Impact of ingredients on quality and sensory characteristics of gluten-free baked goods

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Abstract

The rising awareness of celiac disease, an intestinal intolerance to gluten, has increased the demand for gluten-free products. Gluten is a protein that provides structure to breads, cakes, cookies, and other wheat-flour based baked goods. When flour and water are combined and mixed, the proteins glutenin and gliaden present in wheat combine and a network of gluten is formed. In addition to providing structure and elasticity to dough, it also traps air within the matrix and allows baked goods to rise and maintain desirable characteristics such as an open and airy crumb structure and chewiness of bread products. Removing gluten from a baked good formulation affects the finished product in many ways. This review examines research conducted on the effects of many various ingredients on finished product quality of gluten-free baked goods.

Quality parameters that are most greatly affected by the exclusion of gluten in baked goods include specific volume (a measure of the amount of air incorporated into the finished product), height, spread ratio (the ratio of diameter to thickness in cookies and like products), color, and hardness. Gluten-free baked goods are recognized to be denser, shorter in height, have a larger spread, have a different color, and be harder in texture than traditional wheat-based baked goods. Various gluten-free ingredients have been studied for their use in producing a finished product that exhibits quality parameters similar to wheat-based baked goods. These include rice, potato, tapioca, corn, and sorghum; pseudocereals such as buckwheat, amaranth, and quinoa; legumes; nuts; and waste from fruit and vegetable processing. The inclusion of additives such as hydrocolloids, protein concentrates, emulsifiers, and acidic ingredients are extensively utilized and studied in gluten-free baked good

applications. Gluten-free baked goods commonly have a reduced shelf life as compared to wheat-based products. The weak association of water with the starches present in gluten-free baked goods allows moisture to migrate to the outside of the product and rapidly escape. Shelf life studies are also included in much of the research and are summarized in this review.

Because consumers desire gluten-free products that taste like the gluten-containing products they replace, many studies pertaining to gluten-free ingredient research include sensory analysis. Some studies include a wheat-based product as a control, while others use only gluten-free formulations in the research. Future research using better sensory methods are needed in this product category.

Food manufacturers who wish to compete in the still growing gluten-free market have many ingredient resources available to them to produce high quality gluten-free baked goods. Through research conducted on alternative flours, starches, hydrocolloids, emulsifiers, and other ingredients, gluten-free consumers can enjoy baked goods that exhibit the same desirable qualities as traditional wheat-flour based products.

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Introduction: Growing Importance of Gluten-Free Foods

Gluten is a protein that provides structure to breads, cakes, cookies, and other wheat-flour based baked goods. When flour and water are combined and mixed, the proteins glutenin and gliaden present in wheat combine and a network of gluten is formed. In addition to providing structure and elasticity to dough, it also traps air within the network and allows baked goods to rise and maintain desirable characteristics such as an open and airy crumb structure and chewiness of bread products (38). The claim “gluten-free” has grown in importance over the last decade and, in the United States is regulated by the Food and Drug Administration (FDA). “Gluten-free” is a nutrient content claim as defined in the Code of Federal Regulations (37) and can be declared on any food product that contains less than 20 ppm of gluten; whether the food is naturally free of gluten or has been specially processed to remove gluten from its traditional formulation (14).

The rising awareness of celiac disease, an intestinal intolerance to gluten, has impacted the demand for gluten-free products. The common and most effective treatment for celiac disease is dietary exclusion of gluten (18). With rising awareness of the disease comes an increase in diagnoses of celiac disease and in turn increased demand for products for this growing group of consumers.

Specially formulated gluten-free foods (as opposed to foods that are naturally gluten-free, such as corn, beef, or apples) are becoming more and more ubiquitous in grocery stores and in households. In this report, “gluten-free food” refers to a food that has been specially formulated to exclude gluten as opposed to a naturally gluten-free food. As of 2015, gluten-free foods are present in 30% of American households (33). The food industry has been experiencing a steeply increasing trend in sales of gluten-free products since 2010 (38,57), and sales of gluten-free products are forecasted to exceed $14B in 2017 (55).

