Sensory tools for the development of gluten-free bakery foods

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Highlights

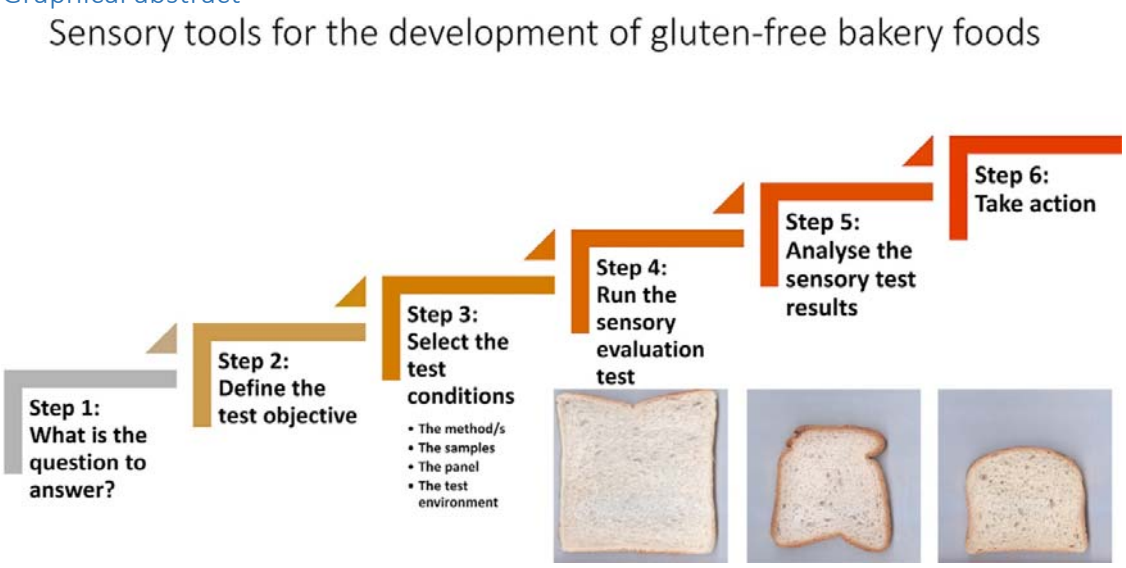
- Update on sensory tools available for development of gluten-free bakery products.
- Six steps to Sensory Evaluation, a simple to use guide to answer questions.
- Suggestions for future sensory studies on gluten-free bakery products.

Abstract

The appearance, taste, aroma and texture of food products, including gluten-free bakery products, is very important predictors for whether or not such products would be acceptable for consumers. Food companies that manufacture and supply gluten-free food and beverage products need to utilise a variety of sensory tools for decision making during product development, evaluation of ingredients, processes and products. The six steps to Sensory Evaluation process is a simple to use, stepwise approach to select the right tools to answer questions. Different sensory evaluation tools are used to address questions of the three different types (1) Are two or more products the same or different? (2) What is the nature and size of differences among products? and (3) What are consumers' opinions about a product/s? It is the intention that the discussion in this review would stimulate ideas for application of more advanced sensory tools to further understanding to enhance development of gluten-free foods and ingredients. Some suggestions for future sensory studies on gluten-free bakery products are presented. These include more research on the acceptance and perception of the sensory properties of gluten-free product options by both coeliac and non-coeliac consumers at different life stages. Evaluation of the sensory properties of gluten-free products in combination with other products, accompaniments and within meals. Also, sensory profiling of the unique properties of naturally gluten-free bakery products, as well as studies to optimize acceptance of these in wider consumer markets. The application of the tools in a systematic manner based on the six steps to sensory testing process presented here will assist researchers to obtain powerful results to answer research questions.

Keywords: sensory evaluation, descriptive, discrimination, consumers

Graphical abstract



1. Introduction

When consumers consider the suitability of bakery products such as bread, cakes, biscuits and cookies for purchase or consumption, the appearance, aroma, and texture of available options are critical determinants of selection. During product consumption these and additional flavour and sound properties contribute directly to the ultimate enjoyment of the products and future choices. Research tools that support the understanding of the basic sensory perceptions and the consequences thereof form the basis of sensory and consumer science. The science has progressed with time and continues to evolve; thus, product developers and cereals scientists should incorporate the most progressive tools available that are suited to the purpose and goals of the research.

