Sensory and consumer evaluation of commercially available gluten-free crackers

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Abstract

Celiac disease is an autoimmune disorder that causes inflammation and damage to the small intestine upon ingestion of gluten. The only effective solution for patients with celiac disease is a lifelong adherence to the complete avoidance of gluten. Gluten is a very important protein responsible for the appearance, flavor, and texture of various baked and non-baked goods. Therefore, the growing demand for gluten-free foods has prompted the food industry to develop products with better sensory properties and consumer acceptability. Crackers are important snack foods that are widely consumed and sometimes serve as an addendum to meals. Gluten-free crackers have not been studied extensively for their sensory characteristics. Therefore, this study was designed to explore sensory characteristics and consumer acceptability of gluten-free crackers. The specific objectives of this study were to 1) use an untrained consumer panel to evaluate commercially available gluten-free crackers using projective mapping for classification and development of consumer terminology using modified flash profiling. 2) to develop a lexicon using a highly trained panel to more analytically describe and characterize the specific sensory characteristics of gluten-free crackers and 3) to investigate consumer liking of gluten-free crackers with different sensory profiles. Sixteen commercial gluten-free crackers with different grain sources were initially selected. These were narrowed down to ten samples using projective mapping for further exploration. Modified flash profiling helped to characterize the different samples using extensive language, which was consumer-friendly, detailed, marketing-friendly, and easy to understand. Brown rice crackers (MAGOGF, SESGF) were described by brown rice, cardboard, and flaxseed. Their texture was described with hardness, crispiness, and grittiness. White rice (LANCGF, GLUTGF, KAMGF), tapioca/potato starch formulation (ABSOGF), and millet blend (SCHAGF) crackers were

described mostly with sweet, butter and oily. Cassava flour (CRUNGF) and nut flour blend (SIMIGF) were characterized by herb, salty and savory. These samples were also evaluated by five highly trained descriptive panelists. The descriptive panel generated 43 different aroma, appearance, texture, and flavor attributes. Some of these attributes were common for all crackers such as presence/absence of holes, thickness appearance, roughness appearance, shiny, thickness, hardness, fracturability, gritty, dryness/moisture absorbency, toothstick/toothpack, astringent while some attributes were unique to certain crackers such as dairy for LANCGF, coconut for CRUNGF, seaweed and soy sauce for MAGOGF, and black pepper for SESGF. All the gluten-free crackers had high flavor intensities. This information helps understand the sensory properties of gluten-free crackers and uncover the white spaces in the market. Both the descriptive panel and consumer panel were able to achieve a clear differentiation of the samples. A central location consumer test was performed using untrained panelists who were frequent consumers of gluten-free products. Only one among the ten products evaluated received an overall mean liking of 7.0, or “like moderately”, on a 9-point hedonic scale, whereas four crackers received a mean liking score of 6.0 indicating that they were liked slightly. These results showed a huge opportunity for improvement in consumer perception of the sensory qualities of gluten-free crackers. Further research can focus on incorporating a greater number of gluten-free samples and studying the effect of different ingredients in a controlled setting on the sensory properties of gluten-free crackers.

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Chapter 1 - Literature Review

Abstract

Gluten is a complex protein found in various grains like wheat, rye, and barley, and plays an important role in the development of a wide range of food products. One of its primary functions is to impart viscoelasticity to the dough, enabling it to expand and trap gases produced during fermentation. This gas retention is responsible for the volume, texture, and leavening of foods, making gluten an essential ingredient for baking.

Celiac disease is an autoimmune disorder that causes inflammation and damage to the small intestine when gluten is consumed. Adherence to a gluten-free diet is the only treatment for celiac patients. Also, there has been a growing consumer trend toward adopting gluten-free diets, often driven by the perception that they are healthier.

However, the removal of gluten from food products presents several significant challenges. First, it affects the sensory characteristics of baked products. Gluten contributes to the color, texture, and overall mouthfeel of many foods, and its absence can lead to alterations in these sensory attributes. The result is that gluten-free products differ in flavor, appearance, and texture from their gluten-containing counterparts. Another challenge lies in the nutritional aspect of gluten-free products. These products often have a higher glycemic index and lower fiber content, giving them a poor nutritional profile.

Crackers are popular snack foods present in the market. Crackers are easy, convenient, and inexpensive. They are traditionally manufactured with soft wheat flour. However, the production of gluten-free crackers uses potato flour, rice flour, cassava flour, and corn flour among others. Gluten-free crackers have not been studied extensively for their sensory properties. It is therefore important to understand the commercial gluten-free crackers in the US

market and develop a lexicon for their sensory attributes, understand their consumer acceptability, and uncover white spaces in the market.

Gluten

Gluten, a protein found in grains like wheat, barley, triticale, and rye, primarily consists of two proteins: glutenin and gliadin. Gliadin contributes to viscosity, while glutenin imparts elasticity. These two components play a crucial role in giving gluten-based products their distinctive characteristics, including the viscoelasticity of dough and leavening properties. The ability to create this viscoelastic network by trapping carbon dioxide is one of gluten's defining features, and its water-holding capacity extends the shelf life and yield of various baked goods Therefore, these remarkable properties of gluten, such as water retention, thermosetting, and viscoelasticity, are pivotal in shaping the structure and texture of a wide range of food products, including baked goods like bread, pastries, and crackers. Gluten's applications go beyond baked goods, encompassing cereals, meat products, pet food, and animal feed, offering enticing opportunities for food developers and scientists to create innovative food products (Day, 2011).

However, the very properties that make gluten an attractive ingredient also present a significant challenge when developing gluten-free products. Gluten-free flours lack the protein responsible for the viscoelastic network formed by glutenin and gliadin components. This absence significantly impacts water absorption capacity, moisture retention, and product elasticity, making it challenging to create gluten-free products with acceptable textural attributes. Consequently, gluten-free products often exhibit poor color, crumb texture, and reduced volume due to the absence of gluten network, which typically traps gases released during baking. The visual appeal of gluten-free products is also affected, as the crumb tends to be less yellow, and crust darkening is more pronounced in the absence of gluten (Gallagher et al., 2003).

For a product to be labeled "gluten-free," it must contain no gluten or contain gluten levels lower than 20 parts per million (ppm) (Xu et al., 2020). The endeavor to create products without gluten thus presents a formidable challenge in terms of formulation and sensory attributes. Recent years have witnessed numerous developments in the production of gluten-free baked and non-baked goods. However, these products continue to diverge from their gluten-containing counterparts in various aspects, including texture due to the absence of the gluten network, nutritional quality, mouthfeel, and crumb color (Gallagher et al., 2004). Consequently, there is considerable interest in further advancing this category of gluten-free products to meet consumer expectations and dietary needs. Consumer and sensory expert feedback are important in assessing the products in the market.

Celiac Disease

Celiac disease is an auto-immune disease that arises because of inflammation of the small intestine due to gluten and individuals with celiac disease patients experience pain and inflammation of the small intestine upon consumption of gluten. Gluten protein is difficult to digest because of its high glutamine and proline content. Enzymes can only degrade it incompletely. The proline fraction of prolamins is resistant to proteolysis and is not broken by the gastric and pancreatic enzymes (Stantiall & Serventi, 2018). This inflammation of the small intestine is caused by antibodies fighting against glutamine in the small intestine. This results in the formation of peptides that contain immunogenic epitopes. These immunogenic receptors in turn force an immune response which leads to severe symptoms on ingestion such as bloating, weight loss, diarrhea, and anemia. Along with the digestive properties, intestinal permeability is also another factor that causes celiac disease.

Celiac disease can emerge at any age, but it mostly appears during adolescence and adulthood (Gambuś et al., 2009). About 2 million people are affected by celiac disease in the US (*Celiac Disease*, n.d.). The only treatment for celiac disease patients is to adhere to a diet with total avoidance of gluten (Nemteanu et al., 2022). Celiac patients are, however, not the only consumers of gluten-free products. These products are also consumed by the family members of the celiac patients, those with gluten sensitivity, those having the perception of following this diet having positive benefits on conditions like autism, and in response to the trendy gluten-free lifestyle promoted by celebrities (Xhakollari et al., 2019). This has led to the development of gluten-free products as niche products with higher prices.

Gluten-Free Trends

The retail value of sales of gluten-free hit $ 3.3 billion in 2015 and it is proposed that this dynamism is still going to rise and expand its range into breakfast cereals and other options as well (Baroke, 2016). The gluten-free industry is expected to grow from USD 6.45 billion in 2022 to USD 7.07 billion in 2023 (*Gluten-Free Products Market Size And Share Report, 2030*, n.d.). Gluten-free foods have been gaining traction in response to 3 trends: the number of celiac patients is increasing as the detection techniques are becoming more and more sensitive, gluten-free foods are seen as a niche market for expansion, and there is a perceived association between gluten-free foods and healthy living (Rosell et al., 2014).

The consumption of gluten-free products is also higher among consumers as the term “free of” has a halo health effect which can be attractive to the consumers. Thus, labeling a product with “free of” creates the perception of a healthy product and has a detrimental effect on the eating habits of the consumers (Christoph et al., 2018). The actual health benefits of gluten-free products are yet to be proven but they are considered healthier by consumer sentiment, and they also believe that consuming gluten-free products would lead to weight loss, and in response to promotion by celebrities who endorse a gluten-free diet. The preference for gluten-free foods has also been closely linked with the consumers who value organic foods, and are concerned with weight loss (Christoph et al., 2018).

Gluten-free products are also more expensive than their gluten counterparts and less available. Therefore, gluten-free foods have a high demand due to reasons ranging from gluten allergies, and sensitivity, and being considered healthier in response to recent trends. This calls for increased research by the food industry for the development of gluten-free foods.

Health and Nutritional Aspects

Gluten-free snacks are characterized by a low nutritional content market with very low protein content. Also, gluten-free products are associated with inferior quality attributes, and consumer acceptability (Lau et al., 2022). This is mainly because they are generally made from starches or flour with low dietary fiber content (Singh et al., 2016). This leaves the human body susceptible to a range of deficiencies including fiber, protein, calcium, folate, iron, and vitamins B12 and D (Stantiall & Serventi, 2018). A survey noted that the intake of fiber, iron, and calcium by consumers of gluten-free products was met only by 67%, 72%, and 47% of the people respectively (Thompson & Simpson, 2015).

The other challenge associated with gluten-free foods is the high glycemic content of these foods. The glycemic index is a measure of digestible carbohydrates in food and the subsequent rise in blood glucose levels (Glade & Smith, 2015). The high glycemic index of gluten-free products is due to formulation with flours which have lower protein, and lower fiber. Further, gluten-free products are formulated with functional starches which are digested differently causing a spike in the glycemic index (Stantiall & Serventi, 2018). The high glycemic content of these products makes them unhealthy for consumption by causing an immediate rise in sugar levels and this high glycemic index is related to diabetes, being overweight, and cardiovascular diseases (Romão et al., 2021)**.** Fat content is also high in gluten-free products with a low supply of minerals, vitamins and calories (Lau et al., 2022). The lower fiber content and high-fat content further leads to a rise in obesity and cardiovascular diseases.

This low nutritional profile has sparked a lot of interest in the addition of ingredients to boost the nutritional profile of gluten-free products. The natural cereals free of gluten include rice, corn, teff, sorghum, and millet which have been used in the making of gluten-free crackers. The adoption of gluten-free flours other than rice and corn leads to a better nutritional profile of gluten-free products as among these flours – quinoa, teff, and buckwheat are sources rich in magnesium, iron, potassium, copper, iron, zinc, and phosphorous. They are also excellent sources of calcium. These pseudo cereals have a higher folate content than products containing gluten (Pellegrini & Agostoni, 2015). Protein-enriched flours and isolates can be used to boost the nutritional profile of gluten-free products by boosting the products fiber, protein, and micronutrients content but these come with their own challenges such as negatively impacting the sensory characteristics such as texture and density (Stantiall & Serventi, 2018). Other approaches to improve the structure, acceptability, mouthfeel, and shelf-life of these products have been to add starch, dairy products, prebiotics or their combinations (Gallagher et al., 2004).

Cracker Industry and Trends

Crackers are thin and crisp products baked from unsweetened and unleavened dough containing low levels of fat, sugar, and moisture. They are popular snack foods that are convenient and inexpensive. Based on the ingredients and production methods, crackers can be divided into three main categories, namely soda crackers (saltines or cream crackers), snack crackers (sprayed crackers), and flavored or savory crackers (Shukla, 1994).

The challenges with developing gluten-free foods also extend to crackers. Crispiness is an important attribute of crackers. The water in the cracker functions as the plasticizer and results in decreased glass transition temperature which leads to a crispy cracker texture (Nikolaidis & Labuza, 1996). However, little is known of this interaction in gluten-free crackers (Xu et al., 2020). In contrast to bread, the gluten network does not need to be extensively developed in crackers, but it should be cohesive.

There are limited gluten-free flours that have been used to manufacture crackers and there is limited knowledge about the development of crackers with increased nutritional and sensory properties (Xu et al., 2020). Only a few gluten-free flours have been used to produce crackers, such as rice flour, corn flour, pulse flour (chickpea, green lentil, red lentil, yellow pea, pinto, navy bean flours, pea protein, starch, and fiber isolates) and soy, pea, and whey protein isolates (Xu et. al. 2020). The substitution of wheat flour by amaranth flour has been accomplished in crackers because of the high protein content of amaranth flour (Hozová et al., 1997). The substitution of buckwheat flour in crackers led to the poor resistance of dough causing a technological challenge for development. These crackers were however higher in total phenolic content than wheat crackers without compromising sensory acceptability (Sedej et al., 2011). The formulation of crackers using cassava and sweet potato flours demonstrated no change in sensory attributes when evaluated by trained panelists (Owusu et al., 2011).

A study indicated that there is a higher consumption of gluten-free crackers and biscuits among celiac disease subjects rather than gluten-free bread which underlines that celiac disease subjects rely on crackers and biscuits as a carbohydrate source (Valitutti et al., 2017). It is therefore surprising that there is limited literature on the development of gluten-free crackers.

Sensory Analysis

Sensory evaluation is a field that uses scientific principles from food science, physiology, psychology, and statistics to evoke, measure, and analyze responses to food and other materials as perceived by the senses of sight, smell, taste, touch, and hearing (Stone et al., 2012a). Sensory evaluation provides techniques to define the technical specifications of the product and also provides the hedonic perception by the user or consumer of that product. The use of sensory evaluation tests employs an expert panel, trained panel, or consumer panel depending on the objectives of the test. An expert panel is a highly trained panel that can produce repeatable and reliable sensory assessments and demonstrate high sensory sensitivity, discrimination ability, and vast knowledge of sensory methodology. A trained panel is composed of panelists who have undergone training for the particular/concerned sensory technique at hand and demonstrate the ability to identify differences and describe sensory characteristics. A consumer panel consists of consumers who have no training and are employed for preference and acceptance tests and their responses are subjective depending on their age, sex, personal experience, and social aspects (Sinesio, 2005).

Sensory evaluation tests have been used for research, product development, quality control, and shelf-life studies. There are three types of sensory tests: Discrimination, Descriptive and Affective. (Penfield & Campbell, 1990).

Affective tests are used to measure the acceptance and preference of products. This is used to evaluate if panelists like or dislike a product or prefer one product over the other and if they would use the product. This test uses untrained panelists or consumers, and the panel size is between 50 – 100. The hedonic scale is commonly used to measure the responses and this scale ranges from 5 to 10 points and it can be used to measure both acceptability and differences among products (Penfield & Campbell, 1990). The acceptance of products is the parameter with the greatest impact on the decision to consume a food or not. Even if it is economically accessible and has nutritional quality, a product with low acceptance is unlikely to remain on the market.

Quantitative consumer testing is generally performed in a central location known as a Central Location Test (CLT). This test is cost and time-effective and can be performed in a controlled environment. However, the Home Use Test (HUT) allows for more understanding of the consumer in their natural environment (Sveinsdóttir et al., 2010). Another type of consumer testing is qualitative testing. This includes focus groups, ethnography, and one-on-one interviews. Qualitative testing helps valuable insights into the product concepts and prototypes (Lawless & Heymann, 2010).

Discrimination testing is an analytical tool in sensory testing and relies on establishing if there is a difference in products or if there is an absence of difference between products which can help to direct action based on if products are perceived as different or not (Stone et al., 2012a). Discrimination tests include difference and sensitivity tests. The difference tests determine if there is a perceived difference among samples and include paired comparison, triangle, duo-trio, and ranking tests. These are not only used for quality control and product development but also for training panelists. Another branch of difference tests are sensitivity tests used to determine the lowest concentration at which a substance will be detected (Penfield & Campbell, 1990).

Descriptive analysis is a vital tool in sensory analysis to provide descriptions of the products. Descriptive analysis is used to characterize, profile and compare samples for one or more attributes. The profiling method in descriptive analysis is used to compare products, quality control, and product development. The panelists in this are highly trained to utilize clearly defined terms to describe a product. Hedonic terms such as good, bad, and fair are avoided (Penfield & Campbell, 1990). There are different variations of descriptive analysis such as flavor profile method, texture profile method, quantitative descriptive analysis, quantitative flavor profiling, spectrum method and free choice profiling (Murray et al., 2001).

Lexicon development is one of the crucial steps in the descriptive analysis of the product. A lexicon provides a set of terms that are repeatable and reliably used to describe the sensory characteristics of products. The development of a lexicon involves the panelists evaluating the products, generating a list of terms, their definitions, standard evaluation procedure for the attributes, and their references followed by the finalization of these terms. These terms should be extensive, complete, non-hedonic, and non-redundant and they should be able to capture all the product differences. It is an effective tool for communication among panelists, sensory scientists, marketers, and product developers (Suwonsichon, 2019). To our knowledge, there is no sensory lexicon for gluten-free crackers. However, there is one published article on the development of a lexicon for gluten-free sorghum bread (Ari Akin et al., 2019).

The sensory techniques in the past years have undergone a dramatic change due to the continuous pressure to innovate from the food industry in a way that is time efficient and flexible. Hence, there has been an evolution of rapid methods in sensory analysis (Delarue, 2023). The terms generated by the descriptive panel are discriminative and nonredundant and the data is useful for product development, quality control, shelf life, and other applications. However, this data is hard to understand for marketers (Talavera-Bianchi et al., 2010). The popularity of rapid methods is growing and is especially important in the present context. Previous studies, Liu et al., 2018; Ares & Varela, 2017; & Worch & Piqueras-Fiszman, 2015; have demonstrated that consumers show acumen in discrimination, consensus, and repeatability when attributes are simple and easy to understand for naive consumers. Several rapid methods have been employed as alternatives to conventional profiling methods. This includes Projective Mapping (Risvik et al., 1997); Flash Profiling (Delarue & Sieffermann, 2004); and HITS (Talavera- Bianchi et al., 2010).

Projective Mapping is a technique in which consumers are asked to place samples on a blank paper in which they are instructed to place similar samples together and different samples farther apart (Pagès et al., 2010). HITS was developed by Talavera-Bianchi et al., 2010 as an alternative to descriptive analysis with trained consumers to limit the terms to 5 and rate them on a scale of 0 to 4 with 0 = none, 1 = low, 2 = medium and 3 = high.

In summary, a comprehensive approach that combines CLTs, expert panel-developed sensory lexicons, and rapid sensory profiling techniques are essential for gaining a holistic understanding of the sensory qualities and consumer preferences for gluten-free crackers. This multifaceted approach empowers manufacturers to enhance their products and better align with consumer expectations in the market.

