who effectively segmented consumers into high and low health and/or taste attitude groups.

Roininen *et al.* (2001) determined both Tarkkonen's rho coefficient (ρ) and Cronbach's alpha coefficient (α) to measure the reliability of the six health and taste attitude factors. It was found that Tarkkonen's coefficient values were more appropriate due to the multidimensional structure of the health and taste attitudes measurement, compared to the Cronbach's alpha measurement which assumes one-dimensionality (Roininen *et al.*, 2001; Vehkalahti, Puntanen & Tarkkonen, 2006). However, the procedure of removing items with low reliability assists in maximising the reliability of a scale (Vehkalahti *et al.*, 2006). It is for this reason that item 5 (*I finish my meal even when I do not like the taste of food*) of the pleasure scale was not considered for segmenting the 173 consumers according to their health and taste attitudes.

5.3 Concluding remarks

Here, the gaps in the knowledge which were filled by this study are highlighted.

This study provided information on the physical and sensory properties of the two main commercial gluten-free pan breads currently available in South Africa, and how they compare to commercial wheat bread. Knowledge on the health and taste attitudes of a selected group of millennial consumers, as evaluated by the health and taste attitudes questionnaire by Roininen *et al.* (1999), was produced. Not only was the acceptability of the sensory properties of commercial gluten-free brown bread amongst millennial consumers determined, the effect of health and taste attitudes of consumers on the acceptance was established. This study also provided knowledge on the drivers of liking and disliking of gluten-free bread and whether knowing the gluten-free status of gluten-free brown had an effect on its acceptability. Lastly, this study revealed the general perceptions consumers have of gluten-free bread compared to wheat bread.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The physical and sensory characterisation revealed that the commercial gluten-free bread types were indeed drier, crumblier and harder/firmer than their wheat control counterparts, as hypothesised.

Millennial consumers' acceptability of the sensory properties of brown gluten-free bread as affected by health and taste attitudes was determined. The four health and taste attitude groups (high health, high taste; high health, low taste; low health, low taste and low health, high taste) did not differ in their assessment of the acceptability of the sensory properties of gluten-free brown bread. The sensory properties of the control wheat bread were most preferred regardless of the health and taste attitudes of the millennials participating in the study. The finding was probably owing to the notion that sensory appeal trumps perceived health benefits when it comes to food choice and consumption. Familiarity with the control sample may have also played a large role in acceptance judgements. Furthermore, information that a sample was gluten-free had a negative effect on the acceptability of the smell of the sample.

Interestingly, the consumers had the general perception that gluten-free bread provides health benefits and that it is more natural and organic than wheat bread. The consumers also thought that wheat bread was more accessible, tasty, convenient and affordable than gluten-free bread. More consumers believed that wheat bread is made from sustainable crops, which is not the case in the context of South Africa, hence the need for more consumer education.

The health and taste attitudes questionnaire is a useful tool for segmenting consumers according to health and taste attitudes. However, some of its statements (e.g., those pertaining to cholesterol) may be outdated for modern day application. Health and taste attitudes are probably defined by different statements, especially in the African context. A recommendation for further studies would therefore be to update the questionnaire by re-creating and validating the statements to suit the African consumer. Another recommendation for future acceptance tests relating to gluten-free bread would be to also determine purchase intention and/or willingness to pay as price is also a very important factor affecting food choice. Determining the acceptance of the full loaves or full slices as available commercially would also be useful in providing a more holistic view of the acceptance of gluten-free bread. It would also be interesting to conduct the study on a wider and more inclusive demographic e.g., more people who identify as male, more people from older and younger age groups and people with various income brackets. This would bring insight into factors affecting health and taste attitudes as well as the acceptance of gluten-free bread.

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