Patients with celiac disease are not the only individuals who seek out gluten-free foods. In fact, most individuals who purchase specially formulated gluten-free products do not have celiac disease. As many as 18 million Americans suffer from non-celiac gluten sensitivity. While this intolerance is not as severe and threatening as celiac disease, many individuals suffering from a sensitivity choose to eliminate or limit gluten from their diets and seek gluten-free foods (33).

Many consumers (42%) who purchase gluten-free foods are doing so for reasons other than celiac disease or an intolerance or sensitivity to gluten. These consumers believe gluten-free foods contribute to their overall health in various ways, ranging from assisting in weight loss to management of other illnesses such as irritable bowel syndrome, attention deficit disorder, autism, depression, inflammation, and multiple sclerosis (33,38,57).

Research on improving the quality and sensory characteristics of gluten-free baked goods has been ongoing since the early 2000s and continues through today to ensure that the growing gluten-free consumer market has access to baked goods that perform equally as well as conventional or traditional products. Gluten-free ingredient functionality has been widely studied to assist manufacturers in producing higher quality and more palatable gluten-free baked goods, meeting the rising consumer demand for such products. However, considerable work still needs to be done.

Important Quality and Sensory Characteristics of Baked Goods

Many measures of quality exist in the baked goods category. Some are specific to certain products, such as height of a cake or bread loaf; while others can be applied across all types of baked goods, such as color and hardness. Gluten-free baked goods generally have been characterized by poor quality indicators. Most consumers are interested in a gluten-free product that closely resembles its traditionally formulated counterpart. In the case of gluten-free baked goods the quality parameters should be as close to a wheat-based product as possible. Frequently discussed indicators of quality follow.

Specific volume

Specific volume is measured by the volume of a product (typically breads or cakes) divided by the weight of a product. Specific volume in gluten-free baked goods is typically lower than their traditional counterparts and is a quality hurdle manufacturers seek to overcome (5,30,44,51). Differences in specific volumes between various gluten-free bread formulations are shown in figures 1 and 2. The lack of a gluten network allows carbon dioxide gas produced throughout the mixing and proofing process to escape instead of be retained in the dough. The lack of air in the finished product causes the texture to be denser and profile to be lower than a conventional baked good. (5,16,30,44,51,54).

Height

Height of a bread loaf or cake is related to specific volume. The absence of gluten promotes a shorter loaf as the air-holding gluten matrix does not exist. Figures 1, and 2 show differences in height of bread slices or loaves produced from gluten-free flours; figure 3 shows height differences among breads produced using various gluten-free flours as well as wheat flour.

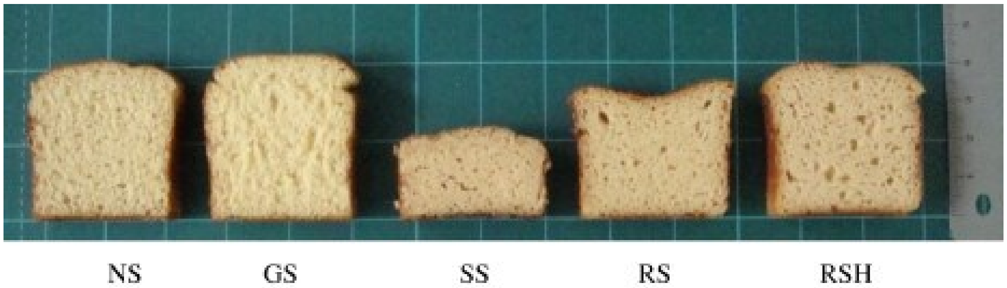

Figure 1. Soy breads made with soy flour subjected to various pre-treatments; NS: raw soy flour; GS: germinated soy flour; SS: steamed soy flour; RS: roasted soy flour; RSH: roasted soy flour with 1% HPMC (54).

Figure 2. Breads produced from untreated and heat treated sorghum flour. (27).

Spread ratio

Spread ratio applies to products such as biscuits and cookies. Gluten acts as a binder that keeps dough tight; when it is removed the dough acts more as a batter. Spread ratio is the ratio of product diameter to thickness, and is generally higher in gluten-free products than their traditional formulations (11,15,21,46,52).