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Chapter 2 - The Use of Novel Methods – Projective Mapping and Modified Flash Profile to Evaluate Consumer Perception of Commercially Available Gluten-Free Crackers using Consumers.

Abstract

Sixteen different commercially available gluten-free crackers were selected from popular brands in the market. The objectives of this study were to 1) use an untrained panel to evaluate commercially available gluten-free crackers using projective mapping for classification and sample reduction, and 2) characterize the selected products using modified flash profiling. Eight untrained panelists participated in this study. Consumer panelists placed the samples on a rectangular sheet of paper with similar samples close together and dissimilar ones far apart. The products that were too similar and would not provide additional understanding of the sensory attributes in the product space were removed and the ones that had attributes that were different from the objective of selecting only "plain/original" crackers were also eliminated. The projective mapping technique generated a map that helped in eliminating six crackers from further testing. The selected products were then evaluated by the modified flash profile panel. The modified flash profile panel further helped characterize the crackers by developing a list of attributes and using that list to rate each cracker on a 4-point scale: none, low, medium, high. The panel generated 71 terms (30 terms for aroma, 28 terms for flavor, 12 terms for texture, and one term for mouthfeel). These attributes were successful in achieving a clear differentiation of samples from one another. Brown rice crackers (MAGOGF, SESGF) were described as brown rice, cardboard, and flaxseed. Their texture was described with hardness, crispiness, and grittiness. White rice (LANCGF, GLUTGF, KAMGF), tapioca/potato starch formulation

(ABSOGF), and millet blend (SCHAGF) crackers were described mostly with sweet, butter and oily. Cassava flour (CRUNGF) and nut flour blend (SIMIGF) were characterized by herb, salty and savory. Consumers successfully generated descriptors for the crackers such as sunflower seed, flaxseed, and corn which were a part of the ingredient list for the respective crackers showing their ability to recognize aroma/flavors. These terms characterized the crackers using extensive language, which was consumer friendly, detailed, marketing-friendly, and easy to understand.

Introduction

The growing demand for gluten-free products along with the growing market share has driven the food industry to develop novel products for consumers. Population growth and modern diets demand constant innovation in the food industry. The gluten-free diet is a growing trend among consumers. These products are also consumed by the family members of celiac patients, those with gluten sensitivity, those having the perception of following this diet as having positive benefits for conditions like autism, and in response to trendy gluten-free lifestyle promoted by celebrities (Xhakollari et al., 2019).

Baked products – bread, biscuits, and crackers are the core segment of the food industry. Gluten-free products are marked with poor nutritional content, lower protein, and increased glycemic index. This is mainly because gluten-free products are generally made from starches or flour with low dietary fiber content (Singh et al., 2016). This leaves the human body susceptible to a range of deficiencies including fiber, protein, calcium, folate, iron, and vitamins (Stantiall & Serventi, 2018).

The development of these products calls for increased nutritional benefits without compromising sensory acceptability (Tomić et al., 2022). To overcome these challenges, different ingredients for the development of gluten-free crackers have been used in both academic and commercial settings. This is evident from the selection of gluten-free products available in the market which contain flour from different grain sources and various added ingredients such as flax to boost nutritional profile.

Crackers are popular snack foods (Sedej et al., 2011). They are thin, crispy, and dry products with incredibly low moisture. Their ingredients are soft white wheat flour, fat, salt, and sugar (Ozgoren et al., 2019). To make gluten-free crackers, soft wheat flour is replaced with gluten-free flour. This replacement changes the physiochemical properties of the crackers which may or may not be acceptable to consumers. An understanding of the sensory characteristics that are key to drive consumer liking is important to help improve acceptability of these products.

The use of profiling methods has been a robust tool in sensory analysis both in academic and commercial research. These methods have been useful and have led to remarkable success. However, they are quite time-consuming and expensive. The increased competition calls for newer and quicker methods and alternatives to descriptive analysis (Pickup et al., 2018). Descriptive analysis is a widely used tool that requires trained assessors. The terms generated by the descriptive panel are discriminative, nonredundant and the data is useful for product development, quality control, shelf life, and other applications. However, this data may be hard to understand for marketers and consumers.

Several rapid methods have been employed as an alternative to conventional profiling methods. This includes projective mapping (Risvik et al., 1997; Pagès et al., 2010); flash profiling (Delarue & Sieffermann, 2004); and HITS (Talavera-Bianchi et al., 2010), among others.

HITS is a tool to differentiate samples using a shorter list of attributes. The use of the HITS panel as an alternative to profiling methods was developed at Kansas State University (Talavera-Bianchi et al., 2010). In this study, the panelists reviewed each of the cheeses and came up with a list of attributes. The number of attributes was limited to 5. The level of intensity used was slight, moderate, and strong. The study noted that even though the list was not detailed and had demonstrated a reduced sensitivity to the attributes, it generally performed well at providing a list of the broad most key descriptive attributes and was able to differentiate among the cheese samples used in the study. Another study used the HITS method to assess which cooking method of potatoes provided the largest differentiation among products. This study also employed a trained panel. The panel was still restricted to 5 attributes, but the intensity was rated on a scale of 0 to 15. However, it should be noted that the panelists in these studies were trained and used the consensus method. Ciccone et al. 2021, showed that the differentiation of potato samples is greater using a trained panel versus an untrained panel. The untrained panelists produced some similar attributes to that of the trained panel, but they were unable to develop a similar profile and showed decreased sensitivity to complex aroma and flavor notes (Ciccone et al., 2020).

Projective mapping was introduced as a quick alternative to the sensory profiling methods by Risvik et al., 1994. The untrained panelists were asked to place the samples on a blank sheet based on their sensory profiles. A rectangular sheet of paper is used, and the data is analyzed using multiple factor analysis. This method has been employed in previous research by both trained and untrained consumers. This method's success has been shown by numerous studies on products ranging from alcoholic beverages to citrus fruits. The use of this method is easier and more convenient for commercial products rather than biological products such as fruits, vegetables, and unprocessed seafood (Pickup et al., 2018). In rapid and conventional methods, the selection depends on the objective, group discussion, and literature research (Huang et al., 2021). The main decisions are being made by the consumer when they are at the grocery store aisle so rapid profiling methods help bring the consumer viewpoint to profiling products which are of immense importance to commercial products. It is, therefore, safe to assume that commercially available gluten-free crackers can be evaluated by untrained panelists (i.e., consumers) using projective mapping.

Flash profiling is a sensory technique used to investigate the sensory characteristics of products in an industry setting. This can be done to profile products already present on the market or characterize a new formulation. The panelists develop a list of attributes individually and then the complied list of all attributes is presented to all the members of the panel so that they can add/remove the attributes as they see fit. The generated attributes are then evaluated on an 11-point intensity scale. The data is analyzed using generalized procrustes analysis (Delarue & Sieffermann, 2004).

The objective of this research was to use projective mapping and modified flash profiling for consumer profiling of commercial crackers.

Materials and Methods

Various popular online stores were searched for gluten-free crackers. A list of crackers with only plain/original flavors was compiled. These were sourced from Amazon, Walmart, Whole Foods, and Sprouts. After receiving the products, they were opened and inspected for their integrity (to see how many whole crackers per box) and carefully stored until the time for the study. Sixteen commercially available gluten-free crackers were selected. They were from various brands and had different grain sources. The different grains in the gluten-free crackers were brown rice, white rice, flaxseed flour, cassava flour blend, nut flour blend, millet blend, and tapioca/potato starch blend. Their details are mentioned in Table 2.1.

These gluten-free crackers were evaluated by an untrained consumer panel on three consecutive days in 90-minute sessions each day. On day one, they evaluated the crackers using the projective mapping technique. Based on the results, the sample set was reduced to 10 samples. On days 2 and 3, the same panelists returned to evaluate these selected samples using the modified flash profiling methodology. The crackers were served in 4 oz cups with clear lids (Dart, Mason, Michigan, USA) at room temperature and were placed in cups just before the projective mapping and modified flash profile sessions to minimize texture changes. Sample lids were labeled with random three-digit codes. The gluten-free crackers were stored at room temperature until ready for evaluation.

Projective Mapping and Modified Flash Profile

The projective mapping panel met for one 90-minute session. In the first 10 minutes, the technique of projective mapping was explained, and the panelists were asked to place the samples on a two-dimensional sheet based on their similarity. They were instructed to put similar samples closer and different samples far away from each other. No other instructions were given. They were presented with all the samples at the same time. Water was provided to cleanse their palate.

The modified flash profile panel was formed by the same participants from the projective mapping exercise. Panelists returned on days 2 and 3 for 90-minute sessions each day. The first day of the panel consists of orienting them with the modified flash profile technique. They were asked to use descriptive terms for the products being evaluated and were asked to avoid hedonic terms such as good, bad, and fair. The samples were served one by one in a monadic order. The panelists were asked to focus on only 3 modalities in a fixed order: Aroma, Flavor, and Texture. They were instructed to devise descriptive terms and limit the terms to 4 terms for aroma, 4 terms for flavor, and 3 terms for texture. The panelists were asked to individually evaluate each sample. It was emphasized that they note those key attributes that they first perceived as they evaluated the product, similar to a High Identity Traits (HITS) technique. The data was collected manually. The list from day 1 was compiled and some attributes which made little sense to the objective were removed i.e., bland: no significant taste/ aroma. It was clear from the discussion with the consumers that this was an intensity attribute and not a descriptive term. The term fiber was closely related to their understanding of grain/seeds and as those attributes were already present, fiber was removed. The attribute ‘pasty’ was changed from texture to mouthfeel as consumers described this attribute as the product dissolving in their mouth. On the second day, the panelists were presented with a compiled ballot of all the 71 attributes collected from day 1. All the panelists evaluated the samples for all 71 attributes. They were then asked to rate the samples on a 4-point scale, with 0 = none, 1 = low, 2 = medium, and 3 = extreme.

Descriptive Analysis

Five highly trained panelists from Sensation Research, Mason, Ohio participated in the descriptive analysis and used consensus method for evaluation. All the panelists had received descriptive sensory training of 7 –12 years on different food and beverage products including crackers and baked products. Three of the five panelists developed the language prior to the evaluation. This was followed by a 1.5-hour long orientation session. This orientation session consisted of all five panelists becoming familiar with the language and references and were asked to make any adjustments if needed. Panelists were instructed to add or remove attributes as per their perception i.e., if a new attribute was perceived, the panel would discuss and if agreed, the attribute would be added to the list. A lexicon of 43 attributes was developed to describe and characterize various gluten-free crackers of “regular” or “plain” flavors.

Table 2.1 List of Gluten-Free Crackers

Name of the Cracker	Code	Flour Base	Ingredients	Variety	Selected for Rapid Panel
Absolutely Gluten-Free Crackers	ABSOGF	Tapioca/Potato starch	tapioca starch, water, potato starch, potato flakes, palm oil, honey, egg yolks, natural vinegar, salt	Original	Yes
CrunchMaster Grain Free Crackers	CRUNGF	Cassava Flour	cassava flour, organic coconut flour, tapioca starch, safflower oil, sea salt, garlic powder	Original	Yes
Glutino Gluten-Free Crackers	GLUTGF	White Rice	corn starch, white rice flour, organic palm oil, modified corn starch, eggs, sugar, salt, vegetable fibers, dextrose, guar gum, sodium bicarbonate, natural flavor, monocalcium phosphate, ammonium bicarbonate.	Original	Yes
Simple Mills Sea Salt Crackers	SIMIGF	Nut Flour Blend	nut and seed flour blend (almond flour, sunflower seeds, flax seeds), tapioca starch, cassava, organic sunflower oil, sea salt, organic onion, organic garlic, rosemary extract (for freshness)	Sea Salt	Yes
Blue Diamond Nut Thins	BLDIGF	White Rice	rice flour, almonds, potato starch, sea salt, safflower oil, natural flavors (contains milk).	Original	Yes
Mary's Gone Crackers	MAGOGF	Brown Rice	brown rice, quinoa, flax seeds, sesame seeds, tamari (water, soybeans, salt, vinegar), sea salt.	Original	Yes

Name of the Cracker	Code	Flour Base	ingredients	Variety	Selected for Rapid Panel
Schar Table Gluten-Free Crackers	SCHAGF	Millet Blend	non GMO corn starch, vegetable fats and oils (palm, palm kernel, non GMO rape seed), maltodextrin, modified tapioca starch, whole millet flour, non GMO soy flour, rice syrup, whole rice flour, buckwheat flour, sorghum flour, flax seed flour, non GMO corn flour, dried sourdough (buckwheat, quinoa), non GMO soy bran, poppy seeds, non GMO sugar beet syrup, sea salt, cream of tartar, ammonium bicarbonate, baking powder, guar gum, modified cellulose, citric acid, natural flavoring (rosemary).	Original	Yes
Lance Gluten-Free Crackers	LANCGF	White Rice	palm oil, rice flour, rice starch, sugar, corn starch, potato starch, baking soda, tapioca flour, glucose, xanthan gum, monocalcium phosphate, salt, soy lecithin, locust bean gum, non-fat milk.	Original	Yes
Ka Me Rice Crackers	KAMGF	Jasmine Rice	jasmine rice, rice bran oil, sea salt, soybean tocopherols (preservative).	Original	Yes
Sesmark Gluten-Free Crackers	SESGF	Brown Rice	rice flour, expeller pressed safflower oil, sesame seeds, sesame flour, wheat free tamari	Sea Salt	Yes

			soy sauce powder [tamari soy sauce (soybeans, salt), maltodextrin (from corn)], wheat free teriyaki powder [wheat free teriyaki sauce (tamari soy sauce [soybeans, salt], sake (rice, salt), apple cider vinegar, garlic, mustard, ginger, white and black pepper), maltodextrin, sucrose, fructose], onion powder and soy lecithin		
Hu Gluten-Free Grain-Free Crackers	HUGF	Almond, Cassava, Coconut flour blend	grain-free flour blend (almond, cassava, organic coconut), black chia seed, flax seed, organic coconut aminos	Sea Salt	No
Mary's Gone Super Seed Gluten -Free Crackers	MAGOGF	Brown Rice	brown rice, quinoa, pumpkin seeds, sunflower seeds, flax seeds, sesame seeds, poppy seeds, sea salt, seaweed, black pepper, spices	Original	No
Crunch Master Multigrain Crackers	CRMSGF	Brown Rice	brown rice flour, whole grain yellow corn, potato starch, safflower oil, oat fiber, cane sugar, sesame seeds, flax seeds, millet, sea salt, quinoa seeds.	Original	No
Doctor in the Kitchen Flackers	DRGF	Flaxseed	organic flax seeds, organic apple cider vinegar, sea salt	Sea Salt	No
Trader Joe's Savory Thin Crackers	TJGF	White Rice	rice, sesame seeds, expeller pressed safflower oil, tamari soy sauce (soybeans, rice, salt), salt, garlic, soybean	Original	No

Name of the Cracker	Code	Flour Base	Ingredients	Variety	Selected for Rapid Panel
Foods Alive Original Flax Crackers	FAGF	Flaxseed	golden flaxseed, bragg liquid aminos (a non-gmo wheat-free soy sauce), lemon juice	Original	No

Participant Recruitment

A total of 8 panelists were recruited from the consumer database of the Sensory and Consumer Research Center at Kansas State University (Olathe, Kansas, USA) to participate in the various stages of the study. The demographics are mentioned in Table 2.2. Panelists purchased gluten-free crackers at least once every 3 months. Participants were required not to work for any food company to avoid bias. They should not have participated in consumer research in the last 3 months. They were seven females and one male from diverse age groups of 18 to 65 years of age. They cleared the standard security screening and were from different income backgrounds. They were also asked about the reasons for consumption of gluten-free crackers.

This study was conducted at the Sensory and Consumer Research Center at Kansas State University, Olathe, Kansas, USA.

Table 2.2 Demographics

Characteristics	Categories	Number of Panelists
Gender	Male	1
	Female	7
Age	18 – 25 years	1
	26 – 35 years	1
	36 – 45 years	6
Reasons for Purchase	Gluten Sensitivity	2
	Celiac Disease	0
	I live with someone who has gluten allergy	1
	I purchase both products with and without gluten	2
	I do not like eating products with gluten, so I buy gluten-free	3
Frequency of Purchase	Once or more a week	3
	Once every 2-3 weeks	3
	Once a month	1
	Once every 3 months	1

Data Analysis

XLSTAT software (Lumivero, Denver, CO, USA) was used to perform data analysis. Multiple Factor Analysis (MFA) was used for analyzing projective mapping data. The coordinates of each sample were measured in inches using a ruler and distance from the X and Y axis. This generated a plot to determine the relationship between the different samples. The modified flash profile data was analyzed using the Generalized Procrustes Analysis (GPA). This was done for aroma and flavor and separately for texture attributes. The attributes that did not elicit or apply to the sample were marked as a 0 to perform analysis.

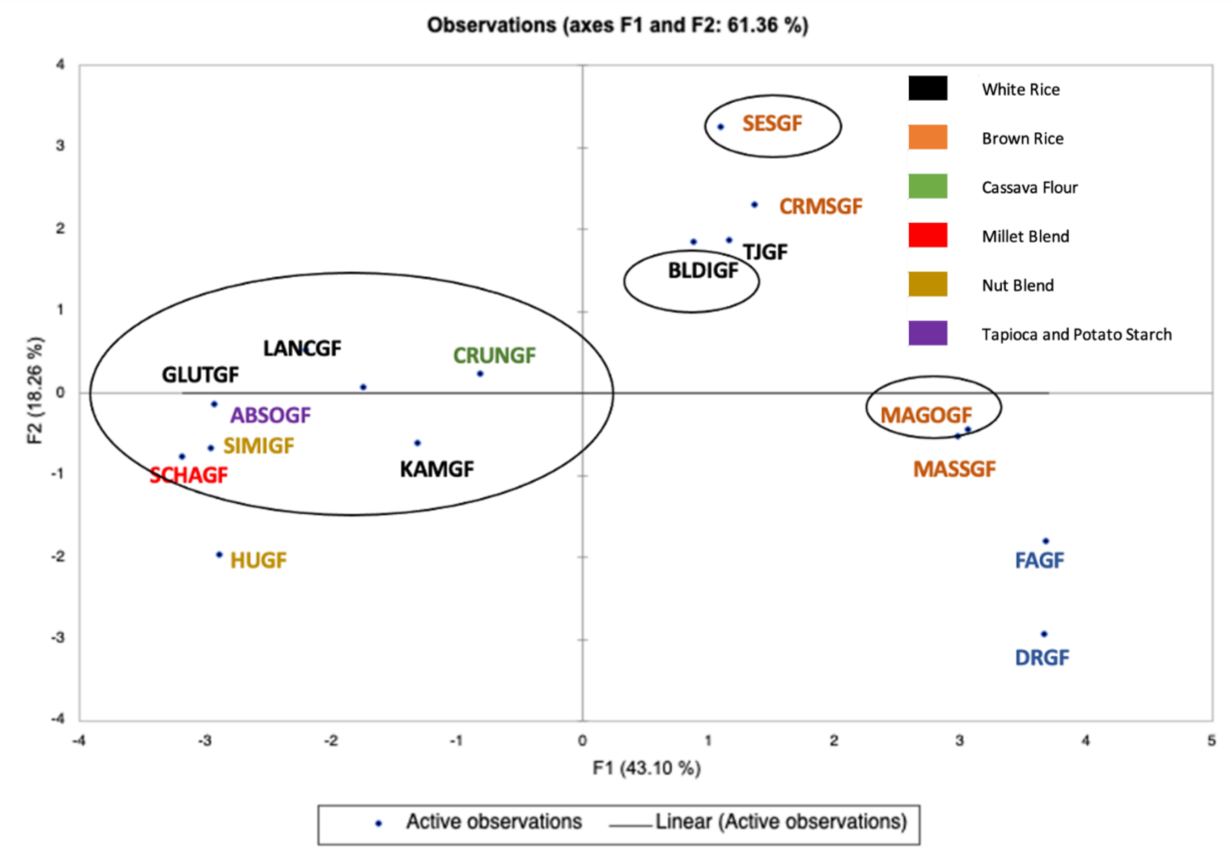
Results and Discussion

Projective Mapping

The products evaluated using projective mapping were plotted with the help of multiple factor analysis, generating Figure 2.1 in which the first two axes explained 61.63% variability. This was used to select the crackers for the modified flash profile panel, descriptive panel, and consumer study. The distinct colors in Figure 2.1 represent different grain sources with orange for brown rice, black for white rice, blue for flaxseed, green for cassava flour, yellow for nut flour blend, red for millet blend, and purple for tapioca/potato starch blend. There were 4 different groups in Figure 2.1 with GLUTGF, LANCGF, CRUNGF, ABOSGF, SIMIGF, KAMGF, SCHAGF, and HUGF placed together in one group. This group included white rice, cassava flour, tapioca/potato starch blend, millet blend as well nut blend formulations. The other group of crackers that were placed together were SESGF, CRMSGF, TJGF, and BLDIGF. This included both brown rice and white rice crackers. This showed that the crackers with the same flour type were not necessarily placed together with white rice and brown crackers interspersed between the two groups. Additionally, the other two crackers with brown rice in their formulation (MAGOGF, MASSGF) were placed close together but apart from the other crackers with brown rice in their formulation. However, the flaxseed crackers were placed further apart in one group which could be owed to the distinct strong aroma and flavor of flaxseed crackers. Some products were excluded from further research steps. CRMSGF (brown rice) was eliminated because it had a similar sensory profile to the SESGF (brown rice). TJGF (white rice) was eliminated as it was shown to have a similar profile to the BLDIGF (white rice) and there were various other crackers that employed white rice in their formulation. MASSGF, FAGF, and

DRGF were eliminated as they all contained flaxseed as the primary ingredient and upon tasting, it was evident that their flavor profile was heavily influenced by flaxseed which was beyond the scope of our study. Our focus was on plain-flavored gluten-free crackers. The difference was so remarkable that the researchers believed that these products belonged to a different category. Similarly, HUGF was eliminated because of onion and garlic notes which deviated from the objective of including only original and sea salt crackers. The study's objective was to only include the crackers that were plain/original so that the effect of different flour blends could be observed on the different sensory attributes. This type of technique can be very valuable for the industry when the goal is to narrow down a selection of products for further evaluation (i.e. descriptive or consumer evaluation). This is common practice, especially in the scenario of a market review of competitive products.