The development of gluten-free bakery products is partly driven by consumers who need or want to consume foods that do not contain gluten. Health reasons for avoiding gluten, include coeliac disease, and gluten sensitivity (noncoeliac gluten intolerance) (Gaesser and Angadi, 2012). Despite a lack of evidence suggesting that following a gluten-free diet has any significant benefits for the general population, many reports (e.g. Gaesser and Angadi, 2012; Prada et al., 2019) show that consumers often perceive gluten-free foods as healthier than their gluten-containing (often wheat based) counterparts. This perception is to some extent fueled by celebrity endorsements of the gluten-free lifestyle and social media food trend influences.

Another compelling reason for the development of gluten-free foods is the need to utilise more locally grown and indigenous climate-smart crops. This is particularly in areas where agro-climatic conditions do not favour wheat production, such as in many African (Nkhabutlane et al., 2019; Olojede et al., 2020) and Latin American (Ballesteros López et al., 2004; Jensen et al., 2015) countries. The development of sensory acceptable bakery products from locally available cereal, pseudo-cereal, tuber and root, nut as well as legume flours could potentially lessen the reliance on expensive wheat imports.

A growing industry around the supply of ingredients and additives for the gluten-free market has developed. Gluten-free bakery products are often compared to traditional wheat-based products, the latter considered as the gold standards. Compared to wheat-derived products, commercial gluten-free bakery products often have inferior quality with respect to flavour and texture and is typically more expensive (Lamacchia et al., 2014). The products are often described as having a flat

appearance, being dry and firm, with a crumbly texture (O'Shea et al., 2014; Torbica et al., 2010) and with poor flavour (Hager et al., 2012). Among coeliac consumers the sensory characteristics of gluten free-bread have been reported as the most important variables considered for purchase decision (Campo et al., 2016).

The appearance, taste, aroma and texture of a food product are very important predictors for whether or not the product would be acceptable for consumers. Food companies that manufacture and supply gluten-free food and beverage products need to utilise sensory tools for decision making during product development, evaluation of ingredients, processes and products. However, it is common for managers, marketing personnel, food scientists even academics and researchers, who otherwise would use careful, analytical experimentation to quantify chemical, physical, psychological and economical properties of food products to resort to unscientific methods when faced with human sensory measurements of the same material. Drake, (2007) laments that sensory testing is often considered a late addition to an experiment without proper design and planning which could lead to unreliable and poor results.

The purpose here is to provide a review of the sensory tools available for studying the sensory properties of gluten-free bakery products. Sensory evaluation is a multidisciplinary challenge that requires an understanding of food science, statistics, chemistry, nutrition, physiology, and psychology (Heiniö, 2014). The broader discipline of Sensory Science is an area where major scientific development has happened in the last few decades (Prescott et al., 2014). Similar to other fields of science, tools and techniques used in sensory science has continued to advance; and researchers and practitioners should keep abreast of the latest tools available for the purpose and goals (Drake, 2007). A number of tools exist for the generation of data relating to different attributes of new or existing food products. The challenge is to apply the right tool for the answer that is needed. Choosing the right method(s) can be a difficult task in which the strengths and weaknesses of each method, budget limitations, and other resource aspects must be contemplated. The six steps to Sensory Evaluation process is a simple to use, stepwise approach to select the right tools to answer questions. It can be used as a baseline for sensory research of any product type, including gluten-free food. Table 1 provides a case study example of the process. The different steps will now be discussed in more detail.

Table 1: Six steps to sensory evaluation – an example of the process

<table>
<tr><th>Step 1
What is the question?</th><th>Step 2
Test objective/s</th><th>Step 3
Select the test conditions</th><th>Step 4
Run the test</th><th>Step 5
Analyse the test results</th><th>Step 6
Take action</th></tr>
<tr><td rowspan="2">Background:
The shelf life of a gluten-free bread formulation is short (less than 3 days). With such a short shelf life the logistics of distribution to retailers is complex and expensive leading to high levels of product waste, consumer complaints and product returns.

Potential solution:
To include guar gum at 4% to improve stability.

Question/s
1. Will the formulation change have an effect on the sensory properties of the bread?
and if not ..
2. Will the change in the formulation increase the shelf life?</td><td>1. To determine whether or not adding 4% guar gum has an effect on the sensory properties of day 0 gluten-free bread.

If no, continue with storage trial 2
If yes, find a new solution (back to step 1)

Test criteria: p < 0.05,</td><td>Test method: Triangle test
Test panel:
Company employees (n=18) familiar with the test method and previously screened for sensory acuity, discriminators of small product differences
Test samples:
Control gluten-free bread Day 0 gluten-free bread with 4 % guar gum Day 0
Test environment:
Staff training room</td><td>Date: 17/10/2019
Time: 10:30 AM
Responsible sensory analyst: L Mongena, Assistant: P Ferreira

Data collection online via smartphones or tablets</td><td>11 employees identified the odd sample correctly.