Color

Color of gluten-free baked goods differs greatly depending on the ingredients used. Baked goods made of primarily starches will be much lighter in color than wheat based products. Other grains such as teff and buckwheat produce products that are darker in color than traditional baked goods (11,16,32,54). Color differences between main ingredient formulations are evident in figure 3.

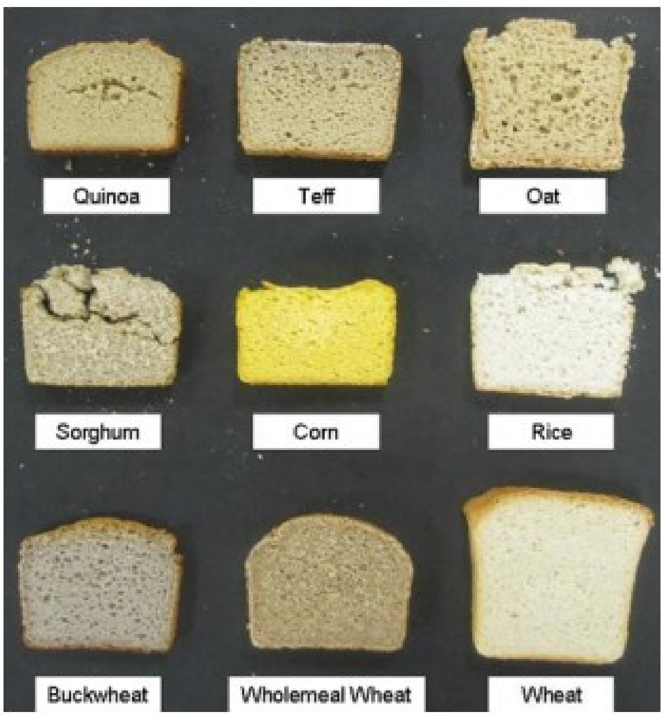

Figure 3. Appearance comparison of various gluten-free and wheat based bread slices (16).

Hardness/Firmness

Hardness or firmness of a product can be measured with a texture analyzer or with a trained sensory panel. Hardness is a key quality parameter in baked goods. Additional ingredients are commonly added to gluten-free baked goods to combat the high level of hardness exhibited by a basic gluten-free product formulation (5,23,44,51).

Ingredient Considerations

Traditional ingredients in gluten-free baking include corn, potato, and rice flour and various starches. As consumers' needs and desires change, the industry must change as well. This is reflected in the emerging use of different grains to formulate new and better quality gluten-free baked goods. Flours made from pseudocereals such as amaranth, quinoa, and buckwheat have been researched alongside other gluten-free alternatives such as teff, sorghum, soy, and even nuts and fruits (16,23,39,43,46,53,54).

Flours & Starches

Flour mixtures

Maize, rice, and oat flours, along with corn, potato, cassava, and rice starches have been used to produce gluten-free baked goods since the 1990s. They have been studied both in combination and independently to assess the quality of gluten-free baked goods (9,10,11,16). Generally, more desirable quality and sensory characteristics are expressed when the formulation includes a mixture of flours and starches rather than a homogeneous formulation (26,30). Hager et al. (16) found that when producing gluten-free breads made exclusively from gluten-free flours of rice, maize, or oat that only the oat flour showed similar quality to wheat bread. However, oat flour often is not used in industry-produced gluten-free baked goods. Oats are at risk for gluten contamination due to the methods of harvesting and milling that are currently used (20). There is risk for the finished product to contain >20 ppm gluten, which would render the product unable to be labeled "gluten-free."

Starches

Starch is a major component of flour and helps give structure and binding ability to flours, especially flours that lack gluten. Some formulations of gluten-free baked goods include additional starch to increase viscosity and create an appropriate texture of the gluten-free dough or batter and of the finished product. Potato, corn, rice, and tapioca starches are common ingredients in gluten-free baked goods.

The addition of starches has been shown to improve the texture of both the dough and the finished product in gluten-free breads. Pongjaruvat et al. (45) found that the addition of up to 20% pregelatinized tapioca starch to a rice flour based dough results in a dough with better workability, and the resulting bread has greater volume and softer texture than the control sample not containing starch. Baked goods produced with combinations of rice flour, potato starch, and corn starch were compared by Matos and Rosell (30) with a formulation containing rice flour and potato starch exhibiting the highest specific volume and lowest hardness values.