Figure 2.1 Plot Generated using Multiple Factor Analysis for Gluten-Free Crackers



Modified Flash Profiling Results

The compilation of all attributes from the panelists resulted in 30 terms for aroma, 28 terms for flavor, 12 terms for texture, and one term for mouthfeel (Table 2.3).

Table 2.3 Final List of Compiled Attributes Generated by the Modified Flash Profile Panel

Aroma	Flavor	Texture	Mouthfeel
Rice	Flour	Crunchiness	Pasty
Herb	Sorghum	Crispiness	
Butter	Salt	Roughness	
Baked	Rice	Puffiness	
Toasted	Sunflower Seed	Thickness	
Chemical	Nutty	Hardness	
Oily	Corn	Grittiness	
Flour	Sweet	Moistness	
Grain	Oxidized Oil	Airy	
Grass	Onion	Chewiness	
Nutty	Seed	Gumminess	
Chemical	Green	Flakiness	
Corn	Garlic		
Earthy	Woody		
Graham	Savory		
Flax	Earthy		
Cardboard	Grain		
Rancid	Bitter		
Woody	Sesame		
Powder	Burnt		
Savory	Flaxseed		
Cheesy	Brown Rice		
Paper	Oat		
Wheat	Butter		
Pepper	Cardboard		
Rosemary	Cheese		
Oxidized Oil	Toasted		
Burnt			
Garlic			
Uncooked Flour			

The relationship between different crackers based on their aroma and flavor is shown in Figure 2.2. The distinct colors represent different grain sources.

For aroma and flavor, the brown rice formulations MAGOGF and SESGF were clearly separated from other crackers. They were associated with flaxseed, nutty, sesame, green, and sunflower seeds. The terms sunflower seed and flaxseed associated with MAGOGF were also present in its ingredient list (Table 2.2).

BLDIGF (white rice) was described as corn, rice, grain, bitter, and grass. Other crackers with white rice in their formulation (LANCGF, KAMGF, GLUTGF), millet blend (SCHAGF), and tapioca/potato starch blend (ABSOGF) were placed close together. They were described using sweet, oily, oat, pepper, graham, butter, cheese, and grain. In a prior study on white rice crackers, the descriptors generated by consumers for flavor were roast rice, buttermilk, burned sugar, and cheese. It can be noted that only one term – cheese, was similar in both studies. (Linh et al. 2014) Also, in a previous study on sensory evaluation of crackers manufactured with millet, sorghum and soy, the crackers were rated acceptable, however, no sensory terms were generated (Pandit et. al. 2018). Sensory terminology is limited for the gluten-free cracker category. Cassava blend crackers (CRUNGF) were characterized by garlic, savory and herb.

One of the aroma terms used to describe SIMIGF and SCHAGF products was rosemary and as seen in Table 2.1, rosemary was present in their ingredient list showing consumer acumen in identifying the sensory characteristics of this cracker. The SIMIGF product (nut flour blend) was also associated with garlic aroma and these crackers contained garlic in their ingredient list. It is important to note that even though these products had garlic as one of the ingredients, they were still marketed as “plain” crackers.

The relationship between texture attributes and crackers is explained in Figure 2.3. Brown rice crackers (SESGF, MAGOGF) were described with attributes crispiness, grittiness, hardness and crunchiness. White rice crackers (LANCGF, BLDIGF) and cassava flour crackers (CRUNGF) were characterized by thickness and puffiness. White rice (KAMGF) and potato/tapioca starch blend (ABSOGF) were airy. Crackers SCHAGF (millet blend), GLUTGF (white rice) and SIMIGF (nut blend) crackers were characterized by chewiness, puffiness, flakiness and pasty. The relationship between texture attributes and various crackers shows that grain type did not have an effect on the texture attributes, except for brown rice crackers which were grouped together.

The panelists were able to clearly differentiate samples using aroma, flavor, and texture terms. For aroma, flavor, and texture attributes, brown rice crackers were placed together with a set list of attributes. The white rice, millet blend, potato/starch blend, nut flour blend crackers were placed together and characterized using various terms. There was an overlap between flavor and aroma terms (Table 2.3) which suggests that consumers have not been able to differentiate the two resulting in some redundancy. It is also obvious that this methodology is a good fit in a scenario where a broad characterization is needed, instead of detecting small differences for specific attributes. In that scenario, conventional descriptive testing will still be the most appropriate route.

Figure 2.2 Plot Generated Using Generalized Procrustes Analysis for Aroma and Flavor Attributes

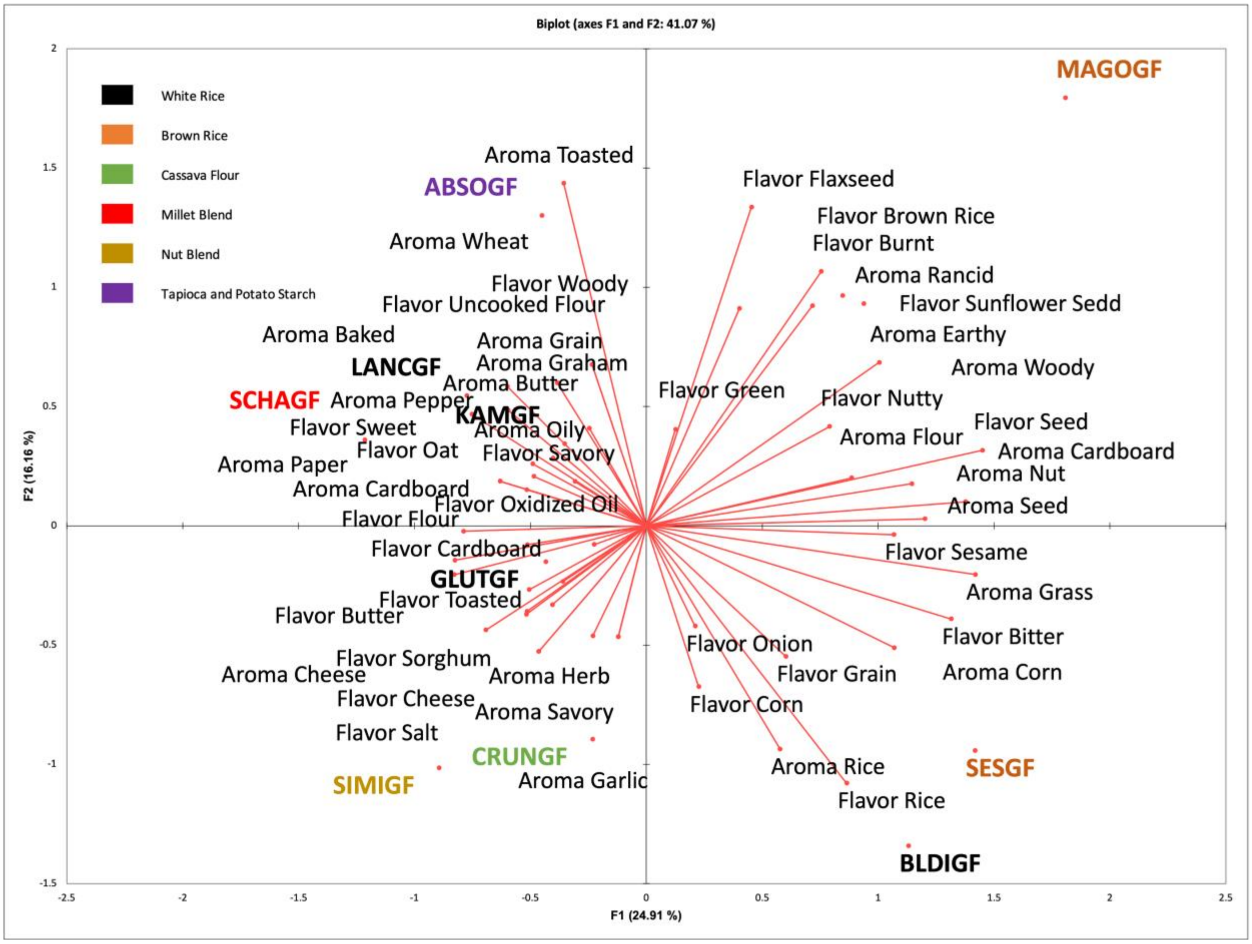
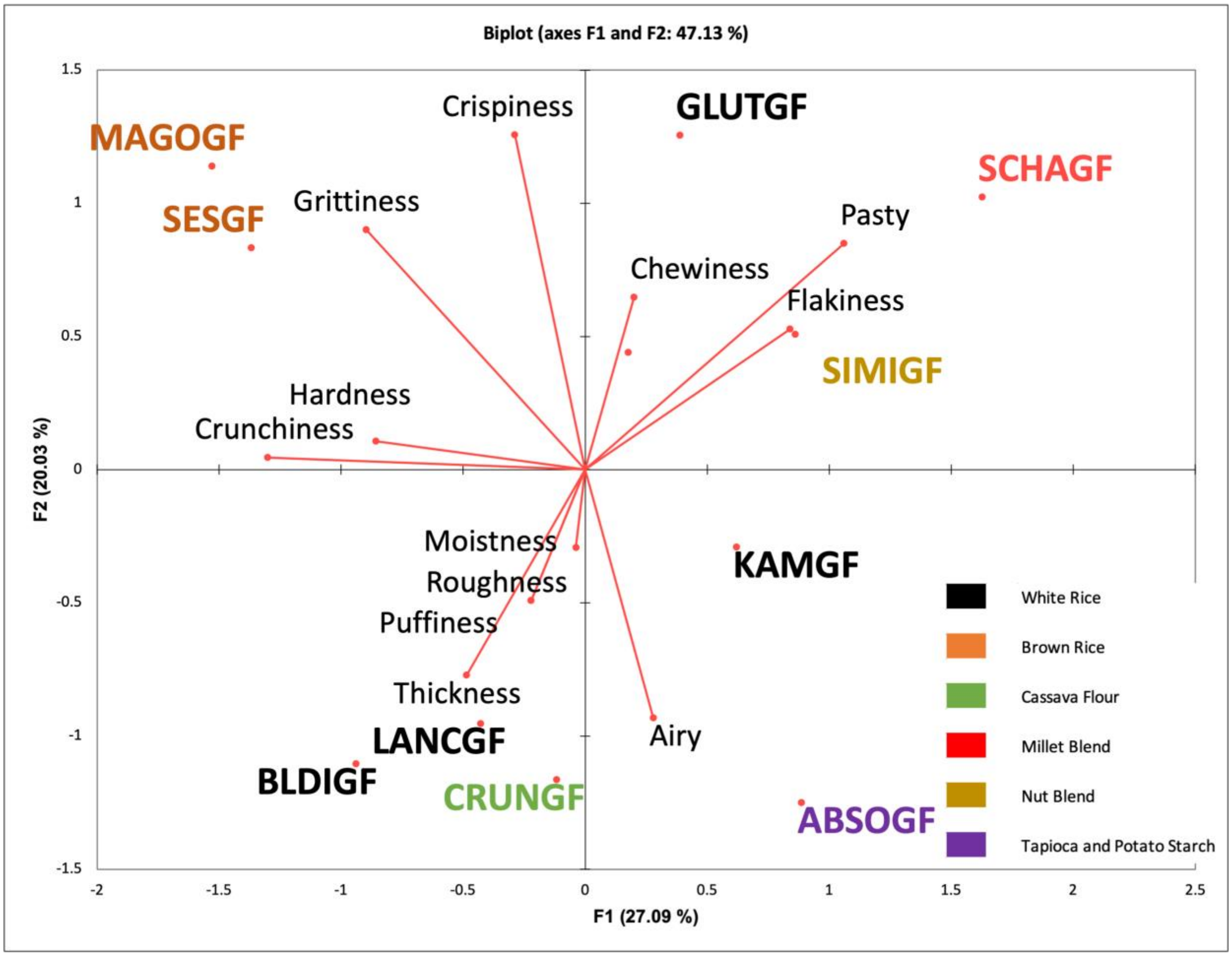


Figure 2.3 Plot Generated Using Generalized Procrustes Analysis for Texture Attributes



Descriptive Analysis and Modified Flash Profiling

A descriptive panel of five highly trained panelists evaluated the gluten-free samples using the consensus method. The descriptive panel used 43 attributes (Chapter 3, Table 3.2) for appearance, aroma, flavor, and texture. However, the consumer panel used 71 terms to characterize gluten-free crackers. Appearance was not evaluated by the consumer panel.

The descriptive panel generated 26 terms for aroma/flavor combined. The consumer panel generated 58 aroma/flavor terms. Among these, 15 terms were common among both consumer and descriptive panel. Another term seedy/sesame/flax used by the descriptive panel was used as 3 different terms by the consumer panel: seedy, sesame, and flax. The common terms are shown below (Table 2.4).

The common terms were bitter, burnt, pepper/back pepper, cardboard, dairy/buttery, garlic, herbs, oily, salty, sweet, toasted, wheat-like/wheat, sesame, seed, flax and earthy. The terms used by the descriptive panel for describing aroma and flavor that were not used by the consumer panel were – baking soda, dairy/nut milk (which may be described as cheesy/buttery by consumers), soy sauce, seaweed, irritating (which might be ascribed to chemical by consumers), burning heat from pepper, true to gluten, sour, potato (flour/starch), starch complex, coconut/coconut flour, astringent, overall aroma intensity, overall flavor intensity, and aftertaste.

A comparison between the biplot generated analyzing modified flash profile data for aroma and flavor (Figure 2.2) with principal component analysis plot generated using descriptive data for aroma and flavor (Chapter 3, Figure 3.1) revealed that the brown rice crackers were placed relatively closer but apart from the rest, and the other crackers with white rice, potato and tapioca starch blend, cassava flour blend, nut and seed blend were placed together. The terms used to describe brown rice crackers such as earthy, flaxseed, and cardboard were common. Another attribute bitter was placed close to cracker GLUTGF by both panels. LANCGF crackers were characterized by sweet and dairy notes by both panels. BLDIGF was described as bitter by both panels. Herbs and salt were used for SIMIGF and CRUNGF.

The terms generated by the consumer panel such as corn flavor was not generated by the descriptive panel although corn was present in 3 out of 10 formulations whereas the term coconut for aroma/flavor was generated by the descriptive panel and was present in two formulations, however, this term was not identified by the consumer panel. The term sunflower seed was generated by the consumer panel, which was on the ingredient list for MAGOGF, but this term was not generated by the descriptive panel. It can be said that the rapid method can be used as an initial technique to understand the sensory descriptors of products using consumers and in developing more marketing and consumer friendly language. For generating sensory data, which is reproducible, accurate, more sensitive to small differences, and has standardized terms which are clearly defined, the output from a descriptive panel will be more appropriate.

Table 2.4 Common Aroma/Flavor Terms Generated by the Descriptive Panel vs Consumer Panel

Descriptive Panel	**Consumer Panel**
Burnt	Burnt
Dairy/Buttery	Butter
Garlic/Onion	Garlic
Herbs	Herb
Salty	Salt
Sweet	Sweet
Toasted	Toasted
Wheat-like	Wheat
Oily	Oily
Black Pepper	Pepper
Rice (flour, starch)	Rice
Cardboard	Cardboard
Bitter	Bitter
Nutty/Nut Milk	Nut
Seedy/Sesame/Flax	Seed
	Sesame
	Flax
Earthy	Earthy

Table 2.5 Different Aroma/Favor Terms Generated by the Descriptive Panel vs Consumer Panel

Descriptive Panel	Consumer Panel
Coconut/Coconut Flour	Cheesy
Irritating	Chemical
Seaweed	Corn
Sour	Earthy
Starch Complex	Flour
True to Gluten	Grain
Overall Aroma	Graham
Overall Flavor	Grass
Astringent	Green
Burning heat from pepper	Baked
Aftertaste	Oxidized Oil
Baking Soda	Paper
Soy Sauce	Powder
Potato (flour/starch)	Rancid
	Rosemary
	Savory
	Sorghum
	Sunflower Seed
	Uncooked Flour
	Woody
	Brown Rice
	Oat
	Butter

For texture, the consumer panel generated 12 terms whereas the descriptive panel generated 7 terms. Five of the terms were common amongst both panels (Table 2.6). The terms roughness, hardness, thickness, grittiness, and dryness/moisture absorbency were common in both studies. However, the descriptive panel also used sophisticated terms such as fracturability, and toothstick/toothpack (Table 2.7). These terms may be too complex for consumers and not part of the common vocabulary. The terms crispiness, puffiness, crunchiness, airy, chewiness, gumminess and flakiness were not generated by the descriptive panel.

A comparison between the biplot generated analyzing modified flash profile data (Figure 2.3) with principal component analysis plot generated using descriptive data (Chapter 3, Figure 3.2) revealed that the terms hardness and grittiness were used to describe brown rice formulations, MAGOGF and SESGF by both panels. Thickness was used to describe LANCGF. The texture terms generated by the consumer panel and descriptive panel were able to differentiate and characterize samples.