No significant difference between Control gluten-free bread Day 0 and gluten-free bread with 4% guar gum (p = 0.01)</td><td>The 4 % guar gum added to the gluten-free bread formulation does not change the sensory properties of the bread?

Continue with a storage trial.</td></tr>
<tr><td>2. To determine whether adding 4% guar gum has a positive effect* on the sensory properties of gluten-free bread stored for 3 days.

If yes, implement the change
If no, find a new solution (back to step 1)

Test criteria: p < 0.05,</td><td>Test method:
Paired preference test
Test panel:
Regular consumers of the product (n=90). Consume the product at least twice a week.
Test samples:
Control gluten-free bread Day 3 gluten-free bread with 4 % guar gum Day 3
Test environment:
Central location area with convenient access for target consumers recruited from the company database.</td><td>Date: 20/10/2019

Time: Four time slots during the day to accommodate schedules of different consumers (8:00, 12:00, 16:00 and 18:00)

Responsible sensory analyst: L Mongena, Assistant: P Ferreira

Data collection via paper-based questionnaire

The incentive for participants: A product gift voucher</td><td>55 of 82 consumers preferred the gluten-free bread with 4 % guar gum Day 3.

Significant preference for the gluten-free bread with 4 % guar gum Day 3 (p = 0.002).</td><td>The 4 % guar gum added to the gluten-free bread formulation has a positive effect on the shelf life of the bread?

Change the formulation of the gluten-free bread to include the 4% guar gum.

Next task: Determine the shelf life of the new formulation gluten-free bread.</td></tr>
<tr><td>Type of question?

A. “Are the products the same/different” Q1
B. What are the nature and size of the differences between the products?”
C. What are consumers’ opinions about the products?” Q2</td><td>*

A positive effect is defined as a preference for the product by regular consumers of the product.</td><td>Consider resources:

Time:

Budget

Labour:

Facilities</td><td>Anything to note?

All participants provided informed consent</td><td>Anything to note?</td><td>Anything to note?

The change in the formulation of the bread adds 4 % to the production cost of the bread.

The added cost to be recovered by:

• More sales
• Less waste
• Fewer product returns</td></tr>
</table>

2. The Six Steps to Sensory Evaluation

2.1. Step 1: What is the question to answer?

Before actually conducting a sensory test, the research question needs to be carefully defined and the experiment properly planned. It is very important to understand the exact nature of the problem or question that needs to be studied. Start with the basic questions:

- WHAT question/s need to be answered and WHY?
- WHAT is the nature of the product/s related to the question?
- In the context of the question, WHO consumes the product/s and HOW is it consumed?

Answering these questions will help the researcher to decide on the practical aspects of conducting the sensory study (See example Table 1). Questions related to Sensory Evaluation can be grouped into three categories. Different sensory evaluation tools are used to address questions of the three different types.

(1) Are two or more products the same or different?

For example, to investigate ways to increase the shelf life of traditional South American gluten-free cheese bread Zapata et al., (2019) had to determine whether cheese bread with guar gum added plus incorporating either a dough freezing or chilling process made a difference to the sensory properties of the product.

(2) What is the nature and size of differences among products?

For example Ari Akin et al., (2019) had to identify and describe the sensory profiles of chemically leavened gluten-free sorghum bread as influenced by different starch/hydrocolloid combinations.

(3) What are consumers' opinions about a product/s?

An example of a question related to the opinion of consumers is when Campo et al., (2016) compared four gluten-free bread formulations with the addition of sourdough in combination with teff flour and wanted to identify the attributes that drive preference for coeliac consumers.

2.2. Step 2: Define the test objective

Based on the evidence available, the anticipated answer to the question formulated in step 1 becomes the hypothesis to test in the study. The hypothesis informs the statement of the test objective, the most appropriate test protocol and the planning of the logistics for the test.

2.3. Step 3: Select the test conditions

During the third step, four important decisions are made, deciding on the specific product samples that need to be evaluated, the test method to use, the criteria and/or characteristics of the human subjects/panel that is needed to evaluate the product samples and the test environment that is most suitable and practical for executing the task. The four aspects are closely interrelated and the one depends on the other.