Pseudocereals

Buckwheat, amaranth, and quinoa belong to the classification of pseudocereals; plants whose seeds are able to be ground and used as flour but do not belong to the cereal group (56). Buckwheat flour has been studied in a variety of gluten-free baked good applications; from breads and biscuits to crackers and cookies (8,16,21,53). The use of buckwheat flour generally has positive results in the finished product, particularly when a hydrocolloid is also present in the formulation. In a study exploring the use of refined and whole buckwheat flour-based crackers compared to refined and whole wheat-based crackers, the crackers containing refined buckwheat flour received the highest ratings for a variety of sensory properties and were rated significantly higher than the refined wheat flour samples for appearance and texture (53).

The addition of buckwheat flour to cookies can decrease the hardness and fracturability of the finished product, leading to improved liking scores by a sensory panel. Such results were exhibited when buckwheat flour replaced rice flour in a formulation of gluten-free cookies. The replacement of 10%, 20%, or 30% rice flour with buckwheat flour in a formulation that also contained hydrocolloid additives resulted in softer and less fracturable cookies as well as increased acceptability scores by a consumer panel of sensory testers (8).

Buckwheat flour lacks structure forming proteins, so it is often explored in tandem with other flours or starches, or with gums or hydrocolloids that assist in forming a desirable bread-like structure (8). In products such as crackers, cookies, and biscuits where less of a gluten-like structure is needed for a desirable texture and dough workability to be achieved, buckwheat on its own with no supplement may be appropriate (53). In a study where gluten-free breads were produced with buckwheat as the sole flour with no additives, the resulting quality and sensory characteristics were poor when compared to traditional wheat bread (16). The buckwheat flour bread was dense, hard, and lacked springiness compared to traditional wheat bread. However, when additives such as gums or emulsifiers are added to buckwheat based dough, quality and sensory characteristics meet or exceed traditional wheat bread formulations (8).

Limited research has been completed on the use of other pseudocereals such as quinoa and amaranth in gluten-free baked goods. One study compared bread samples formulated with a single alternative flour source for traditional wheat bread. In this study, the quinoa flour sample was rated as inferior to traditional wheat bread (16).

Greater success was found when a 50:50 mixture of rice flour and pseudocereal flour was used in bread formulations. When compared to control gluten-free bread comprised mainly of rice flour and potato starch, quinoa and amaranth containing formulations yielded breads with softer crumb. The quinoa containing bread also boasted increased loaf volumes compared to the gluten-free control that lacked pseudocereal enrichment (2). Pseudocereals are best used in combination with other traditional gluten-free flours such as potato or rice, and/or with the addition of hydrocolloids or gums.

Rice bran

The use of rice bran as an additive in gluten-free baked goods is related to its fiber content. Phimolsiripol et al. optimized a gluten-free bread formulation including rice bran, which contains high amounts of soluble dietary fiber (44). The researchers attributed the positive results to the soluble dietary fiber in the rice bran. It was found that the inclusion of the rice bran produced a bread with desirable characteristics such as higher loaf volume, softer crumb, and better color than control gluten-free bread not containing rice bran. Additionally, the high soluble fiber rice bran containing bread had higher overall sensory acceptance and a longer shelf life than other samples tested. There is an opportunity for more research to be completed on the effects of soluble dietary fiber on quality and sensory attributes of gluten-free baked goods.

Sorghum

Combinations of various flours have been explored in research, but with so many different alternative flours there is room for more exploration and experimentation. Multiple studies cite sorghum flour as an excellent substitute for wheat flour in cookies (6,46,48) and have satisfactory sensory results in the finished product. Rai et al. (46) conducted a study where multiple types of flour blends were tested for quality and sensory parameters. They found that a 50:50 blend of sorghum and pearl millet flours yielded sensory acceptance scores that were greater than the control wheat flour cookie. While other flour blends tested (including those of rice, maize, pearl millet, and sorghum) also gave favorable results, the sorghum and pearl millet blend performed best (46).