Table 2.6 Common Texture Terms Generated by Descriptive Panel vs Consumer Panel

Descriptive Panel	Consumer Panel
Hardness	Hardness
Thickness	Thickness
Grit/chalky/mouthcoat	Grittiness
Dryness/Moisture Absorbency	Moistness
Roughness from seed/particulates	Roughness

Table 2.7 Different Texture Terms Generated by the Descriptive Panel vs Consumer Panel

Descriptive Panel	Consumer Panel
Fracturability	Crispiness
Toothstick/Toothpack	Puffiness
	Crunchiness
	Airy
	Chewiness
	Gumminess
	Flakiness

Descriptive panel and modified flash profile panel used similar terms to characterize various crackers. Both methods were able to achieve a clear differentiation of the samples using the terms generated by them. Still some differences were noted in the discussion.

The objective of study, time, and budget can be taken into consideration when choosing the appropriate method for the study.

Study Limitations

The study was conducted using an untrained consumer panel and they were only given a 15-minute orientation session. There is scope for providing more training to the consumers for more insightful results. A trained panel would provide more detailed and reproducible results giving more insights into the sensory attributes of the crackers. Some of the terms used by the consumers might mean different things to different panelists, as these were not standardized as commonly done for conventional descriptive evaluation. Even though products were tested blind, consumer familiarity might have interfered with their perception as these are commercial products.

Conclusion

Commercially available gluten-free crackers were evaluated by untrained panelists using the projective mapping technique and modified flash profile. The need for continuous and fast innovation calls for rapid methods, as conventional methods can be quite time consuming and require a lot of resources. The rapid methods help to generate terms which are easy to understand for consumers and marketers and not only sensory scientists or product developers. Sixteen commercially available gluten-free crackers were initially evaluated using projective mapping which helped to narrow down the selection of samples for the follow-up rapid panel using modified flash profile, descriptive panel, and consumer study. The selected samples were evaluated by the rapid panel. This panel generated 71 terms as a group (30 terms for aroma, 28 terms for flavor, 12 terms for texture, and one term for mouthfeel). These terms were evaluated on a 4-point scale with 0 = none, 1 = low, 2 = medium, and 3 = high. The results helped to characterize the commercially available gluten free crackers in the United States and their relation to various aroma, texture, and flavor modalities, which at the same time, helps provide a better understanding of the sensory space in which most commercially available crackers exist in the market. White rice crackers (LANCGF, KAMGF, GLUTGF), tapioca/potato starch blend (ABSOGF), millet blend (SCHAGF) crackers were sweet, oily, oat, butter, grain and cheese. Cassava flour (CRUNGF) and SIMIGF (nut flour blend) crackers were described as garlic, herb, savory and salt. Brown rice formulations (MAGOGF, SESGF) were placed closer together and were clearly differentiated using brown rice, flaxseed, green, nut and sesame.

The consumer panel showed great acumen in characterizing the crackers. Fifteen aroma and flavor terms were common in both the descriptive and consumer panel. Almost all the terms (5 out of 7) generated for texture by the descriptive panel were used by the consumer panel. The descriptive panel generated characterization of samples using fewer and concise terms. However, the use of an extensive list of terms by a consumer panel could be helpful in providing a broader understanding of the products for consumers and marketers alike. Rapid techniques can be used initially to understand the sensory descriptors of products using consumers and for broad characterization. However, for generating sensory data which is reproducible, accurate, sensitive, and that has standardized terms which are clearly defined, a conventional descriptive panel is appropriate.

The objective of the study, coupled with budget, time, and cost constraints can be used to select the appropriate method for sensory characterization of products.

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Chapter 3 - Lexicon Development and Descriptive Analysis of Commercially Available Gluten-Free Crackers

Abstract

Descriptive analysis was conducted using five highly trained panelists. All the samples were evaluated for sensory attributes including appearance, overall aroma, flavor, overall aftertaste, and texture. Some of these attributes were common for all crackers such as presence/absence of holes, thickness appearance, roughness appearance, shiny, thickness, hardness, fracturability, gritty, dryness/moisture absorbency, toothstick/toothpack, astringent while others were unique to certain crackers, such as dairy for LANCGF (white rice), coconut (CRUNGF), seaweed and soy sauce (MAGOGF), and black pepper (SESGF). Principal Component Analysis (PCA) results for descriptive analysis showed that crackers with the same flour type were not necessarily placed close together, showing the distinct sensory profiles of crackers even when formulated with the same flour. The first two axes of PCA were able to explain 56.65% of the variability for appearance and texture attributes which was mainly explained by the amount of seeds/inclusions, size of seeds, roughness (from seeds/particulates), and hardness. The first two axes of PCA for aroma/flavor attributes were able to explain 49.1% of the variability and were characterized by earthy, cardboard, burnt, nutty/nut milk, oily, and salty attributes. This information helps better understand the sensory properties of gluten-free crackers and uncover the white spaces in the market. It also serves to provide sensory attribute specifications for product developers in the category.

Introduction

Gluten-free baked products are an important segment of the food industry. The Food and Drug Administration defines a product as gluten-free when it contains less than 20 ppm of gluten proteins. (FAO, 2014). Industrial pollution might have led to a change in the gut micro biome resulting in increased sensitivity to gluten in foods. In the United States, approximately 2 million people are diagnosed as celiac-sensitive (Kahlon et al., 2016). Nevertheless, the sensitivity to gluten is on the rise, and so is the demand for these products. Celiac disease is the result of one or all three factors which are the genetic combination, environmental factors, and immunological factors which lead to intestinal damage. There has been a growing increase in gluten-free options available outside the home, but most patients are limited to prepackaged foods (Caponio et al., 2008). This serves as an additional pressure on the food industry to innovate and come up with solutions. The improvement and progress in gluten-free products benefits people with celiac disease, gluten sensitivity, gluten intolerance, wheat allergy, and non-celiac gluten sensitivity (Woomer & Adedeji, 2021).

Crackers serve as snacks and are often used to complement other meals. Crackers are traditionally made with soft wheat flour where water functions as a plasticizer to help the product to be shaped and molded during production. The gluten in the wheat cracker is integral to the flavor and texture of the cracker. The water in the cracker increases as gluten is not available to hold it and it leads to a reduction in the crispiness of the crackers (Xu et al., 2020). This results in poor sensory quality. The diets of adults with celiac disease are often unbalanced as they have higher energy levels coming from fat rather than carbohydrates (Alvarez-Jubete et al., 2010). This leads to a more challenging nutritional profile for these products. These products also contain lower levels of B vitamins, iron, and fiber. To improve the nutritional profile and sensory aspects of the crackers, various gluten-free flours are used. This has been explored by the use of gluten-free flours such corn (Colombo et al., 2021), rice (Kim & Shin, 2014), potato (Lu et al., 2021), sorghum (Perraulta Lavanya et al., 2023), diverse cereal pseudo cereal legume flours (Dizlek & Polat, 2023); pulse flour and fractions (Han et al., 2010); buckwheat (Sedej et al., 2011) soy pea protein isolates (Nammakuna et al., 2016); chickpea and pumpkin seed press cake flour (Tomić et al., 2022); white and brown tef flour (Rico et al., 2019); carota urens flour (Ranaweera & Gunathilake, 2022); and amaranth flour (Hozová et al., 1997).

Descriptive sensory analysis continues to be one of the most important tools in sensory analysis. This technique uses trained panelists to develop a list of attributes and rate their intensity on a scale. Lexicon development employs trained descriptive panelists to create a frame of reference for products. They come up with a list of attributes and generate the vocabulary for the entire group of products using consensus. They go on to eliminate the redundant terms from the said vocabulary (Lawless et al., 2012). The lexicon plays a crucial role in serving as a communication tool among sensory panelists, product developers, and marketing professionals who may have a different understanding of the terms/attributes involved (Suwonsichon, 2019).

The spectrum method for descriptive analysis is a robust method that generates robust product profile with its attributes and intensities and allows for product profiles to be compared over different products. It utilizes a universal 150-point scale. The highest intensity point is 150. The intensities are rated relative to the absolute universal scale and not relative to each other which allows for comparison not only in a particular product category but across multiple product categories. The evaluation of different products is done individually or by consensus method. The independent ratings are analyzed using ANOVA and consensus ratings are analyzed using PCA (Kemp et al., 2018).

There have been no lexicon development studies for gluten-free crackers. However, a list has been compiled of various studies using descriptive analysis to characterize the sensory properties of baked products in general (Table 3.1). The objective of this research was to develop a lexicon for commercially available gluten-free crackers and describe their sensory characteristics.

Table 3.1 List of Sensory Characteristics Used to Describe Gluten-Free Crackers in Previous Studies

Name of the study	Sensory Attributes
The Instrumental Texture, Descriptive Sensory Profile, and Overall Consumer Acceptability of Lentil Enriched Crackers (Li, 2020)	Beany Floury Roased legumy Buttery popcorn Cheesy Saltiney Baked Salty Bitter Umami aftertaste Salty aftertaste Beany aftertaste Floury aftertaste Crunchy Snappy Easy to dissolve Tooth packing Crumbly Gritty Flaky Moisture absorbing
Effect of Wheat Replacement by Pulse Flours on the Texture, Color and Sensorial Characteristics of Crackers: Flash Profile Analysis (Koukoumaki et al., 2022)	Burnt Floury Buttery Hard Crispy Healthy-tasting Nutty

	Savory Salty Dry Rigid Wheat/Wheaty Bland Flaky Bitter Solid Brittle Rough Grainy Aromatic Dry Salty Savory Sweet Rough Raw Pea Tough Thick Tender Oily Layered Flaky Creamy Soggy Spicy
Sensory Descriptive Analysis, Sensory Acceptability and Expectation Studies on Biscuits with Reduced Added Salt and Increased Fiber (Vazquez et al., 2009)	Color Intensity Toasted color uniformity Height/thickness Presence of bran Internal Airiness Fried aroma and flavor Baked/toasted aroma and flavor Frying oil Baked/toasted dough Salty Bran taste Residual taste Manual Hardness Oral Crispy texture

Sodium Reduction in Crackers: Optimization of Process to Keep Sensory Quality Without Technological Impacts (Pieta Et Al., 2021)	Color Uniformity Roast Color Thickness Brightness Roast Aroma Mignon Cracker Flavor Bread Aroma Salty Taste Sweet Taste Aftertaste (bitter or residual) Hardness Crunchiness
Sensory Characteristics and Consumer Acceptance of Bread and Cracker Products Made from Red or White Wheat (Challacombe et al., 2011)	Sweet Salt Sour Bitter Astringent Grainlike Wheat Toast Yeast Malted Molasses Branlike Dairy Earthy Hard Crisp Coarse
Quality Assessment of Gluten-Free Crackers Based on Buckwheat Flour (Sedej et al., 2011)	Appearance (shape, uniformity, surface) Texture (Structure, break, firmness) Chewiness Aroma Odour Taste
Lexicon Development for the Sensory Description of Rye Bread (Tran et al., 2019)	Overall grain Wheat like Rye Bran Malt Musty-dry Nutty

	Brown
	Toasted
	Burnt
	Brown-sweet
	Molasses
	Honey
	Dark fruit
	Dark chocolate
	Dough-like
	Leavening
	Yeasty
	Fermented
	Caraway
	Coriander
	Dill
	Anise
	Salt
	Sweet
	Sour
	Bitter
	Astringent
Lexicon for the Sensory Description of Bread in Japan (Hayakawa et al., 2010)	Degree of Upraise of Coupe
	Smoothness
	Shape of cross section
	Crust
	Dullness
	Color irregularity
	Darkness of brown color
	Size of cracks
	Size of pores
	Thickness
	Crumb
	Grayish whiteness
	Melted appearance
	Stout
	Starch-like
	Caramel
	Baked chestnut
	Nut
	Sweetness
	Crispiness
	Chewiness
	Moistness
	Firmness

	Elasticity Resisting to dissolve in saliva
Influence of Bread Shape on the Sensory Characteristics of Galician Breads: Development Of Lexicon, Efficacy Control of the Trained Panel and Establishment of a Sensory Profile (Estévez-López Et Al., 2021)	Crust color Crumb color Uniformity of cell distribution Amount of large cells Amount of medium cells Amount of small cells Flour residue Fermented dough odor Moistness Compactness Springiness Crispiness Hardness Softness Adhesiveness Chewiness Sour taste Salty taste Bitter taste Wheat aroma Persistency
Sensory Profile and Quality of Chemically Leavened Gluten-Free Sorghum Bread Containing Different Starches And Hydrocolloids (Ari Akin et al., 2019)	Cell size Cell uniformity Overall grain Nutty, grainy Wheat Cardboard Dry/dusty grain Overall sweet Overall grain Nutty, grainy Wheat Cardboard Dry/Dusty grain Overall sweet Starchy Doughy Leavening Salt Sour Bitter Astringent

	Crumbliness Moistness Denseness Cohesiveness of mass Rate of breakdown Mouth coat, Starchy Tooth-packing

Materials and Methods

Ten gluten-free crackers were selected for descriptive analysis using a projective mapping technique. The study's objective was to only include the crackers that were plain/original so that the effect of different flour blends could be observed on the different sensory attributes. The details of the crackers are mentioned in Table 3.2.

Table 3.2 Gluten-Free Crackers Used for Descriptive Analysis

Name of the Cracker	Code	Flour Base	Ingredients	Variety
Absolutely Gluten-Free Crackers	ABSOGF	Tapioca/Potato starch blend	tapioca starch, water, potato starch, potato flakes, palm oil, honey, egg yolks, natural vinegar, salt	Original
Crunch Master Grain Free Crackers	CRUNGF	Cassava Flour	cassava flour, organic coconut flour, tapioca starch, safflower oil, sea salt, garlic powder	Original
Glutino Gluten-Free Crackers	GLUTGF	White Rice	corn starch, white rice flour, organic palm oil, modified corn starch, eggs, sugar, salt, vegetable fibers, dextrose, guar gum, sodium bicarbonate, natural flavor, monocalcium phosphate, ammonium bicarbonate.	Original
Simple Mills Sea Salt Crackers	SIMIGF	Nut Flour Blend	nut and seed flour blend (almond flour, sunflower seeds, flax seeds), tapioca starch, cassava, organic sunflower oil, sea salt, organic onion, organic garlic, rosemary extract (for freshness)	Sea Salt
Blue Diamond Nut Thins	BLDIGF	White Rice	rice flour, almonds, potato starch, sea salt, safflower oil, natural flavors (contains milk).	Original
Mary's Gone Crackers	MAGOGF	Brown Rice	brown rice, quinoa, flax seeds, sesame seeds, tamari (water, soybeans, salt, vinegar), sea salt.	Original

Name of the Cracker	Code	Flour Base	Ingredients	Variety
Schar Table Gluten-Free Crackers	SCHAGF	Millet Blend	non GMO corn starch, vegetable fats and oils (palm, palm kernel, non GMO rape seed), maltodextrin, modified tapioca starch, whole millet flour, non GMO soy flour, rice syrup, whole rice flour, buckwheat flour, sorghum flour, flax seed flour, non GMO corn flour, dried sourdough (buckwheat, quinoa), non GMO soy bran, poppy seeds, non GMO sugar beet syrup, sea salt, cream of tartar, ammonium bicarbonate, baking powder, guar gum, modified cellulose, citric acid, natural flavoring (rosemary).	Original
Lance Gluten-Free Crackers	LANCGF	White Rice	palm oil, rice flour, rice starch, sugar, corn starch, potato starch, baking soda, tapioca flour, glucose, xanthan gum, monocalcium phosphate, salt, soy lecithin, locust bean gum, non-fat milk.	Original
Ka Me Rice Crackers	KAMGF	Jasmine Rice	jasmine rice, rice bran oil, sea salt, soybean tocopherols (preservative).	Original
Sesmark Gluten-Free Crackers	SESGF	Brown Rice	rice flour, expeller pressed safflower oil, sesame seeds, sesame flour, wheat free tamari soy sauce powder [tamari soy sauce (soybeans, salt), maltodextrin (from corn)], wheat free teriyaki powder [wheat free teriyaki sauce (tamari soy sauce [soybeans, salt], sake (rice, salt), apple cider vinegar, garlic, mustard, ginger, white and black pepper), maltodextrin, sucrose, fructose], onion powder and soy lecithin	Sea Salt

Five highly trained panelists from Sensation Research, Mason, Ohio participated in the descriptive analysis and used consensus method for evaluation. All the panelists had received descriptive sensory training of 7 –12 years on different food and beverage products including crackers and baked products. Three of the five panelists developed the language prior to the evaluation. This was followed by a 1.5-hour long orientation session. This orientation session consisted of all five panelists becoming familiar with the language and references and were asked to make any adjustments if needed. Panelists were instructed to add or remove attributes as per their perception i.e., if a new attribute was perceived, the panel would discuss and if agreed, the attribute would be added to the list. A lexicon of 43 attributes was developed to describe and characterize various gluten-free crackers of "regular" or "plain" flavors. Each attribute was clearly defined and assigned a reference standard shown in Table 3.3. The appearance attributes were clearly defined but did not include any references and the panelists were asked to visually evaluate the product based on the attribute and its definition. The aroma/flavor references were not assigned intensities. These were only used as identifiers for the particular attribute by the panelists. The texture attributes were assigned clear definitions and references with intensities. The final list of attributes as shown in Table 3.3, included appearance (10 attributes), aroma/flavor (26 attributes), and texture (7 attributes) Then, the panel evaluated all the samples using the consensus method over three 90-minute evaluation sessions, evaluating 4 samples on day 1 and day 2, and 2 on day 3. The samples were served on 4-inch white plates. The Spectrum Analysis Method using consensus was used to evaluate the crackers. A 150-point scale with 1.0 increments was used for intensity quantification of the attributes. Water was provided as the only palate cleanser.

Data Analysis

XLSTAT statistical software (Lumivero, Denver, CO, USA) was used to perform the Principal Component Analysis. Principal Component Analysis (PCA) was applied to the consensus scores of the 43 attributes. PCA was conducted for appearance and texture and separately for aroma/flavor.

Results and Discussion

A lexicon was developed based on 10 samples including a total of 43 descriptive terms (Table 3.3). These attributes have a corresponding definition to describe them and references, which support the characterization of the appearance, texture, and aroma/flavor profiles of the samples. Detailed information about the developed lexicon is listed in Table 3.3.

The commercially available gluten-free crackers were evaluated for 43 attributes by the highly trained descriptive panel. The final list of attributes included appearance (10 attributes), overall aroma, flavor (26 attributes), overall aftertaste, and texture (7 attributes).

Some of these terms have been used to describe the sensory characteristics of gluten-free products in previous studies. This includes crispy, hard, burnt, nutty, and rough that were used to describe crackers formulated with pulse flour (Koukoumaki et al., 2022). Those attributes align with the terms crispness, hardness, burnt, and nutty/nut milk used in the current study. Additionally, attributes toothpacking and gritty have been used as descriptors for lentil-enriched crackers (Li, 2020) which is similar to the attributes toothstick/toothpack and grit/chalky/mouthcoat used in this study. The attributes for various basic tastes have been used to describe crackers formulated with pulse flour, sodium-reduced, sorghum bread, and crackers made from red or white wheat (Koukoumaki et al., 2022; Pieta et al., 2021 & Challacombe et al., 2011). The attributes cardboard and astringent have also been used in a previous study to describe sorghum bread (Ari Akin et al., 2019).