2.3.1. The test method/s to use

Traditionally, two clearly defined areas of sensory evaluation are recognised: *analytical tests* to objectively evaluate the sensory characteristics of products, and *affective tests* used to measure product acceptance/preference with consumers (Ares and Varela, 2017). Analytical sensory methods in the difference, also called discrimination, tests category are used to determine, with statistical relevance, whether or not consumers will notice a difference between two or more products. Analytical sensory tests that are also used to describe and quantify the nature of differences among

product options are called descriptive or sensory profiling tests. In contrast, affective sensory methods are employed to quantify and/or qualify the affective opinions of consumers towards product options.

2.3.1.1. Difference test methods

Let us consider the case where the addition of an ingredient has the potential to add a substantial quality or shelf life benefit to a product yet will also add extra cost (Table 1). The decision whether or not to add the ingredient depends on its effect, if any, on the sensory properties of the product and evidence that the addition definitely contributes the benefit. Results from a difference test will enable the researchers to make the decision whether or not to add the ingredient with confidence and minimal risk.

Table 2 shows examples of test methods in this category. The tests are not difficult to set up nor to use. Each of the difference/similarity sensory methods has advantages and disadvantages, including the sensitivity of the method, which determines the number of judges necessary. The number of panelists required varies depending on the goal and the type of panelists considered (screened for discrimination ability or not). Generally, 25 to 50 panelists are recommended (Drake, 2007). The researcher may want to establish whether products are different but oftentimes also whether products are similar. While the same test methods may be applied, the analysis and application of difference and similarity test statistics are different. For a recent and comprehensive review of methods, see Rogers, (2017). Detailed instructions on the practical setup of the methods can be found in the practical and detailed manuals of the ASTM (www astm.org).

Table 2 Examples of difference or discrimination test methods

Test name	**Basic explanation of presentation of samples and task required**
Difference Paired comparison test,	A set of two samples (A and B) is presented simultaneously to each panellist. The set orders AA, BB, AB, BA should be presented. A panellist is asked to indicate whether the samples are the **same** or **different**.
Directional paired comparison test or 2-Alternative force choice (2-AFC) test	A set of two samples (A and B) is presented simultaneously to each panellist. The set orders AB or BA should be presented. A panellist is asked to indicate which one of the two samples is present in a lower/higher magnitude e.g. sweeter.
A not A test	A reference sample A is presented first. Blind-coded samples are presented and the panellists have to decide if a sample is A or Not A.
Degree of difference test	Usually, a reference or control sample is presented first. Thereafter blind-coded samples are presented and the panelists indicate the degree of difference from the reference using a scale ranging from 'same as reference' to 'very different from reference'.
Triangle test, 3-Alternative force choice* (3-AFC) test	A set of three samples is presented simultaneously to each panellist; two samples are the same and one is odd or different. The panellists are asked to identify the odd sample. *For the 3-AFC version of this test, two samples are the same and one is different in a specified attribute e.g. sweetness
Duo-trio test	A sample marked reference R and two other blind-coded samples are presented. Panellists are asked to identify which one of the two blind coded samples are the most similar to the R sample.
Tetrad test	The objective is to determine if two samples (e.g. A and B) are the same or different. Four coded samples are presented simultaneously, two A samples and two B samples. The panelists have to make two pairs of the two most similar samples.
Attribute ranking test	Coded samples (more than two) are presented simultaneously. The panellist has to put the samples in a descending or ascending order based on a single attribute, e.g. hardness.

2.3.1.2. *Sensory test methods to describe or characterise products*

Traditionally sensory test methods to describe the nature of sensory differences were limited to evaluation by specifically screened and trained panelists. Such tests involved small groups of 8-12 judges. Fig. 1 provides a summary of methods that have been developed over the years for profiling the sensory properties of food products. These range from the classic Flavor Profile and Texture Profile methods (Muñoz and Keane, 2017) developed in the 1950s to, Check-all-that-apply (CATA) and its different variations, Temporal Dominance of Sensations (TDS) and many others. Essentially the basic approach of most of the methods are 1) to select panelists, 2) to develop and/or select appropriate terms for description of sample differences (lexicon), 3) concept formation by training and/or discussion or by a free choice process, 4) confirmation of panel functioning, and 5) evaluation of products.