Legumes

Aside from providing specific nutritional properties, legume flours also provide textural and structural benefits to baked goods. For this reason, legumes such as chickpea, pea, soy, and carob have been studied as ingredients in gluten-free baked goods (12,32,54). Carob germ flour specifically has been reported to possess gluten-like properties in baked goods (12). While carob germ flour forms a thicker batter than other legume-based formulations, the finished product exhibits poorer quality and sensory results compared to the other samples of legume-based breads (32). Chickpea flour has been found many times over to produce a high quality gluten-free baked good (11,32,49). In the study by Minarro et al. (32), the chickpea-based formulation yielded the least dense bread (highest specific volume) and the softest crumb. Additionally, the chickpea bread sample boasted the longest shelf life of the samples studied and was amongst the highest rated for sensory acceptability. Pea protein isolate samples also yielded acceptable results in this study (2012).

Nuts

The additions of acorn and chestnut flours have been studied for their use in gluten-free baked goods. Korus et al. observed that the replacement of 20% of total starch with acorn flour in a gluten-free bread formulation positively influenced some physical characteristics of the product as well as overall sensory acceptability (24). With the addition of acorn flour at 20% came a larger total volume, decreased hardness, increased sensory acceptability, and increased shelf life. It also increased appearance acceptability of the finished products. The nut flour strengthened the structure of the dough and was only effective up to 20%. Replacement of 40% and 60% of total starch with acorn flour was also tested; hardness increased and total volume decreased with the increasing amounts of acorn flour (24).

Chestnut flour addition was studied by Paciulli et al. (43). Addition of 20% chestnut flour yielded breads with an improved shelf life. The chestnut flour suppressed the hardness of the bread throughout the shelf life of the product, while the control sample without chestnut flour increased in hardness throughout its shelf life.

Fruit-based ingredients

Up to 1/3 of fruit and vegetable material is sent to waste during processing of produce based foods (39). Much of this waste is fiber rich and can be repurposed as a food additive in other products. O'Shea et al. (39) used waste from orange juice production, orange pomace, in formulations of gluten-free bread. Orange pomace is rich in fiber. The researchers utilized the functional properties of fiber including gelling, structure forming, and water binding to enhance gluten-free bread dough. While the orange pomace did not influence the overall acceptability of the finished product from a sensory perspective, it did improve the structure of the batter by increasing its viscosity and in turn making it easier to work with (i.e. process) due to the high water binding capability of the orange pomace (40).

Blackcurrant and strawberry seeds have been studied in up to a 15% addition in gluten-free bread formulations (22). Defatted strawberry seeds had a greater positive impact on texture qualities than did blackcurrant seeds. The study indicates that up to 10% defatted strawberry seed can be added to gluten-free bread dough to exhibit less hardness and increased loaf volume as compared to a control formulation. Sensory results show that the 10% strawberry seed sample is equally as acceptable as the control for appearance, color, and structure/porosity; acceptance scores are significantly higher for taste and smell. It should be noted that the acceptance test was performed with a small number of participants (n=10).

Raisin juice, both in concentrated and dried forms, was studied as an ingredient in gluten-free bread. While the breads produced using concentrated raisin juice were preferred from a sensory aspect, the shelf life of the product was shortened due to the added moisture in the formulation. The addition of dried raisin juice at 3% or 5% of flour weight showed higher loaf volume and increased shelf life as compared to a control formulation (50).

Additives

Hydrocolloids/Gums

Hydrocolloids, also referred to as gums, are often used in gluten-free baking to add structure to the uncooked dough or batter. Hydrocolloids help to fill gluten's role of providing stretch and elasticity to dough, increasing the amount of air incorporated into the dough through mixing ultimately allowing for better gas retention and higher loaf volumes after baking in the case of gluten-free breads (51). Additionally, the use of hydrocolloids helps to retain moisture throughout the shelf life of a product and reduce the rate of staling (3). Commonly utilized and studied hydrocolloids include xanthan, guar gum, locust bean gum, carrageenan, and hydroxypropyl methylcellulose (HPMC) (1,21,41,51). While carboxymethylcellulose (CMC) is used as a binding agent in traditional baked goods, it has been shown to bind with gluten while HPMC binds with starches (7). Although the addition of CMC has shown positive results in quality attributes in gluten-free cookies (8), the chemical binding structure of HPMC makes it a better choice as a binding and structure forming agent in gluten-free baked goods.