Table 3.3 Final Developed Language for Gluten-Free Crackers

Attributes	Definitions	References
Appearance		
Color Comment	Color(s) of sample.	N/A
Shape Comment	Geometric shape of cracker.	N/A
Holes Comment (yes/no)	Deliberately added holes through sample.	N/A
Thickness	The perceived average thickness of sample.	N/A
Shiny	The appearance of the surface of the sample from no shine to high shine as viewed under lamp light.	N/A
Amount of seeds	The amount of seeds present as measured.	N/A
Size of seeds	The appearance of small to large seeds as viewed under lamp light.	N/A
Rough	Visually how smooth or rough the product appears.	N/A
Seasoning particulates	The number of particulates visible on the surface of the product.	N/A
Uneven Browning	The uneven visual browning throughout the product.	N/A
Aroma/Flavor		
Overall Aroma	Aroma associated with total aromatics.	N/A
Overall Flavor	Flavor associated with total aromatics.	N/A
Sweet	The basic taste, perceived on the tongue, simulated by sugars and high potency sweeteners.	Sucrose in spring water
Salty	The basic taste, perceived on the tongue, simulated by sodium salt, especially sodium chloride.	Sodium chloride in spring water
Sour	The basic taste, perceived on the tongue, simulated by acids, such as citric acid.	Citric acid in spring water
Bitter	The basic taste, perceived on the tongue, simulated by substances such as quinine, caffeine, and certain other alkaloids.	Caffeine in spring water
Astringent	The drying effect the product has in the mouth, after 3 sips/chewing and swallowing.	Mott's apple juice=40, Welch's grape juice=80
Starch Complex	The overall taste of combined starches and flours in a product.	Concept
Rice (flour, starch)	Flavor associated with rice flour.	Bob's red mill white rice flour
Potato (flour, starch)	Flavor associated with potato flour.	Baked lays
Coconut/Coconut Flour	Flavor associated with coconut.	Kroger unsweetened coconut flakes
Wheat-like	Flavor associated with wheat flour.	Nabisco wheat thins
Baking soda	Flavor associated with the taste of baking soda.	Arm & Hammer baking soda

Attributes	Definitions	References
Dairy/buttery	Flavor associated with butter or butter solids.	Land O Lakes unsalted butter
Seaweed	Flavor associated with seaweed.	Yamamotoyama roasted seaweed
Garlic/onion	Flavor associated with garlic, garlic powder, or dried onion powder.	McCormick's garlic/onion powder
Soy Sauce	Flavor associated with soy sauce.	Kikkoman soy sauce
Toasted	Flavor associated with toasted bread.	Wonder white bread, medium toasted in toaster
Herbs	Flavor associated with herbal flavor.	McCormick thyme, rosemary
Black pepper	Flavor associated with black pepper.	McCormick black pepper
Oily	Flavor associated with the taste of oil.	Wesson Vegetable oil
Burnt	The bitter/acrid taste of burnt/charred.	Gold medal flour cooked to very brown in sauté pan
Cardboard	The taste of slightly oxidized paper/cardboard.	Cardboard hydrated with water
Irritating	The irritation felt on the tongue.	Concept
Burning heat from pepper	The burn felt on the tongue from peppers.	McCormick's cracked black pepper
True to Gluten	The perception of a full gluten cracker recipe.	N/A
Texture		
Thickness	The perceived thickness of the cracker in the mouth. Chew the sample until ready to swallow. Evaluate the chip thickness.	Lays potato chips = 15, Lays kettle chip = 55
Hardness	The force/work required to compress the sample between the molars multiple times. Place the sample between the molars and bite or chew down evenly, measuring the force required to break through the sample.	Kellogg's Rice Crispies=15, Malt O Meal Golden Puffs=25, Lays Potato chips = 35, Kellogg's Honey Puffs =45, Kellogg's Corn Pops=60, Lays Kettle chips = 80
Fracturability	The degree to which the samples fractures when compressed between molars. Place sample between molars and chew down evenly, measuring the degree to which the sample fractures.	Cheeto puff = 25, Lay's kettle flat =75, Nabisco saltine =100, and Lay's classic = 125
Roughness from seeds/particulates	The rough feeling from seeds or particulates.	N/A
Grit/chalky/mouthcoat	The feeling of gritty or chalky coating in the mouth. Move the chewed sample around in the mouth and determine the size and amount of the grit.	Arm & Hammer baking soda = 40, Quaker cornmeal 125-130
Dryness/Moisture absorbency	Amount of drying in the mouth when sample is chewed. Take a sip of water. Place the sample between the molars and chew 10 to 12 times, swallow or expectorate, then measure the drying effect.	Quaker rice cake =100

Toothstick / Toothpack	Degree to which the sample sticks to the surface of the teeth.	After sample is swallowed or expectorated, feel the surfaces of molars with the tongue. Cheetos Puffs = 150

Appearance

The panel conducted a detailed evaluation of the appearance attributes of the crackers. The terms are clearly defined in Table 3.3. Some of the attributes are common among all crackers - the presence of holes, color, thickness appearance, and rough appearance. Other attributes were present only in certain crackers. The terms unique for some crackers were the amount of seeds/inclusions, size of seeds, and seasoning particulates, which made sense as this depended on whether the cracker used seeds or flax in its formulation or not. Another attribute that was only common to some crackers was uneven browning which was defined as the uneven visual browning throughout the product. A similar term ‘toasted color uniformity’ was used by Vazquez et al. 2014, for descriptive analysis on biscuits with reduced added salt and increased fiber. The intensity scores are listed in Table 3.4. ABSOGF, LANCGF, GLUTGF, and SIMIGF exhibited the presence of holes, while BLDIGF, SESGF, CRUNGF, KAMGF, and MAGOGF had no holes. These crackers displayed a diverse array of shapes, ranging from circular and scalloped circle to hexagonal, square, and rough-edged rectangles. SCHAGF and GLUTGF were noted for their thick appearance, while SIMIGF and BLDIGF were perceived as thinner in comparison. Additionally, CRUNGF, KAMGF, SESGF, and BLDIGF received high consensus scores surpassing 100, for their shiny appearance. SCHAGF, BLDIGF, SESGF, SIMIGF, and MAGOGF were characterized by the presence of seeds and inclusions. Conversely, ABSOGF, LANCGF, GLUTGF, CRUNGF, and KAMGF were given a score of 0, indicating an absence of seeds or inclusions. Among these, MAGOGF received a high consensus score for the amount of seeds. Some crackers exhibited uneven browning, with ABSOGF and SESGF displaying the highest uneven browning, and MAGOGF showing the least. All crackers were perceived as rough, with consensus scores exceeding 55. Certain crackers were noted to have seasoning (SCHAGF, BLDIGF, LANCGF, SESGF, SIMIGF, CRUNGF, KAMGF), distinguishing them from others in this aspect. Overall, this evaluation provides valuable insights into the varied visual characteristics of the different cracker varieties. However, it can be noted that flour type does not affect appearance characteristics as crackers from a particular flour type do not have similar presence or absence of appearance attributes.

Aroma/Flavor

The panel evaluated the crackers for 26 aroma and flavor attributes. These are defined in Table 3.3. The intensity scores are clearly listed in Table 3.4. ABSOGF had the lowest overall aroma intensity, receiving a consensus score of only 22. The other samples had variable overall aroma intensity. Among these, SIMIGF and MAGOGF had the highest aroma intensity with consensus scores of 123 and 125, respectively. Meanwhile, GLUTGF, SCHAGF, and CRUNGF had moderate overall aroma intensities. Basic tastes including sweet, salty, sour, and bitter were evaluated. Only one sample, MAGOGF, had no sweetness. Other crackers, BLDIGF, ABSOGF, SESGF, and KAMGF were also low on sweetness. LANCGF was the cracker with the highest sweetness score. MAGOGF had no salty and sour flavor but received a score of 42 for bitterness, providing insights into the sensory profile of this brown rice and flax cracker for various basic tastes.

SIMIGF was the cracker with the highest salty score with a consensus score of 83. KAMGF, MAGOGF, and BLDIGF were not sour, and all other samples also received low scores indicating that sourness is not a predominant characteristic in gluten-free crackers. GLUTGF was the most bitter sample, whereas ABSOGF and MAGOGF showed moderate bitterness. The remaining crackers received low scores for bitterness. All crackers were moderate for astringency, with consensus scores ranging from 40 to 71. SCHAGF had the highest starch complexity. Interestingly, while all samples scored above 65 for starch complexity, ABSOGF, which was a blend of starch and tapioca, did not have the highest intensity for this attribute.

Rice character was most prominent in BLDIGF, LANCGF, SESGF, KAMGF, and GLUTGF, all of which were rice-based formulations. SCHAGF received a consensus score of 40 for rice (flour, starch) but 90 for starch complex, indicating a perception of more starch complexity than rice character. Potato (flour/starch) was identified in only two of the ten samples, with ABSOGF receiving a score of 70 and LANCGF receiving a score of 40.

Some aroma/flavor attributes were unique to certain crackers. Coconut (flour) attribute was exclusive to CRUNGF. Only two crackers, ABSOGF and SCHAGF, were noted for their wheat-like attributes. Baking soda received varying intensities in six of the ten samples, with GLUTGF receiving the highest score of 80. Seedy/Sesame/Flax attributes were present in only three crackers – SCHAGF, SIMIGF, and MAGOGF – with MAGOGF exhibiting the highest intensity at 145. Dairy/butter attributes were found exclusively in LANCGF. The nutty/nut milk attribute was noted in five samples – SCHAGF, BLDIGF, SIMIGF, CRUNGF, and KAMGF. Seaweed and soy sauce attributes were exclusively present in MAGOGF, while garlic/onion attributes were identified in SIMIGF and CRUNGF.

MAGOGF and SESGF were the only crackers in which 'toasted' was not present. SCHAGF was the most toasted sample, while GLUTGF, SIMIGF, CRUNGF, and KAMGF had consensus scores lower or equal to 40 for the attribute 'toasted'. Herbs were only present in SCHAGF and SIMIGF. Black pepper was only present in SESGF.

The 'oily' attribute was present in intensities equal to or lower than 40 in BLDIGF, LANCGF, SIMIGF, CRUNGF, and KAMGF. The 'earthy' attribute was present in LANCGF, MAGOGF, and in a very low intensity in SCHAGF. ABSOGF, LANCGF, and MAGOGF were characterized as having a burnt aroma/flavor. Cardboard aroma/flavor was present in seven of the samples with lower or equal to 40 intensities. Only BLDIGF sample was not described using the term irritating. The rest of these samples were given intensities in the range of 15 to 45. Burning heat from pepper was only present in SESGF and CRUNGF. All crackers but MAGOGF were characterized by the term ‘true to gluten’. Crackers SCHAGF and ABSOGF were given scores of 118 and 110, respectively, showing their strong resemblance to a gluten cracker. BLDIGF, SESGF, GLUTGF, CRUNGF and KAMGF were given relatively low scores for this attribute. Overall aftertaste was most pronounced in MAGOGF and SESGF. It was the least intense for ABSOGF and KAMGF.

Texture

The panelists gave a consensus score to all the texture attributes. All the terms were clearly defined and assigned references (Table 3.3). The intensity scores are clearly listed in Table 3.4. The crackers SCHAGF and GLUTGF were the thickest. For hardness, all samples were given consensus scores above 90, except for SIMIGF which was not as hard as other crackers with a consensus score of 72. This shows that hardness is a predominant attribute in gluten-free crackers. MAGOGF had the highest levels of hardness, fracturability and roughness. Only crackers ABSOGF, SESGF, CRUNGF, and MAGOGF were characterized by roughness.

The attributes gritty, chalky, and mouthcoat were noted in all crackers, with GLUTGF and MAGOGF receiving particularly high consensus scores, surpassing 100. Dryness and moisture absorbency were observed to varying degrees across the samples. All crackers were characterized by the attribute toothstick/toothpack with consensus scores ranging between 80 and 120.

Table 3.4 Intensities for Gluten-Free Crackers in Descriptive Analysis

	SCHAGF	**BLDIGF**	**ABSOGF**	**LANCGF**	**SESGF**	**GLUTGF**	**SIMIGF**	**CRUNGF**	**KAMGF**	**MAGOGF**
	Millet blend	White rice	Tapioca/ potato starch	White rice	Brown rice	White rice	Nut blend	Cassava flour	White rice	Brown rice
Holes (yes/no)	yes	no	yes	yes	no	yes	yes	no	no	no
Shape CATA (write in)	rectangle	circle	rectangle	scalloped circle	hexagon	scalloped circle	square	rough edged rectangle	circle	circle
Color	golden tan	cream, brown	white, brown	golden brown	cream, black	cream	tan	orange-tan	creamy white	brown, black
Thickness Appearance	50	20	25	45	28	56	17	25	33	35
Shiny	23	100	20	33	103	15	50	117	110	40
Amt of seeds/inclusions	55	95	0	0	88	0	30	0	0	139
Size of seeds	23	32	0	0	67	0	12	0	0	85
Rough Appearance	55	105	117	103	125	95	81	130	128	129
Seasoning particulates	15	8	0	110	95	0	75	20	24	0
Uneven Browning	117	0	130	105	0	35	47	0	0	27
Thickness	45	35	27	45	30	60	20	35	37	40

	SCHAGF	**BLDIGF**	**ABSOGF**	**LANCGF**	**SESGF**	**GLUTGF**	**SIMI GF**	**CRUNGF**	**KAMGF**	**MAGO GF**
Hardness	101	105	105	107	110	90	72	120	118	133
Fracturability	133	115	125	90	110	102	100	127	123	140
Roughness (from seeds/particulates)	25	0	0	0	40	0	25	0	0	150
Grit/chalky/mouthcoat	75	52	70	90	75	123	85	63	55	110
Dryness/Moisture Absorbency	117	105	135	107	110	127	77	113	107	135
Toothstick/Toothpack	105	102	80	110	95	100	105	90	92	120
Overall Aroma	70	57	22	37	105	80	123	88	35	125
Overall Flavor	98	95	77	105	111	80	125	115	88	135
Sweet	58	30	45	90	18	43	63	70	27	0
Salty	42	75	38	50	70	35	83	75	55	13
Sour	20	0	25	20	0	17	15	20	0	0
Bitter	25	0	45	22	25	100	23	15	0	42
Astringent	65	40	65	55	62	65	60	62	48	71
Starch Complex	90	70	73	85	75	80	68	83	85	0
Rice (flour, starch)	40	70	35	70	75	70	0	62	85	0
Potato (flour, starch)	0	0	70	40	0	0	0	0	0	0
Coconut (flour)	0	0	0	0	0	0	0	75	0	0
Wheat-like	85	0	25	0	0	0	0	0	0	0
Baking soda	30	0	50	35	63	80	18	0	0	0
Seedy/ sesame /flax	95	0	0	0	0	0	50	0	0	145
Dairy/buttery	0	0	0	100	0	0	0	0	0	0
Nutty/nut milk	20	80	0	0	0	0	55	15	20	0
Seaweed	0	0	0	0	0	0	0	0	0	28
Garlic/onion	0	0	0	0	0	0	90	83	0	0
Soy Sauce	0	0	0	0	0	0	0	0	0	30
Toasted	80	17	40	70	0	20	35	25	30	0
Herbs	25	0	0	0	0	0	45	0	0	0
Black pepper	0	0	0	0	90	0	0	0	0	0
Oily	0	35	0	30	0	0	40	25	23	0

	SCH AGF	BLD IGF	ABS OGF	LAN CGF	SES GF	GLU TGF	SIM I GF	CR UN GF	KA MGF	MAG O GF
Earthy	19	0	0	0	88	0	0	0	0	62
Burnt	0	0	48	0	13	0	0	0	0	65
Cardboard	25	17	27	0	29	30	20	0	0	40
Irritating	35	0	22	20	21	45	15	20	15	35
Burning heat from pepper	0	0	0	0	77	0	0	17	0	0
True to Gluten Cracker	118	30	110	55	20	25	50	20	20	0
Overall Aftertaste	75	45	30	80	105	55	97	95	35	115

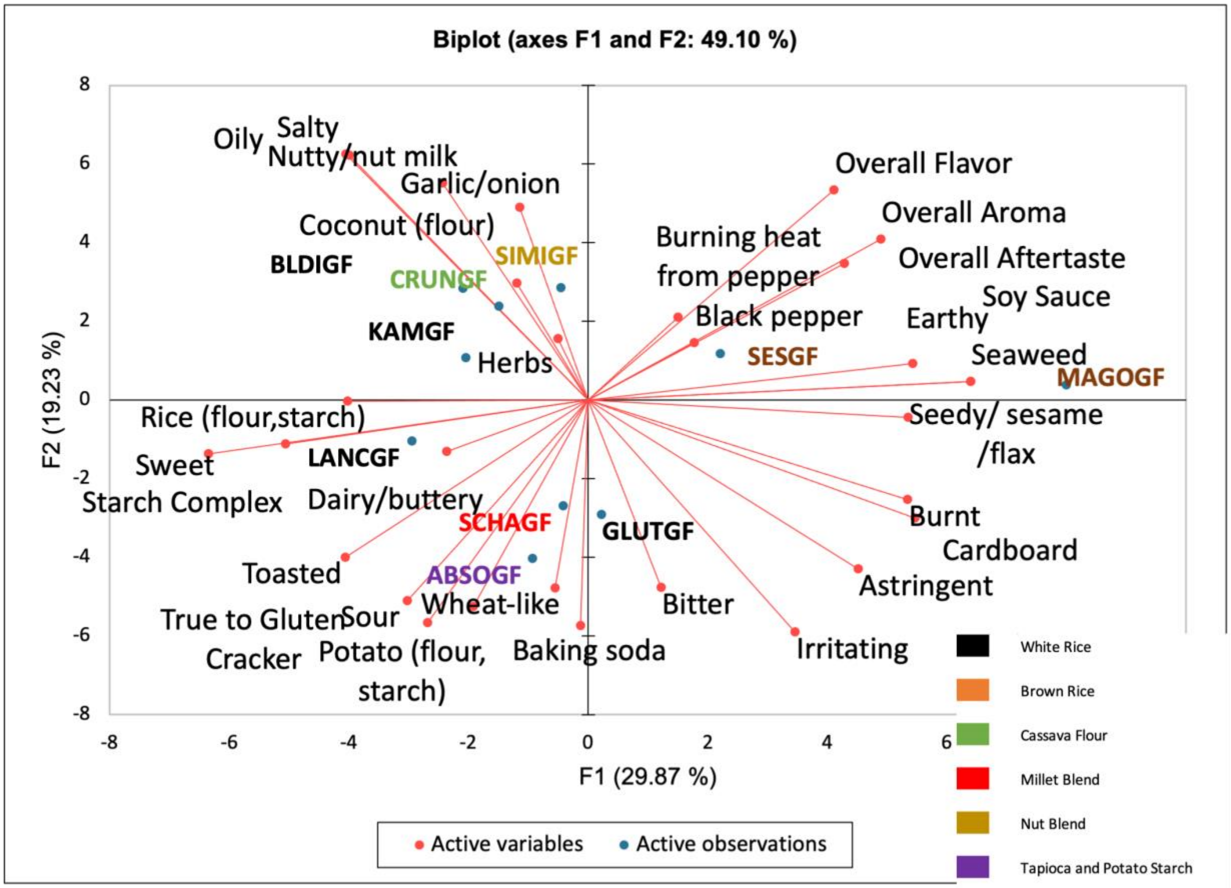
Principal Component Analysis for Aroma/Flavor

Principal Component Analysis was conducted to evaluate the relationship between different aroma/flavor attributes and gluten-free crackers. The first two components were able to explain 49.1% of the variability (Figure 3.1). PC1 was explained by attributes seedy/sesame/flax, seaweed, soy sauce, earthy, burnt, cardboard, astringent, irritating, and black pepper. The attributes along PC1 characterized the samples MAGOGF and SESGF, formulated with brown rice flour. PC2 was explained by oily, salty, nutty/nut milk, garlic/onion, coconut (flour), and herbs. The attributes along PC2 explained KAMGF, CRUNGF, BLDIGF, and SIMIGF crackers. These crackers had different flour compositions and they were: white rice crackers (BLDIGF and KAMGF), cassava flour crackers (CRUNGF), and nut flour blend (SIMIGF).