In a study by Sabanis and Tzia, gluten-free bread formulations based on rice and corn flours were studied with the addition of xanthan, HPMC, guar gum, and carrageenan added separately at 1%, 1.5%, and 2% (51). The researchers found that the analytical values of specific volume, crumb firmness, crumb moisture, and crumb color all varied dependent not on the amount of hydrocolloid present, but dependent on the type of hydrocolloid present in the formulation. Hedonic sensory values of appearance, flavor, and acceptability depended on both type and amount of hydrocolloid.

From a sensory perspective, the HPMC containing formulations were consistently rated higher than control (gluten-free bread with no hydrocolloids) for flavor, appearance, crust color, texture, and overall acceptability. Guar gum containing samples showed similar liking scores to HPMC samples except it was rated similarly to control for crumb color and flavor. The same conclusions were not found in samples made with xanthan and carrageenan. Carrageenan samples performed similarly to control for appearance, crumb texture, and overall acceptability and better than control for crust color and flavor at the 1% and 1.5% formulations. Xanthan samples were rated similarly to control for appearance, crumb texture, and overall acceptability at 1%, but were liked less than control for crust color and flavor (51).

Another study compared the effect of the additives xanthan gum, whey protein, and inulin on chickpea flour based muffins (17). The additives were studied independently of each of other at varying levels, and were compared to chickpea flour and wheat flour controls. Formulations with xanthan gum scored closer to wheat flour muffins for key texture attributes including hardness, springiness, sponginess, and cohesiveness as well as color and height.

Protein concentrates and emulsifiers

Like fiber and hydrocolloids, proteins also exhibit gelling behaviors. They have been studied in gluten-free baked goods to improve the structure and texture of the dough and the finished product (13,28,35,47,52). Soybean, egg, and whey proteins have been studied for their role in the quality of baked goods.

In a study where the effects of protein concentrates and emulsifiers on the quality and sensory attributes of gluten-free cookies were explored, Sarabai et al. (52) found that both soy protein isolate and whey protein concentrate perform best when supplemented with the emulsifier glycerol monostearate. The protein/emulsifier combination produced a cookie dough with improved texture as compared to the control gluten-free dough lacking protein and emulsifier. The test dough exhibited decreased hardness, adhesiveness, and gumminess and increased cohesiveness and springiness as measured by an LR-5K Texture Analyser (Lloyds Instruments Ltd, Hampshire, England), and was closer in these attributes to a wheat flour-based cookie dough than the gluten-free control cookie dough (52).

From a sensory perspective, the overall quality of cookies produced with soy protein isolate and glycerol monostearate were rated higher than the gluten-free control cookies, and approached the overall quality score of the wheat-flour control cookies. The whey protein/glycerol monostearate cookies did not score as well in sensory testing as the soy protein/glycerol monostearate cookies (52).

The protein concentrates were tested independently without any added emulsifiers but did not test as well for quality or sensory characteristics as the protein/emulsifier combination. In addition to glycerol monostearate, the emulsifiers of sodium stearoyl-2-lactylate and lecithin were also tested; glycerol monostearate yielded the most favorable results.

Acidic additives

Acidic ingredients such as vinegar are sometimes added to gluten-free baked good recipes as an attempt to improve quality. In one study, the effects of acetic acid, citric acid, lactic acid, and monosodium phosphate on rice flour and HPMC based gluten-free bread were tested (4). Finished loaves were tested for pH, bread volume, cell area of the crumb, and hedonic sensory analysis.

The ingredient with the most promise for improving the texture of rice flour-based gluten-free bread was monosodium phosphate, which significantly improved texture liking of the finished product compared to other test samples, and significantly increased the bread volume and cell area compared to test and control samples. Monosodium phosphate was most effective at improving volume and cell area at a dose of 0.8% flour weight (4).