The attributes rice (flour, starch), sweet, starch complex, dairy/buttery, toasted, sour, wheat-like, true to gluten cracker, and baking soda were negatively loaded on the plot.

The spatial presence of the different gluten-free crackers indicated no relation between the flour type of the crackers and their aroma/flavor attributes. However, LANCGF (white rice) crackers were characterized by the attributes sweet, starch complex, and dairy/buttery. The millet blend crackers, SCHAGF, and the starch blend crackers, ABSOGF, were characterized by the attributes toasted, sour, wheat like, true to gluten cracker, sour, and potato (flour, starch).

Figure 3.1 PCA for Aroma and Flavor Attributes for Gluten-Free Crackers



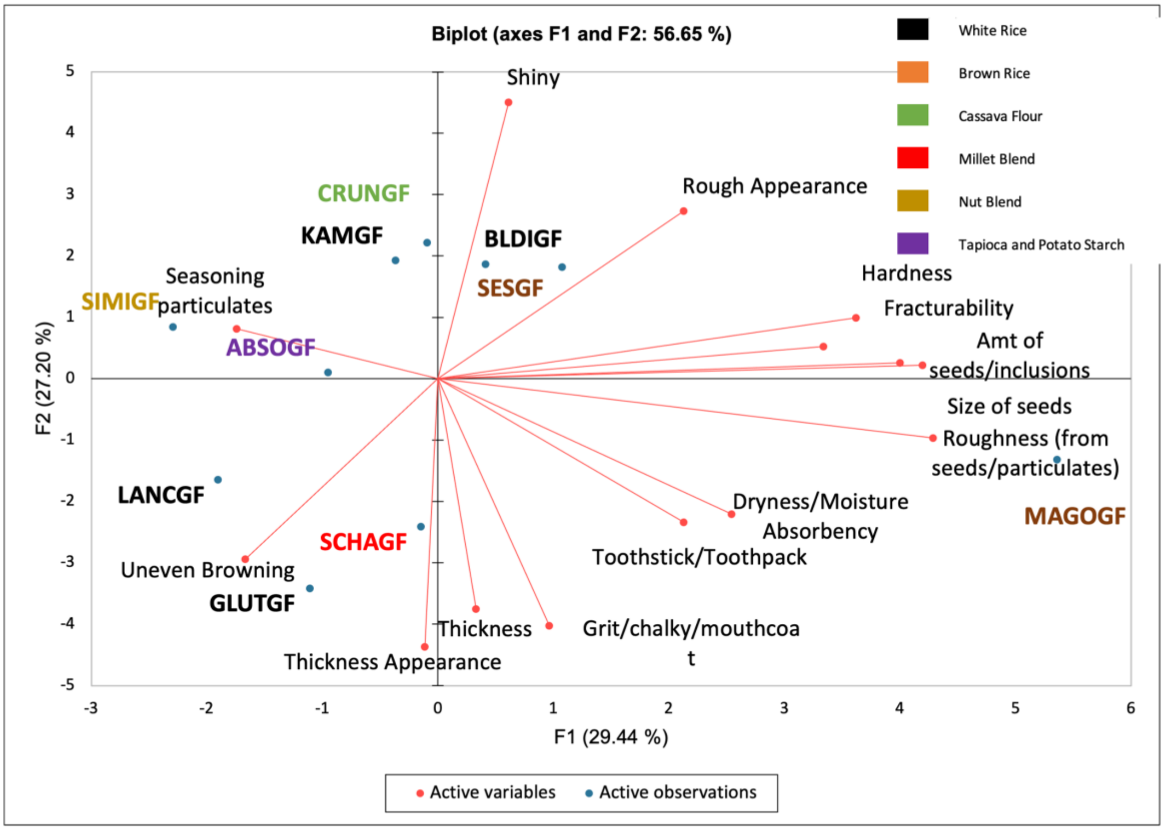
Principal Component Analysis for Appearance and Texture

PC1 and PC2 were able to explain 56.65% of the variability as shown in Figure 3.2. PC1 was explained using attributes size of seeds, amount of seeds/Inclusions, roughness (from seeds/particulates), hardness, fracturablity, rough appearance, dryness/moisture absorbency, toothstick/toothpack, grit/chalky/mouthcoat, and thickness. PC2 was mainly by the attribute seasoning particulates and the attributes shiny, and rough appearance.

The attributes uneven browning and thickness appearance were negatively loaded on the PC biplot. The spatial configurations of the crackers revealed that crackers with a similar flour composition were not necessarily placed together. However, the spatial configurations gave key insights into the associations of the crackers and various appearance/texture attributes.

The crackers SIMIGF (nut and almond flour) and ABSOGF (tapioca and starch blend) were characterized by seasoning particulates. Crackers LANCGF, GLUTGF and SCHAGF had uneven browning and were thick. The crackers CRUNGF and KAMGF were characterized by shiny. The brown rice crackers (MAGOGF and SESGF) were characterized by roughness (from seeds/particulates), size of seeds, and rough appearance.

Figure 3.2 PCA for Appearance and Texture Attributes for Gluten-Free Crackers



Study Limitations

This study focused on only ten commercially available gluten-free crackers. However, it would be good for lexicon development to include a greater number of commercial products to fully understand the gluten-free crackers in the US market.

Conclusion

Five highly trained descriptive panelists evaluated ten commercially available gluten-free crackers in this study. The panel developed a lexicon of 43 attributes, including appearance (10 attributes), overall aroma, flavor (26 attributes), overall aftertaste, and texture (7 attributes). These attributes were used to evaluate the crackers on a 150-point scale.

Some attributes were common to most of the crackers, such as the presence/absence of holes, thickness appearance, roughness appearance, shininess, thickness, hardness, fracturability, grittiness, dryness/moisture absorbency, toothstick/toothpack, and astringency. However, certain attributes were unique to specific crackers, such as dairy for LANCGF (white rice), coconut (CRUNGF), seaweed, soy sauce (MAGOGF), and black pepper (SESGF).

Principal Component Analysis (PCA) for aroma/flavor attributes helped visualize the distinct samples in relation to their attributes. Notably, brown rice crackers (MAGOGF and SESGF) clustered closely together and were described as having seedy/sesame/flax, seaweed, soy sauce, earthy, burnt, cardboard, astringent, irritating, and black pepper attributes. On the other hand, the crackers formulated with nut and seed flour blend, white rice and cassava flour (SIMIGF, KAMGF, CRUNGF, BLDIGF, and SIMIGF) were characterized by attributes such as oily, nutty/nut milk, and herbs.

Principal Component Analysis (PCA) for appearance/texture attributes helped visualize the distinct samples in relation to their appearance and texture characteristics. The brown rice crackers were characterized by attributes such as roughness (from seeds/particulates), the amount of seeds/inclusions, size of seeds, hardness, and fracturability. The white rice crackers (BLDIGF and KAMGF), as well as cassava flour crackers (CRUNGF), were also placed in proximity, and were described as shiny. Furthermore, crackers SIMIGF (nut flour) and ABSOGF (tapioca and starch blend) were distinguished by seasoning particulates. In contrast, crackers LANCGF, GLUTGF, and SCHAGF displayed uneven browning and a thick texture. Generally, for commercially available gluten-free crackers and based on their main sensory dimensions, there does not appear to be a clear differentiation or patterns among various products depending on their main grain source. Manufacturing process and other added ingredients seem to have a higher influence on the appearance, aroma, flavor, and texture of these products. Still, this is not conclusive. A more controlled study with specific ingredient variations will be needed to fully assess the effect that flour source has on the sensory properties of gluten free crackers.

This study offers valuable insights into the appearance, texture, aroma, and flavor attributes of crackers, serving as a guide for the food industry in product development. It helps uncover the unique characteristics of various gluten-free crackers, aiding in the identification of areas for product improvement and innovation within this market category.

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Chapter 4 - Consumer Perception of Commercially Available Gluten-Free Crackers

Abstract

Ten (10) commercially available gluten-free crackers with different grain sources and compositions from different popular brands were selected. The objectives of this study were to investigate 1) consumer liking of commercially available gluten-free crackers with different sensory profiles, 2) investigate drivers of liking using CATA questions and 3) to understand the gluten-free cracker market and potential sensory white spaces. A central location test was performed using (N= 104) consumers who are frequent gluten-free cracker users. Results showed a huge scope for improvement in consumer perception of the sensory qualities of gluten-free crackers. Only one of the ten products evaluated received an overall mean liking of 7.0 which indicated 'like moderately' ($p<0.05$) whereas four crackers received a mean liking score of 6.0 indicating that they were liked slightly. The results also showed that one of the crackers made with white rice flour had the highest overall liking, flavor liking, and texture liking. Aroma liking was highest for a cracker made with nut flour blend being one of the two samples which used rosemary for freshness in its formulation. The performance of a white rice cracker with a dairy ingredient was significantly higher than other samples showing that there is a huge white space in the market. This study helps understand the gluten-free cracker market space in the United States at present. It also shows that most crackers were penalized for too little flavor intensity, too little sweetness, and too little nutty and toasty flavor representing the want for higher and more well-rounded flavor profiles. They were also penalized for strong aftertaste intensity. Texture was also penalized for hardness, oiliness, and crispiness.

Introduction

Crackers are baked products that are a significant segment of the snack market. The classification can be varied but they are often characterized as dry, thin, flaky, and crispy. They can be either plain or savory. They are traditionally made with soft wheat flour which contains gluten. (Xu et al., 2020) Gluten in crackers is a vital component that affects the texture and is responsible for the crispiness of crackers. Thus, the production of gluten-free crackers is more challenging than products with gluten. The challenge arises from the lack of a gluten network in gluten-free dough to retain air and carbon dioxide. Crispiness is an important sensory attribute for cracker quality. The different flour blends used in gluten-free cracker production are pulse flour, buckwheat, sorghum, potato flour, and soy, pea, and wheat protein isolates. (Xu et al., 2020). Tomic et al. (2022) points out that the reason for choosing rice and corn flour to produce gluten-free crackers is that they have acceptable color, neutral taste, and hypo allergic properties.

Gluten-free products are consumed worldwide by not only people who have celiac disease, wheat allergies, gluten ataxia, non-celiac gluten sensitivity, and wheat-dependent gluten ataxia but also by those who prefer gluten-free products. These products are also consumed by people who live with someone who has gluten sensitivity and by those who follow the trend of the gluten-free diet (Khairuddin & Lasekan, 2021). This trend has become popular in most Western countries such as the United States, UK, and many countries in Europe among the large population who perceive gluten-free products as unhealthy and believe that consuming gluten-free products is healthier compared to consuming wheat products. It becomes increasingly important in these circumstances to evaluate the consumer acceptability of commercially available crackers, discover limitations, and uncover white spaces in the market. The avoidance of gluten is the only treatment for people who have celiac disease or gluten-related sensitivity.

Gluten-free crackers are manufactured from refined gluten-free grains or just starch (Perraulta Lavanya et al., 2023). Gluten-free products are challenged by poor nutritional profiles which arise because most commercial products are low in protein and fiber, high in saturated fatty acids, and glycemic index which leads to vitamin and micronutrient deficiency.

The different flours that can be used to formulate gluten-free products are rice, corn, amaranth, quinoa, buckwheat, maize, millet, sorghum, chestnut, chia seed, and legume flour. The technological challenge associated with making gluten-free products has been alleviated using hydrocolloids such as guar gum and xanthan gum, starch, protein, fiber, dairy ingredients, enzymes, and sourdough. Hydrocolloids can be used to replace gluten because of their network-forming abilities and water retention capacities. Modified starch is often used in the baking industry to achieve thickening and more elastic crumb structure. Protein enrichment prevents structural disintegration. The addition of fiber leads to better porosity and volume in baked products. The incorporation of dairy ingredients helps facilitate improved flavor and texture. Sourdough has also been used to increase the quality of gluten-free products as the acidification of dough by sourdough can to a small degree replace the function of gluten (Hosseini et al., 2018).

There is limited literature on the functionality of gluten-free technologies in crackers. In gluten-free crackers, hydrocolloids increase puffiness, which is an important parameter of cracker quality, and the addition of protein isolate increases water activity and moisture content, while adding whey protein can help to achieve elasticity. Rice crackers do not have gluten protein to hold the gas during fermentation and this leads to a crumbly rice cracker. This challenge has been overcome by adding whey protein to the crackers. Crackers manufactured with sorghum flour showed no difference in acceptability with soft wheat crackers. However, the soft wheat crackers performed better for flavor, crispiness, and mouthfeel attributes. Sorghum crackers were liked more for their appearance and color attributes. The addition of tef flour to rice flour for the manufacture of gluten-free crackers showed an increase in antioxidant properties and a reduction in glycemic index (Rico et al., 2019). The sensory acceptability and profile were also similar to rice crackers and crackers composed of 50% teff and 50% rice flour. Crackers manufactured with the addition of carob peel and germ showed a lower sensory acceptability, however, the antioxidant content was higher for these crackers (Martin-Diana et al., 2017). The addition of caryota urens flour to rice flour for production of gluten free crackers had higher phenolic content, however, the sensory acceptability of these crackers was not studied (Ranaweera & Gunathilake, 2022). The formulation of crackers with chickpea and pumpkin seed pressed flour also received high acceptability scores as well as were higher in nutritional content (Tomić et al., 2022). The fortification of millet crackers with sorghum and soybean flour resulted in higher overall acceptability, and flavor liking, however, there was minor impact on texture liking (Pandit et al., 2021). The overall acceptability was impacted by lower flavor liking in the manufacture of crackers using pulse flours and fractions (Han et al., 2010) The nutritional quality of crackers manufactured using cassava and sweet potato flour was higher, but their sensory acceptability was not studied (Elwakeel & Ismael, 2022). The addition of apple pomace to brown rice led to higher flavor and texture acceptability compared to brown rice crackers but there were no differences in overall acceptability (Mir et al., 2017). The replacement of green gram flour led to lower sensory acceptability for all sensory attributes - flavor, texture, appearance, and color (Venkatachalam & Nagarajan, 2017). The addition of sourdough to gluten-free dough has been shown to improve the texture and flavor of baked products. The substitution of potato flour with a blend of pseudo-cereal (amaranth, buckwheat, quinoa) flours resulted in a higher overall acceptability as well as higher scores for flavor, chewiness, and crispiness (Turk Aslan & Isik, 2022). Crackers manufactured with hemp seeds, green tea leaves, and chia seeds were described to have a nutty flavor and crunchiness. (Radočaj et al., 2014). It would be interesting to note the effects of different flour and ingredients on sensory attributes such as flavor, aroma, texture, and overall acceptability in commercial gluten-free crackers.

Consumer Testing in a Central Location Test (CLT) has been used in several studies for determining consumer acceptance of various products. One such study evaluated nutritional, functional, and sensory properties of gluten-free crackers based on chickpea and pumpkin seed press cake flour (Tomić et al., 2022). Additionally, check all that apply (CATA) questions were asked for various attributes to understand the sensory space further. A CATA question consists of a list of attributes that requires the respondent to select all the attributes applicable to the given product or question. Ares et al., 2014 note that this approach has been used for a wide range of products including crackers.

In general terms, gluten-free crackers are consumed by a significant number of people in the United States. These are consumers who may or may not be allergic to gluten in baked products. For patients with celiac disease, cutting out gluten completely is the only treatment available. As a result, there are various commercial products available, although they are limited in their nutritional and sensory characteristics. Therefore, it becomes important to collect information on consumers' acceptance of gluten-free crackers. The objectives of this study, therefore, were to investigate 1) consumer liking of commercially available gluten-free crackers with different sensory profiles, 2) investigate drivers of liking using CATA questions and 3) to understand the gluten-free cracker market and potential sensory white spaces.

Materials and Methods

Ten (10) commercially available gluten-free crackers were selected for this study. The ten selected gluten-free crackers had different grain, starch and ingredient compositions and were from varied brands. The details of the selected crackers are mentioned in Table 4.1. The selected crackers were plain/original and offered good representation of the commercial gluten-free crackers in the market. The crackers were served in odor-free 4-oz cups covered with clear lids (Dart, Mason, Michigan, USA) at room temperature. The crackers were placed in cups just before the CLT in the morning of testing day to minimize effects in texture and were labeled with random three-digit codes. Water was given to rinse the palate in between products. Products were presented to consumers as gluten-free crackers. No other information about the crackers was made available.

Table 4.1 Gluten-Free Crackers Used in the Central Location Test

Name of the Cracker	Code	Flour Base	Ingredients	Variety
Absolutely Gluten-Free Crackers	ABSOGF	Tapioca/Potato Starch Blend	tapioca starch, water, potato starch, potato flakes, palm oil, honey, egg yolks, natural vinegar, salt	Original
CrunchMaster Crackers	CRUNGF	Cassava	cassava flour, organic coconut flour, tapioca starch, safflower oil, sea salt, garlic powder	Original
Glutino Gluten-Free Crackers	GLUTGF	White Rice	corn starch, white rice flour, organic palm oil, modified corn starch, eggs, sugar, salt, vegetable fibers, dextrose, guar gum, sodium bicarbonate, natural flavor, monocalcium phosphate, ammonium bicarbonate.	Original
Simple Mills Sea Salt Crackers	SIMIGF	Nut Flour Blend	nut blend (almond flour, sunflower seeds, flax seeds), tapioca starch, cassava, organic sunflower oil, sea salt, organic onion, organic garlic, rosemary extract (for freshness)	Sea Salt
Blue Diamond Nut Thins	BLDIGF	White Rice	rice flour, almonds, potato starch, sea salt, safflower oil, natural flavors (contains milk).	Original

Name of the Cracker	Code	Flour Base	Ingredients	Variety
Mary's Gone Crackers	MAGOGF	Brown Rice	brown rice, quinoa, flax seeds, sesame seeds, tamari (water, soybeans, salt, vinegar), sea salt.	Original
Schar Table Gluten-Free Crackers	SCHAGF	Millet Blend	non gmo corn starch, vegetable fats and oils (palm, palm kernel, non gmo rape seed), maltodextrin, modified tapioca starch, whole millet flour, non gmo soy flour, rice syrup, whole rice flour, buckwheat flour, sorghum flour, flax seed flour, non gmo corn flour, dried sourdough (buckwheat, quinoa), non gmo soy bran, poppy seeds, non gmo sugar beet syrup, sea salt, cream of tartar, ammonium bicarbonate, baking powder, guar gum, modified cellulose, citric acid, natural flavoring (rosemary).	Original
Lance Gluten-Free Crackers	LANCGF	White Rice	palm oil, rice flour, rice starch, sugar, corn starch, potato starch, baking soda, tapioca flour, glucose, xanthan gum, monocalcium phosphate, salt, soy lecithin, locust bean gum, non-fat milk.	Original
Ka Me Rice Crackers	KAMGF	Jasmine Rice	jasmine rice, rice bran oil, sea salt, soybean tocopherols (preservative).	Original
Sesmark Gluten-Free Crackers	SESGF	Brown Rice	rice flour, expeller pressed safflower oil, sesame seeds, sesame flour, wheat free tamari soy sauce powder [tamari soy sauce (soybeans, salt), maltodextrin (from corn)], wheat free teriyaki powder [wheat free teriyaki sauce (tamari soy sauce [soybeans, salt], sake (rice, salt), apple cider vinegar, garlic, mustard, ginger, white and black pepper), maltodextrin, sucrose, fructose], onion powder and soy lecithin	Sea Salt

Participant Recruitment

A total of N=104 participants (males and females) were recruited from a consumer database of over 8,000 people of the Kansas City area from the Sensory and Consumer Research

Center at Kansas State University (Olathe, Kansas, USA). The demographics are mentioned in Table 4.2. Consumers had to be frequent users of gluten-free crackers. Participants were required not to work for any food company to avoid bias. They should not have participated in Consumer research in the last 3 months. They were from diverse age groups of 18 to 65 years of age. They were also asked about their reasons for consuming gluten-free crackers and ten had gluten sensitivity, 10 preferred to live a gluten-free lifestyle and 19 lived with someone who has celiac/gluten-free intolerance/sensitivity so they ate gluten-free crackers and 58 said that they purchase both gluten and gluten-free products, depending on the product.