Sensory Aspects

Most of the studies conducted on the influence of various ingredients on gluten-free baked good quality include a sensory section. As the gluten-free market continues to grow, it can be expected that consumers' expectations for these products will rise. Sensory studies will continue to be key in linking consumers' perceptions of products to the quality and ingredient functionally assessed in studies. Although some sensory analysis has been conducted there is a need for more complete sensory work to be done. Most sensory studies involved in the research were acceptance tests. Descriptive analysis was conducted in only a few of the studies found. Table 1 summarizes the sensory studies completed by type (acceptance or descriptive) and include the ingredient variables and attributes tested.

Limitations exist within the sensory research that has been completed thus far in the gluten-free baked good category. Many of the acceptance tests completed were performed on a low number of participants (n=10-15). While these results can serve to screen formulations, many sensory professionals working in industry would require a greater number of participants in the tests (n=75-100). It is also unclear in much of the research what consumer base is being used for the acceptance studies; mainly whether or not the consumers are screened for use of gluten-free products. Laureati and others compared both descriptive and acceptance test results from two consumer groups: celiac disease-suffers and general population. It was found that a properly trained descriptive panel showed no differences between the groups, but acceptance results differed between the two groups (25). This indicates that screening for panelists who suffer from celiac disease can change the outcome of an acceptance study of gluten-free bakery items.

Additional limitations exist in the descriptive analyses that have been completed. More emphasis can be placed on the product as a whole; most of the descriptive studies seemed to be narrowly focused on only a few attributes, which means that important product differences or characteristics beyond the few measured may have been missed. These limitations are not unexpected given the infancy of sensory research into the gluten-free baked good product category, but must be improved as the market develops further.

Table 1: Summary of sensory evaluations of gluten-free baked goods.

Author(s)	Ingredient(s) tested	Testing type	Attributes tested	Reference
Korus, J., Witczak, T., Ziobro, R., Juszczak, L.	Acorn flour, varying percentages	Acceptance	Smell, Taste, Appearance, Color, Structure and porosity	(24)
Phimolsiripol, Y, Mukprasirt, A., Schoenlechner, R.	Rice bran with varying rations of insoluble to soluble fiber	Acceptance	Appearance, Color, Odor, Taste, Texture, Overall impression	(44)
Sabanis, D., and Tzia, C.	HPMC, Xanthan gum, Carrageenan, Guar gum; independently at varying levels	Descriptive	Appearance: Crust color; Crackings on crust Flavor: Toasted, Bakery, Sour, Semolina, Yeasty, Sweet, Salty, Sour, Bitter Texture: Crumb hardness, humidity, Cohesiveness of mass, Elasticity, Crispiness (tactile)	(51)
Sabanis, D., and Tzia, C.	HPMC, Xanthan gum, Carrageenan, Guar gum; independently at varying levels	Acceptance	Overall acceptability	(51)

Author(s)	Ingredient(s) tested	Testing type	Attributes tested	Reference
Kaur, M., Sandhu, K. S., Arora, A., Sharma, A.	Buckwheat flour with the independent additions of guar gum, gum acacia, xanthan gum, and gum tragacanth	Acceptance	Appearance, Color, Taste, Overall	(21)
Ergin, A, Herken, E.N.	Potato flour, corn flour, chickpea flour, corn starch, potato starch, egg, milk; in varying combinations and ratios	Acceptance	Overall, Color, Taste, Odor, Texture	(11)
Hadnadev, T. R., Torbica, A. M., Hadnadev, M. S.	Buckwheat flour and CMC independently and in varying ratios	Acceptance	Overall acceptability	(15)
Marston, K., Khouryieh, H., Aramouni, F.	Sorghum flour heat treated at varying temperatures	Acceptance	Appearance, Color, Flavor, Texture, Overall	(27)
Rai, S., Kaur, A., Singh, B.	Rice, maize, sorghum, and millet flours independently and in varying ratios	Acceptance	Grain flavor, Texture, Flavor, Overall acceptability	(46)
Blanco, C. A., Ronda, F., Perez, B., Pando, V.	Acetic acid, lactic acid, citric acid, monosodium phosphate; independently at varying levels	Acceptance	Appearance, Odor, Taste, Texture	(4)
Shin, D., Kim, W., Kim, Y.	Soy flour undergoing various treatments (Raw, Germinated, Steamed, Roasted); tested independently	Descriptive	Appearance: Shape, Crumb color Odor: Beany, Savory Taste: Beany, Savory, Aftertaste Texture: Hardness	(54)