Table 4.2 Consumer Demographics from the Central Location Test (N=104)

Characteristics	Categories	Percentage (%)
Gender	Male	14%
	Female	86%
Age	Under 18 years	0
	18-25 years	2
	26 – 35 years	12
	36 – 45 years	28
	46 – 55 years	33
	56 – 65 years	26

Questionnaire

Participants were required to sign a consent form prior to the evaluation of products. Compusense Software (Compusense Inc., Guelph, Ontario, Canada) was used for screening of panelists as well as for data collection.

The questionnaire consisted of overall liking, overall appearance liking, aroma liking, aftertaste liking, and texture liking on a 9-point hedonic scale which ranged from dislike extremely (1) to like extremely (9). Consumers were also asked Just About Right (JAR) questions in which they were asked to evaluate aroma intensity, flavor intensity, aftertaste intensity, sweetness, saltiness, nutty flavor, toasted flavor, hardness, crispiness, and oiliness. The JAR Scale was a 5-point scale to determine product penalties related to the attributes evaluated. In this scale, 1 indicates "much too weak", 3 indicates "just about right" and 5 indicates "much too strong." The questionnaire also consisted of Check All That Apply (CATA) questions in which the consumers were asked to select the terms that best described the sensory attributes of each of the crackers (Table 4.3). These terms were selected from the list of terms developed by consumers in the modified flash profile exercise. The terms which were used most frequently by consumers were used for CATA. For the modified flash profile (Chapter 2), consumer panelists were presented with all the samples at once and they were asked to describe the crackers using 4 terms for aroma, 4 for flavor, and 3 for texture. The terms which were redundant, or made little sense were removed.

Table 4.3 Terms for Check All That Apply

Terms for Check All that Apply (CATA)		
Rice	Soft	Flaky
Butter/Buttery	Sweet	Chewy
Grainy	Moist	Oily
Puffy	Gritty	Strong Flavor
Salty	Hard	
Sesame	Strong Aroma	
Grassy	Nutty	
Crispy	Seeds	
Toasty	Herbs	
Burnt	Chemical	

Data Analysis

XLSTAT software (Lumivero, Denver, Colorado, USA) was used to perform all data analysis. Analysis of variance (ANOVA) was performed using Tukey's honest significant difference (Tukey's HSD) for liking questions. Penalty analysis was performed on Just About Right (JAR) data. The Check All That Apply (CATA) questions were analyzed using Correspondence Analysis. The first two variables explained 66.48% of the probability. This generated a plot to help visualize the relationship between attributes and samples. Preference mapping was performed using consumer overall liking and descriptive data (Chapter 3).

Results and Discussion

Consumer Liking

All the products evaluated had significant differences for all parameters evaluated – overall liking, aroma liking, appearance liking, flavor liking, texture liking, and aftertaste liking (Table 4.4).

Overall liking score was highest for LANCGF, being the only sample, which received a liking mean score over 7. It is interesting to note that this sample was made from white rice fortified with tapioca starch and employed hydrocolloids like xanthan gum, and locust bean gum, in addition to employing a dairy ingredient. A combination of xanthan gum and locust bean gum has been shown in bread to improve crumb structure by more even cells, increased height of loaf, and a reduction in staling (Gallagher et al., 2004). Bakery products with dairy are also shown to have greater acceptability because of the ability of a dairy ingredient to form gluten-like network (Nammakuna et al., 2016).

SCHAGF, SIMIGF, and BLDIGF received both overall liking scores and flavor liking scores greater than 6 (i.e., like slightly) whereas the other samples did not perform so well. The grain source in these was millet blend, nut flour blend, and white rice respectively. SCHAGF used guar gum, a hydrocolloid, which is known to exhibit gluten like network, as well as sourdough which helps in the acidification of the dough leading to the development of a network (Nammakuna et al., 2016). SIMIGF and BLDIGF use almond flour which has high protein content, color like wheat flour, and has pleasant taste and smell (Martínez et al., 2022).

The aroma-liking score was highest for SIMIGF, which was the only sample besides SCHAGF that contained rosemary extract. Aroma liking was lower than 6.0 (i.e., like slightly) for all the other samples.

Overall appearance liking was highest for LANCGF. Aftertaste liking was highest for sample LANCGF, followed by sample SCHAGF which was consistent with the flavor liking of these samples. Texture liking was above 6.0 (i.e., like slightly) for SESGF, BLDIGF and SCHAGF and was the highest for LANCGF being above 7.0 (i.e., like moderately). The samples CRUNGF, ABSOGF, KAMGF and MAGOGF received very low overall liking scores (less than 4.0 i.e., dislike slightly). Additionally, ABSOGF, CRUNGF, KAMGF and MAGOGF got significantly low scores on all the attributes (less than 5.5 i.e., neither like nor dislike). ABSOGF was the only sample composed of starch, specifically, potato starch. The substitution of potato flour with a blend of pseudo-cereal (amaranth, buckwheat, quinoa) flours resulted in higher overall acceptability as well as higher scores for flavor, chewiness, and crispiness (Turk Aslan & Isik, 2022). It can be noted that the formulation of crackers using just starch without including functional ingredients such as pseudo cereals, proteins and hydrocolloids was detrimental to the liking scores of this sample. MAGOGF received a lower score for all sensory attributes. This product used quinoa and brown rice in the formulation. A previous study demonstrated that the addition of quinoa flour by rice flour in gluten-free cookies led to a decrease in the color, texture, taste, flavor, and overall acceptability in direct proportion to the amount of quinoa flour added (Păucean et al., 2015). CRUNGF used cassava flour and the formulation of crackers using cassava flour, which is a starch-based flour was shown to have lower sensory acceptability scores (Owusu et al., 2011). The choice of the flour base significantly impacts the consumer's liking. Crackers made with white rice, tapioca flour, and a blend of various starches and hydrocolloids (LANCGF) received high overall liking scores indicating a high consumer preference for this blend. Crackers made with almond flour or almond in their ingredients were well-liked for their overall liking scores, overall appearance liking, and flavor liking. (i.e., greater than 6, like slightly). The crackers formulated with starch as their key ingredient (ABSOGF, CRUNGF, KAMGF) received relatively lower overall liking scores.

Table 4.4 Consumer Liking Results from Consumer Evaluation of Gluten-Free Crackers on 9-Point Hedonic Scale (N=104).

	Simplified Flour Base	Overall liking	Aroma Liking	Overall Appearance Liking	Flavor Liking	Texture Liking	Aftertaste Liking
ABSOGF	Tapioca/Potato Starch	4.3 e	5.2 cde	5.7 de	3.8 f	5.6 de	4.0 g
CRUNGF	Cassava Flour	4.9 d	5.2 cd	4.8 f	4.6 de	5.1 ef	4.6 f
GLUTGF	White Rice	5.7 c	4.9 def	6.3 c	5.1 cd	5.9 cd	5.2 de
SIMIGF	Nut Flour Blend	6.1 c	6.7 a	7.0 ab	6.2 b	5.8 cd	5.6 cd
BLDIGF	White Rice	6.2 c	5.1 cdef	6.0 cd	6.2 b	6.3 c	6.0 bc
MAGOGF	Brown Rice	4.3 c	4.8 efg	5.4 e	3.9 f	4.8 f	3.6 g
SCHAGF	Millet Blend	6.8 b	5.9 b	6.5 bc	6.4 b	6.9 b	6.2 b
LANCGF	White Rice	7.7 a	5.5 bc	7.5 a	7.8 a	7.7 a	7.3 a
KAMGF	White Rice	4.4 de	4.4 g	4.1 g	4.3 ef	5.2 ef	4.7 ef
SESGF	Brown Rice	5.8 c	4.7 fg	6.5 c	5.3 c	6.3 bc	5.0 ef
Pr > F(Model)		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Note. Means with same letter are not significantly different (p>0.05)

Penalty Analysis

Consumers were asked to evaluate the crackers on various pre-selected sensory attributes - these were related to flavor (sweetness, saltiness, nutty, toasted), texture (hardness, crispiness, oiliness), as well as overall intensity (for overall aroma, flavor, and aftertaste) using a 5-point JAR scale with 1 corresponding to ‘not at all strong enough’ and 5 corresponding to ‘much too strong.’ Penalty analysis explains the drop in liking due to less-than-ideal perception of attributes as shown in Tables 4.5, 4.6 and 4.7.

Penalty scores were only calculated in instances were the “non-ideal” frequency of responses exceeded 20%.

Table 4.5 Percentage of Consumer Responses and Mean Drop for Flavor Attributes (Sweetness, Saltiness, Nutty Flavor, Toasted Flavor) on Just-About-Right (JAR) Scale (N=104).

	Simplified Flour Base	Level	Sweetness	Mean Score	Penalty Score	Saltiness	Mean drop	Penalty Score	Nutty Flavor	Mean drop	Penalty Score	Toasted Flavor	Mean drop	Penalty Score
ABSOGF	Tapioca/	Too little	60%	1.5	**0.9**	80%	1.5	**1.2**	66%	2.2	**1.5**	20%	2.6	
	Potato	JAR	37%			18%			25%			33%		
	Starch	Too Much	3%	1.9		2%	-3		9%	3.1		47%	1.8	**0.8**
CRUNGF	Cassava	Too little	47%	1.7	**0.8**	40%	1.6	**0.6**	31%	2	**0.6**	22%	1.3	0.3
	Flour	JAR	49%			54%			44%			51%		
		Too Much	4%	1.3		6%	2.4		25%	1.7	0.4	27%	1.3	0.4
GLUTGF	White Rice	Too little	40%	1.5	**0.6**	48%	1.2	**0.6**	47%	1.4	**0.7**	47%	1.7	**0.8**
		JAR	56%			47%			46%			47%		
		Too Much	4%	3.6		5%	0.9		5%	1.6		4%	2	
BLDIGF	Nut Flour	Too little	38%	1.1	0.4	20%	1.7		30%	2	**0.6**	29%	1	0.3
	Blend	JAR	62%			67%			56%			65%		
		Too Much	0%	0		13%	0.8		11%	2.4		6%	2	
SIMIGF	White Rice	Too little	26%	1.6	0.4	11%	0.4		21%	1.6	0.3	25%	1.1	0.3
		JAR	62%			17%			66%			70%		
		Too Much	0%	2.9		18%	1.1		13%	1.6		5%	2.7	
MAGOGF	Brown Rice	Too little	70%	2.1	**1.5**	73%	0.5	0.4	13%	1.4		3%	2.1	
		JAR	30%			25%			28%			25%		
		Too Much	0%	0		2%	-1.4		39%	2.3	**0.9**	72%	1.9	**1.4**
SCHAGF	Millet Blend	Too little	20%	2.3		53%	1.4	**0.7**	39%	1.8	**0.7**	22%	2.3	**0.5**
		JAR	75%			46%			39%			74%		
		Too Much	5%	0.8		1%	1.6		2%	3.6		4%	2.4	
LANCGF	White Rice	Too little	5%	2.3		9%	1.5		19%	1.6		9%	1.8	
		JAR	91%			86%			78%			86%		
		Too Much	4%	0.8		5%	-0.2		3%	1.7		5%	2.6	
KAMGF	White Rice	Too little	58%	1.4	**0.8**	55%	1.3	**0.7**	54%	1.9	**1.0**	60%	1.7	**1.0**
		JAR	41%			40%			33%			28%		
		Too Much	1%	3.3		5%	3.2		13%	3.8		12%	3.3	
SESGF	Brown Rice	Too little	49%	1.4	**0.7**	38%	1.7	**0.6**	19%	1.9		19%	0.3	
		JAR	41%			47%			55%			69%		
		Too Much	1%	0		15%	1.1		26%	2.5	**0.7**	12%	2.9	

Note: > 0.5 high penalties

ABSOGF received penalties for all flavor attributes (sweetness, saltiness, nutty flavor and toasted flavor). It was criticized for having too little sweetness, saltiness, nutty flavor and for being too toasted. This product was formulated using potato and tapioca starch. LANCGF was the only cracker to receive no penalties for any of the flavor attributes. This sample received very high overall liking scores as well. SIMIGF, made with nut flour blend received no high penalties but medium penalties for too little sweetness, nutty and toasted flavor. BLDIGF, which was manufactured using nut flour received a high penalty for too little nutty flavor. MAGOGF made with brown rice and quinoa received a high penalty for too little sweetness, a medium penalty for saltiness and high penalties for having too much toasted and nutty flavor. SCHAGF, which was a millet blend, received high penalties for too little saltiness and nutty flavor. KAMGF, made of only rice flour received high penalties for 'too little' flavor attributes (sweetness, saltiness, nutty flavor, and toasted flavor), which can be attributed to the fact that rice flour by itself lacks flavor. SESGF received high penalties for too little sweetness and saltiness and too much nutty flavor.

Seven of ten crackers were penalized for too little saltiness. Six out of ten crackers received penalties for having 'too little toasted flavor while three were penalized for 'too much' toasted flavor. It is safe to say that most of the crackers are being criticized by consumers for having a "weak" flavor.

Table 4.6 Percentage of Consumer Responses and Mean Drop for Texture Attributes (Hardness, Crispiness and Oiliness) on Just-About-Right (JAR) Scale (N=104).

	Simplified Flour Base	Level	Hardness	Mean drop	Penalty Score	Crispiness	Mean drop %	Penalty Score	Oiliness	Mean drop %	Penalty Score
ABSOGF	Tapioca/ Potato Starch	Too little	6%	0.5		14%	0.8		29%	1.5	0.4
		JAR	74%			73%			66%		
		Too Much	20%	1.3		13%	1.9		5%	3.3	
CRUNGF	Cassava Flour	Too little	0%	0		4%	2.6		8%	2	
		JAR	44%			60%			59%		
		Too Much	56%	1.8	**1**	36%	2.2	**0.8**	33%	1.4	**0.5**
GLUTGF	White Rice	Too little	7%	2.2		19%	1.8		25%	0.9	0.2
		JAR	80%			77%			68%		
		Too Much	13%	1.8		4%	1.3		7%	2.2	
BLDIGF	Nut Flour Blend	Too little	0%	0		1%	0.5		11%	1.6	
		JAR	71%			86%			75%		
		Too Much	29%	1	0.3	13%	2.2		14%	1.2	
SIMIGF	White Rice	Too little	21%	0.4	0.1	40%	0.7	0.3	7%	1.1	
		JAR	69%			59%			72%		
		Too Much	10%	0.6		1%	3.4		11%	2	
MAGOGF	Brown Rice	Too little	2%	-0.3		7%	0.8		29%	0.7	0.2
		JAR	48%			61%			66%		
		Too Much	52%	0.8	0.4	32%	1.5	**0.5**	5%	2	
SCHAGF	Millet Blend	Too little	23%	1.5	0.3	13%	1.6		8%	2.3	
		JAR	75%			80%			84%		
		Too Much	2%	-0.3		7%	1.1		8%	1.1	
LANCGF	White Rice	Too little	3%	3.9		7%	1.5		0%	0	
		JAR	93%			89%			68%		
		Too Much	4%	0.3		4%	1.3		32%	0.9	0.3
KAMGF	White Rice	Too little	3%	1.2		3%	0.3		18%	1.1	
		JAR	53%			69%			67%		
		Too Much	44%	1.6	**0.7**	28%	1.9	**0.5**	15%	2.1	
SESGF	Brown Rice	Too little	1%	-0.1		2%	0		15%	1.7	
		JAR	77%			83%			70%		
		Too Much	22%	0.9	0.2	15%	1.3		15%	1.3	

Note: > 0.5 high penalties

The texture attributes evaluated were hardness, crispiness, and oiliness (Table 4.6). CRUNGF, MAGOGF and KAMGF were the only crackers to have received high penalties for all texture attributes being evaluated (hardness, crispiness, and oiliness). They were made of cassava flour; brown rice; and white rice respectively. CRUNGF received high penalties for hardness, crispiness as well as oiliness. MAGOGF received a high penalty for too much crispiness, a medium penalty for ‘too much’ hardness and a low penalty for ‘too little’ oiliness. KAMGF received high penalties for ‘too much’ hardness and crispiness. It was interesting to note that LANCGF, which received very high overall liking scores and no flavor penalties, received a medium penalty for being too oily which is not surprising as butter is the first ingredient for LANCGF.

Table 4.7 Percentage of Consumer Responses and Mean Drop for Intensity Attributes (Aroma, Flavor and Aftertaste) on Just-About-Right (JAR) Scale (N=104).

	Flour Base	Level	Aroma Intensity	Mean drop	Penalty Score	Flavor Intensity	Mean drop %	Penalty Score	Aftertaste Intensity	Mean drop %	Penalty Score
ABSOGF	Tapioca/Potato Starch	Too little	70%	1.3	**0.9**	50%	2.2	**1.1**	13%	2.5	
		JAR	18%			34%			46%		
		Too Much	2%	2.8		16%	2.5		41%	2	**0.8**
CRUNGF	Cassava Flour	Too little	42%	0.9	0.4	19%	1.9		6%	1.5	
		JAR	49%			43%			50%		
		Too Much	9%	0.8		38%	2.1	**0.8**	44%	1.4	**0.6**
GLUTGF	White Rice	Too little	42%	0.1	0.0	36%	0.9	0.3	10%	0.8	
		JAR	41%			47%			63%		
		Too Much	17%	1		17%	2.2		27%	1.9	**0.5**
BLDIGF	Nut Four Blend	Too little	62%	0.2	0.1	38%	1.9	**0.7**	13%	0.6	
		JAR	30%			47%			79%		
		Too Much	8%	0.2		5%	1.5		8%	0.9	
SIMIGF	White Rice	Too little	3%	-0.9		11%	1.6		4%	1.4	
		JAR	65%			56%			65%		
		Too Much	32%	2.1	**0.7**	32%	2.6	**0.8**	31%	1.6	**0.5**
MAGOGF	Brown Rice	Too little	5%	0.2		6%	1.6		4%	1.9	
		JAR	35%			22%			65%		
		Too Much	59%	1.6	**0.9**	72%	3.1	**2.2**	27%	2.6	**0.7**
SCHAGF	Millet Blend	Too little	53%	1.3	**0.7**	38%	1.9	**0.7**	13%	1.9	
		JAR	46%			57%			75%		
		Too Much	1%	1.5		5%	4.6		12%	2.7	
LANCGF	White Rice	Too little	70%	0.3	0.2	7%	2.3		1%	6	
		JAR	30%			86%			89%		
		Too Much	0%	0		7%	2.4		10%	2	

	Flour Base	Level	Aroma Intensity	Mean drop	Penalty Score	Flavor Intensity	Mean drop %	Penalty Score	Aftertaste Intensity	Mean drop %	Penalty Score
KAMGF	White Rice	Too little	65%	0.9	**0.6**	60%	1.8	**1.1**	19%	1.5	
		JAR	28%			25%			55%		
		Too Much	7%	1		15%	2.9		25%	2.3	**0.6**
SESGF	Brown Rice	Too little	21%	0.5	0.1	30%	1.1	0.3	4%	1.9	
		JAR	43%			45%			66%		
		Too Much	36%	1.6	**0.6**	22%	2.4	**0.5**	30%	2.5	**0.8**

Note: > 0.5 high penalties

The consumers were also asked to evaluate the aroma and flavor intensity using the 5-point JAR scale (Table 4.7). All the crackers were penalized for aroma intensity. SIMIGF and SESGF, the only samples which contained rosemary extract were awarded high penalties for 'too much' aroma intensity. SIMIGF also received the highest aroma liking score. In contrast, ABSOGF, KAMGF AND SCHAGF were given high penalties for 'too little' aroma intensity.

Most crackers were penalized for flavor intensity. CRUNGF and MAGOGF composed of cassava and brown rice respectively were given high penalties for 'too much' flavor intensity. SESGF made from brown rice was given a medium penalty for too little flavor intensity and a high penalty for too much flavor intensity. It is vital to note that although most crackers were penalized for too little flavor for all flavor attributes evaluated (sweetness, saltiness, nutty flavor, and toasted flavor), in the case of flavor intensity some crackers were penalized for too much and some for too little flavor intensity which demonstrated that it is not only the intensity which calls for improvement in commercial gluten-free crackers but also the flavor profile.

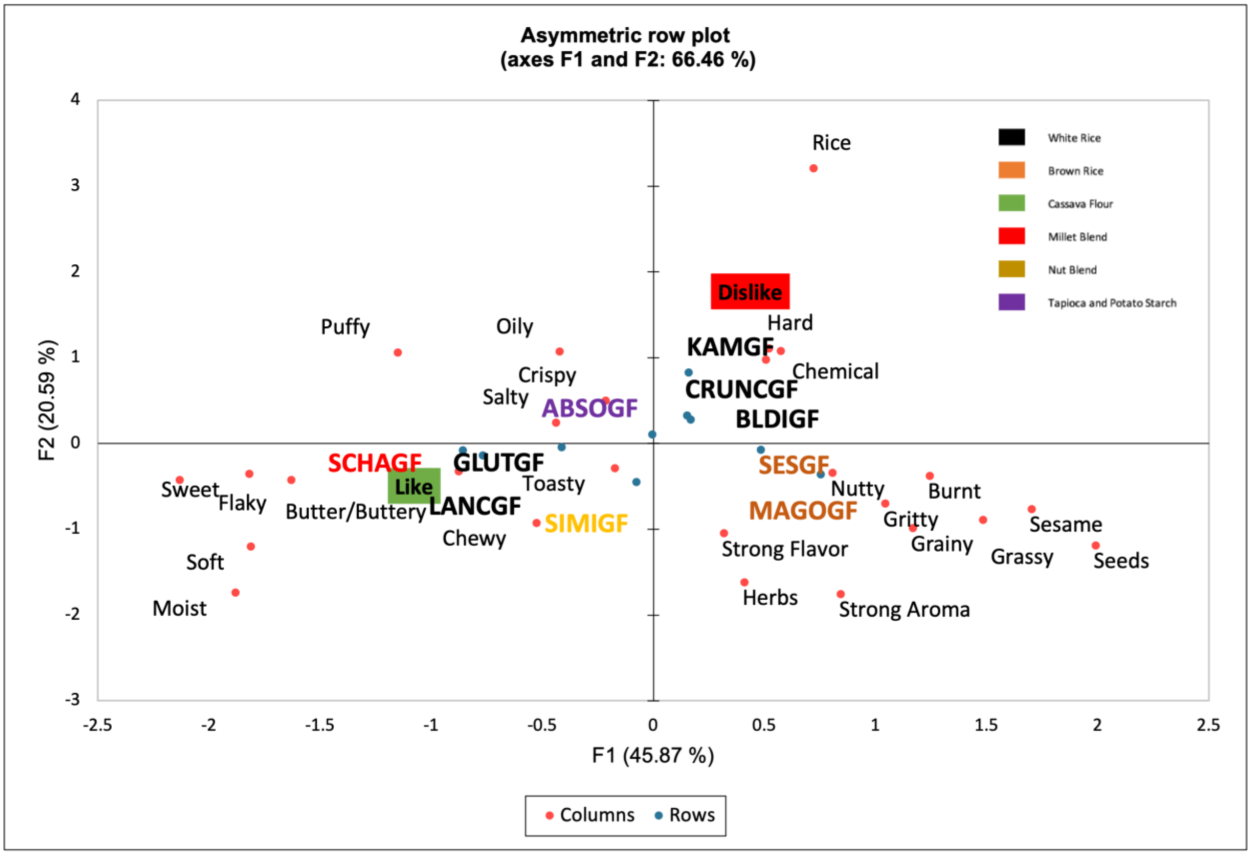
Seven out of ten crackers were penalized for having 'too much' aftertaste intensity. This reflects a challenge in developing gluten-free crackers with an acceptable aftertaste. There was no evidence of one flour base preferred over the other for various sensory attributes.

Check All That Apply

Consumers were asked to select the terms that best described the sensory attributes of each of the crackers. A graph was generated using correspondence analysis, and the first two dimensions explained 66.99% of the variability (Figure 4.1). MAGOGF and SESGF, both composed with brown rice, were associated with sesame, seeds and strong aroma. KAMGF, CRUNGF, BLDIGF were associated with attributes hard, chemical and rice. LANCGF, GLUTGF (white rice), and SCHAGF (millet blend) were placed together with attributes soft, moist, flaky, butter/buttery, and sweet. LANCGF, SCHAGF, SIMIGF were well received for overall liking and flavor liking. This helps understand the sensory space in commercial gluten-free crackers. Millet flour blend and white rice are associated with attributes comparable to a wheat cracker (soft, moist, butter/buttery, and sweet). Most of the gluten-free products try to imitate gluten-rich products to satisfy consumers. (Demirkesen & Ozkaya, 2022).

The consumers like crackers with sweet, moist, butter attributes indicating a want for crackers with these sensory attributes. The consumers disliked the attributes burnt, hard, chemical attributes in gluten-free crackers.

Figure 4.1 Biplot Showing the Relation Between Different Sensory Terms Selected in CATA and Gluten-Free Crackers



The crackers with white rice in their formulation (LANCGF, GLUTGF, and SIMIGF) were associated with buttery attribute by over 40% or more of the consumers. There are not many other similarities among the white rice crackers except for crispy which was chosen by 60% of the consumers to describe these crackers. The crackers formulated with brown rice (MAGOGF, SESGF) were associated with toasty, hard, crispy, sesame, seeds and nutty by over 40% of the consumers. The crackers formulated with brown rice flour were not evaluated as soft, or moist by any of the consumers. The potato tapioca starch crackers were characterized by burnt, crispy, hard, and toasty by over 40% of the consumers. These samples were also least liked (Table 4.4) and penalized for crispiness (Table 4.6). SCHAGF which was made of a blend of millet was associated with the sensory attributes butter, flaky, crispy and toasty by over 50% of respondents. This helps understand the sensory profile of different commercial gluten-free crackers.

Table 4.8 Percentage of Consumers that Chose Each Attribute for Check All That Apply Question

	ABSO GF	CRUNC GF	GLUT GF	BLDI GF	SIMI GF	MAGO GF	SCHA GF	LANC GF	KAM GF	SES GF
	Tapioca, Potato Starch	Cassava flour	White Rice	Nut Flour Blend	White Rice	Brown Rice	Millet Blend	White Rice	Jasmine Rice	Brown Rice
Butter /Buttery	22	18	46	22	40	1	67	90	9	7
Burnt	54	17	1	2	3	58	1	1	5	10
Nutty	5	16	14	46	42	68	8	17	24	55
Grainy	4	8	13	17	22	56	3	3	8	28
Rice	5	31	6	45	0	7	4	0	66	31
Seeds	1	3	2	26	5	81	0	0	2	63
Puffy	4	7	14	7	3	0	21	18	17	8
Soft	6	1	13	0	17	0	16	18	1	0
Herbs	3	13	3	7	44	12	2	2	0	13
Salty	13	33	26	55	58	8	28	61	31	42
Sweet	7	4	9	2	6	1	17	24	3	1
Chemical	13	16	10	5	8	13	2	0	13	6
Sesame	4	13	1	20	8	59	1	1	4	48
Moist	1	0	6	0	12	0	5	14	0	0
Flaky	17	5	32	3	2	4	65	45	2	2
Grassy	2	2	3	1	2	13	0	0	2	6
Gritty	2	10	17	13	8	44	3	2	6	12
Chewy	5	3	15	3	23	5	4	7	5	3
Crispy	59	70	63	85	54	59	75	81	69	79
Hard	38	59	32	44	23	55	11	14	61	41
Oily	6	30	11	17	13	2	11	26	18	13
Toasty	54	42	29	41	40	66	55	60	14	46
Strong Aroma	2	12	7	3	44	31	0	3	3	21
Strong Flavor	17	27	15	4	47	56	9	28	9	21

Preference Mapping

The relationship between descriptive data and liking by consumers is explained in Figure 4.2. Cluster 2 was composed of the fewest consumers (15%) and contained a majority of consumers who chose to lead a gluten-free lifestyle whereas cluster 1 and cluster 3 were composed of consumers who bought crackers with or without gluten depending on the product (Table 4.9). No difference between household income level and gender was seen between the different clusters of consumers.

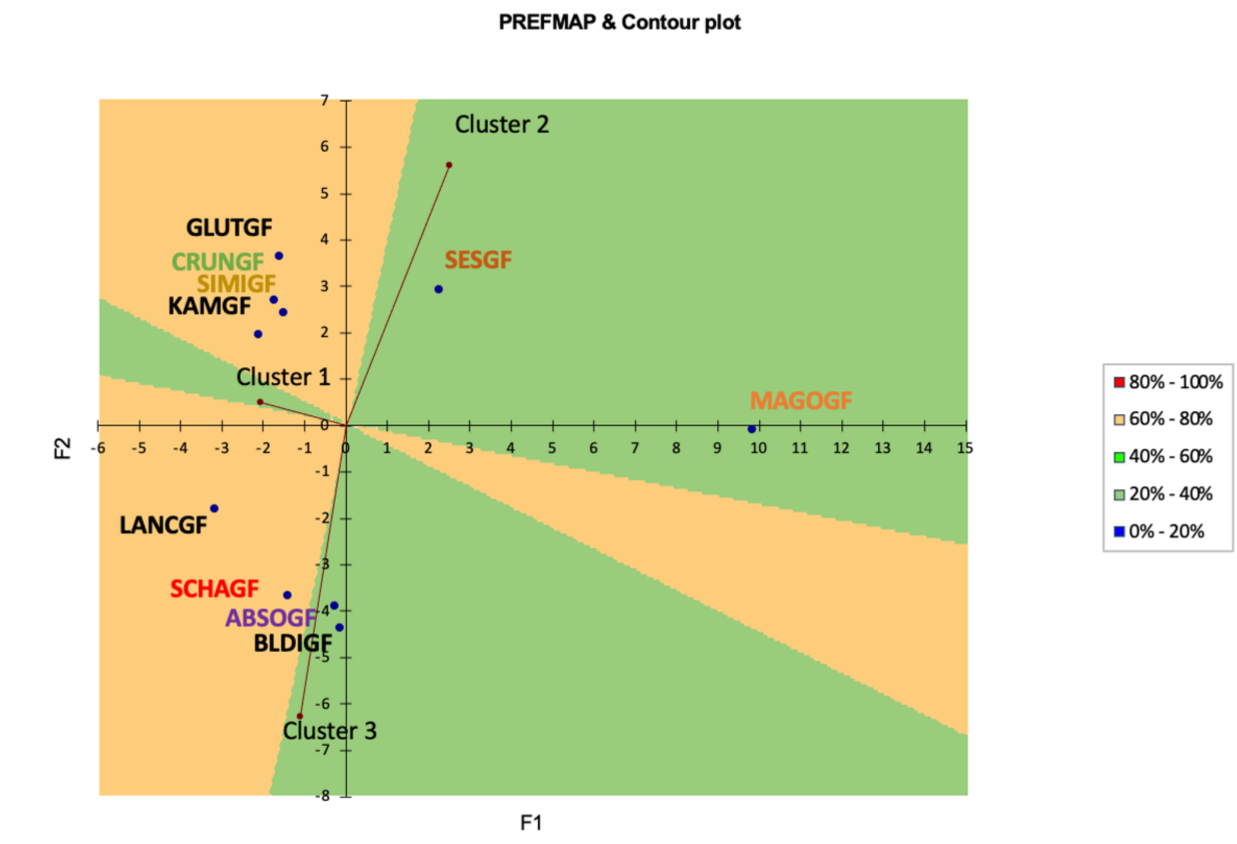
The crackers with brown rice (MAGOGF and SESGF) were liked by consumers from cluster 2. These crackers were characterized by roughness, toothstick/toothpack, seedy/sesame/flax, burnt and earthy. The brown rice crackers with these characteristics were preferred by 20 to 40% of the consumers. Crackers GLUTGF, CRUNGF, SIMIGF, KAMGF were characterized by nutty/nut milk, garlic/onion, seasoning particulates, and rice. They were liked by consumers from clusters 1.

Cluster 3 of consumers liked LANCGF, ABSOGF, SCHAGF, BLDIGF which were characterized by sweet and dairy. It is interesting to note that the crackers preferred by consumers in cluster 2 are not well-liked by consumers from cluster 1 and 3 showing the preference for different attributes. This could be due to preference for certain ingredients such as flaxseed and quinoa by cluster 2 consumers as these ingredients have a higher health perception rather than crackers characterized by buttery, oily and sweet attributes. However, most consumers prefer sweet, dairy/buttery, starch complex and shiny crackers.

Table 4.9 Sensory Aspects of Different Consumer Clusters

	Cluster 1	Cluster 2	Cluster 3
Consumer Segments	Seasoning preference	Healthy	Buttery/Sweet preference
Demographics	42% of consumers Purchase both gluten and gluten-free products	15% of consumers Gluten-free lifestyle	43% of consumers Purchase both gluten and gluten-free products
Sensory Aspects	Seasoning, oily, salty, garlic	Healthy, nutritional, quinoa	Buttery, sweet, dairy

Figure 4.2 Preference Map for Gluten-Free Crackers



Study Limitations

The growing popularity and trends in gluten-free products has led to the market being populated with gluten-free products. This study included a few gluten crackers which were made using different flour blends, starches, hydrocolloids and focused on original and sea salt products. They were selected by making a comprehensive list of products. Although much care was taken to order the sample with the same expiration date, some samples were still closer to their best buy date than others. All these products were market products so consumer familiarity might have affected liking scores. This study also focused only on consumer perception from the Kansas City area. It would be interesting to note the perception in a broader field.

Conclusion

Ten gluten-free crackers were evaluated in the study. The crackers were composed of different flour blends, starches, and hydrocolloids. All the crackers were significantly different from each other for all liking attributes (appearance, aroma, flavor, and texture). The choice of the flour base significantly impacts the consumer liking. Crackers made with white rice, tapioca flour and a blend of various starches and hydrocolloids (LANCGF) received high overall liking scores indicating a high consumer preference for this blend. The association of the most well-liked crackers with the attribute buttery shows that this attribute is the highest driver of liking. However, this cracker also received a medium penalty for oiliness which shows the importance of development of crackers with buttery attribute without it being too oily. The crackers made with almond flour (SIMIGF) or almond (BLDIGF) in their ingredients were well-liked for their overall liking scores, overall appearance liking, and flavor liking. (i.e. greater than 6, like slightly). The crackers formulated with starch as their key ingredient (ABSOGF, CRUNGF, and

KAMGF) received relatively lower liking scores. The association with attribute 'burnt' leads to lower overall liking (MAGOGF, ABSOGF) while a lower intensity of this attribute leads to an increase (SCHAGF, LANCGF, SIMIGF) in the overall liking of gluten-free crackers. Penalty analysis showed that the commercial gluten-free crackers were penalized for both low and high flavor intensity, so only increasing the flavor intensity is not a solution but to develop a better flavor profile. All crackers were penalized for their sweetness showing that the increase in sweetness can possibly lead to an increase in liking for the crackers. Aroma liking scores were generally low among all crackers. Some segmentation shows that consumers who chose a healthier lifestyle may be more willing to like products with sensory characteristics less popular for the general population.

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Appendix A - Questionnaire Used in Consumer Study (Chapter 4)

Q1. How much do you like or dislike the overall appearance of this gluten-free cracker?

Dislike extremely – Like Extremely (9-point)

Q2. How much do you like or dislike the overall aroma of this gluten-free cracker?

Dislike extremely – Like Extremely (9-point)

Q3. How would you describe the overall aroma intensity?

Not at all strong enough

Not quite strong enough

Just about right

Slightly too strong

Much too strong

Q4. Considering everything (appearance, aroma, flavor, and texture), how much do you like or dislike this gluten-free cracker overall?

Dislike extremely – Like Extremely (9-point)

Q5. How much do you like or dislike the overall flavor of this gluten-free cracker?

Dislike extremely – Like Extremely (9-point)

Q6. How would you describe the overall flavor intensity?

Not at all strong enough

Not quite strong enough

Just about right

Slightly too strong

Much too strong

Q7. How would you describe the sweetness of this gluten-free cracker?

Not at all sweet enough

Not quite sweet enough

Just about right

Slightly too sweet

Much too sweet

Q8. How would you describe the saltiness of this gluten-free cracker?

Not at all salty enough

Not quite salty enough

Just about right

Slightly too salty

Much too salty

Q9. How would you describe the nutty flavor of this gluten-free cracker?

Not at all nutty enough

Not quite nutty enough

Just about right

Slightly too nutty

Much too nutty

Q10. How would you describe the toasted flavor of this gluten-free cracker?

Not at all toasted enough

Not quite toasted enough

Just about right

Slightly too toasted

Much too toasted

Q11. How much do you like or dislike the overall texture of this gluten-free cracker? Dislike extremely – Like Extremely (9-point)

Q12. How would you describe the hardness of this gluten-free cracker?

Not at all hard enough

Not quite hard enough

Just about right

Slightly too hard

Much too hard

Q13. How would you describe the crispiness of this gluten-free cracker?

Not at all crispy enough

Not quite crispy enough

Just about right

Slightly too crispy

Much too crispy

Q14. Select the terms that best describe the sensory characteristics of the product you just evaluated (choose all that apply)

Butter/Buttery

Grainy

Puffy

Salty

Sesame

Grassy

Crispy

Toasty

Burnt

Rice

Soft

Sweet

Moist

Gritty

Nutty

Hard

Seeds

Herbs

Chemical

Flaky

Chewy

Oily

Strong Aroma

Strong Flavor

Q15. How much do you like or dislike the overall aftertaste of this gluten-free cracker?

Dislike extremely – Like Extremely (9-point)

Q16. How would you describe the overall aftertaste intensity?

Not at all strong enough

Not quite strong enough

Just about right

Slightly too strong

Much too strong