Author(s)	Ingredient(s) tested	Testing type	Attributes tested	Reference
Hager, A., Wolter, A., Czerny, M., Bed, J., Zannini, E., Arendt, E. K., Czerny, M.	Various flour types: Wheat, Whole wheat, Rice, Sorghum, Oat, Quinoa, Teff, Buckwheat, Maize; independently	Descriptive	Aroma: Yeast dough, Oat flakes, Cooked potato, Popcorn (roasty), Moldy, Pea, Buttery, Vomit, Vinegar, Malt	(16)
Minarro, B., Albanell, E., Aguilar, N., Guamis, B., Capellas, M.	Chickpea flour, Pea isolate, Soy flour, Carb germ flour; tested independently	Consumer	Intensities and Acceptability of the following: Crumb porosity, Crumb color, Crust color, Hardness (tactile), Hardness (mouth), Chewiness, Flavor, Taste; Overall preference	(32)
Herranz, B., Canet, W., Jose Jimenez, M., Fuentes, R., Alvarez, M.	Whey protein, xanthan gum, inulin; independently and in various ratios	Descriptive	Chickpea taste, Aftertaste, Typical muffin taste, Stickiness, Adhesiveness, Moisture, Cohesiveness, Sponginess, Springiness, Hardness, Color, Height, Difficult to swallow	(17)

Shelf Life

The shelf life of gluten-free baked goods is shorter than that of wheat-based baked goods. Retrograded starches in gluten-free products crystallize rapidly, resulting in faster staling (23). Additionally, water in gluten-free baked goods is bound more weakly than in traditional products. Water is unable to bind with starches present in gluten-free formulations as strongly as it does with proteins that comprise the gluten complex in wheat-based formulations (31). This weak association allows moisture to migrate from crumb to crust and ultimately out of the product completely at a faster rate. The product becomes stale, hard, and crumbly much more quickly than a wheat-based product (23).

Ingredients with water binding capabilities such as hydrocolloids are used to help extend the shelf life of gluten-free baked goods (3). Ozkoc and Seyhun (42) studied the effect of the flaxseed and the hydrocolloids guar gum, xanthan gum, and locust bean gum on the shelf life and staling of gluten-free bread. The highest quality sample tested included a combination of guar gum and flaxseed. Quality parameters were tested after 1 hour of being baked and after 3 days storage. The guar gum/flaxseed sample was rated as being the highest quality as it exhibited low hardness and high specific volume. In other studies supplemental ingredients such as acorn flour, rice bran high in soluble dietary fiber, HPMC, and guar gum have shown to improve the shelf life of gluten-free breads (24,44,51).

Conclusion

Many different types of ingredients have been researched for their effectiveness in creating high quality gluten-free baked goods with desirable sensory attributes. The gluten-free consumer market will only continue to expand through the coming years. Food processors can utilize a vast array of ingredients to produce a gluten-free product that exhibits specific quality and sensory attributes. Finding the right balance of ingredients from alternative flours and starches to various additives will take some experimenting to find the formulation that creates the best gluten-free product possible.

Limitations exist in the sensory work that has been completed thus far in this product category. There is a need for more robust descriptive analysis to be completed in order to really understand the impacts of various ingredients on sensory qualities of the product variations. In addition, acceptance testing using a greater number of participants who are actually likely to eat the product in question (i.e. targeted consumers who use gluten-free products) is necessary when designing acceptance tests for the category of gluten-free baked goods.

More research can be completed on processing techniques specific to gluten-free baking. While a few different types of pretreatments of ingredients have been tested, this area of research has not yet been exhausted.

Food manufacturers looking to improve on or begin production of gluten-free baked goods would be wise to approach their optimization and development with an experimental design approach. By changing a few variables in the formulation at a time and working within a production plant's own processing and ingredient handling restraints, a successful gluten-free bread, biscuit, cookie, or cracker is not out of reach.

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