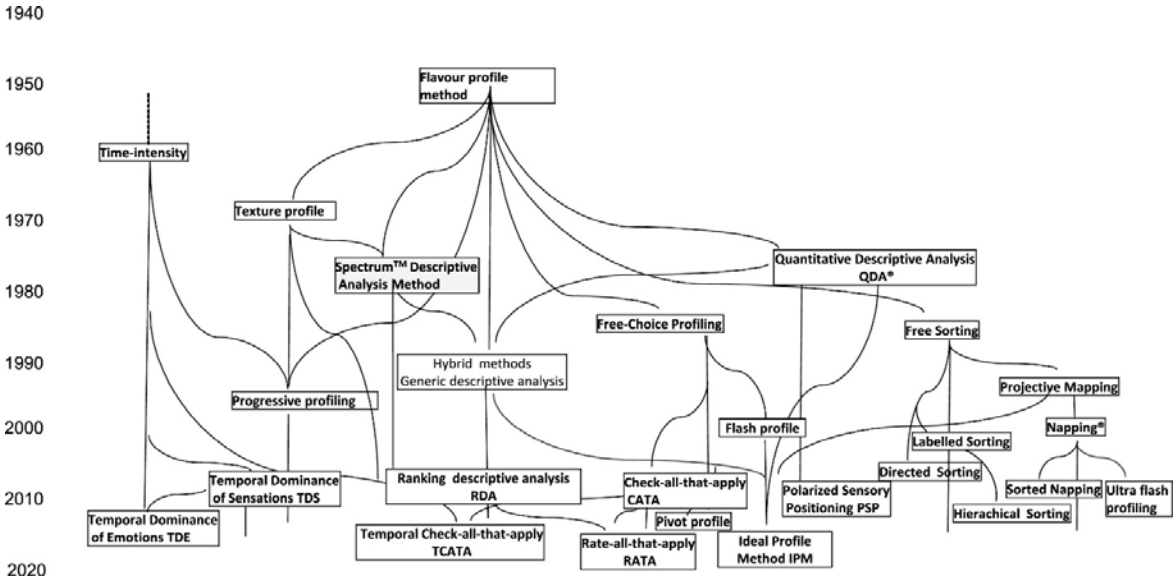


Figure 1. Development of descriptive sensory methods. Adapted from a slide by Prof Wender Bredie, University of Copenhagen presented at ESN Seminar 2008, Pretoria South Africa.

The development of rapid product profiling techniques, stimulated by the need for more speed, flexibility and, less time spent on panel training, is a feature of modern descriptive sensory evaluation. In fact, the need for problem-solving methods that use shortcuts to produce good-enough solutions given a limited time frame or deadline (heuristics) is a priority of sensory and consumer scientists (Jaeger et al., 2017). In the last couple of decades, various new methods for sensory characterisation using also regular consumers as panellists for describing products have been recognized (Varela and Ares, 2012). The reader is referred to the Sensory Wiki pages of the Society for Sensory Professionals (sensorysociety.org) for short descriptions of many of the methods indicated. Several reviews of the techniques and methodologies regularly used to describe food samples (Delahunty, C.M.; Drake, 2004; Lawless and Heymann, 2010), including bread (Callejo, 2011) have been published. Active debates on the pros and cons of the various methods and approaches are ongoing (Ares and Varela, 2017; Muñoz and Keane, 2017).

The development of a standardised method for the descriptive analysis of a product category and a descriptive lexicon or descriptor list with suitable definitions is a vital part of classic sensory profiling methodology. Sensory lexicons or words to describe different sensory properties are effective communication tools and useful for product development, quality control, product improvement, for

monitoring shelf-life changes, and for evaluating effects of ingredients and manufacturing processes (Suwonsichon, 2019). Lexicons for bread (Callejo, 2011; Elía, 2011), gluten-free bread (Morais et al., 2014; Pagliarini et al., 2010), chemically leavened sorghum bread (Ari Akin et al., 2019), sorghum biscuits (Serrem et al., 2011), quinoa products (Wu et al., 2017), butter cakes from composite rice flours (Chueamchaitrakun et al., 2011) and many others are available.

Another aspect highlighted in literature focuses on the selection of the most suitable panelists for evaluating products. Considering that an important market for gluten-free products is coeliacs, Laureati et al., (2012) and Pagliarini et al., (2010) used trained sensory panels consisting of coeliacs to describe the sensory properties of the main commercially available gluten-free bread in Italy. Results showed no difference between trained panels of coeliacs or non-coeliacs in the description and perception of gluten-free bread (Laureati et al., 2012). In addition, the hedonic bread preferences for coeliacs and non-coeliac consumers were based upon the same sensory attributes.

The need to monitor the dynamic oral breakdown and evolution of sensory properties during consumption has given rise to a number of temporal descriptive sensory methods (Fig. 1). For example, Machado Alencar et al., (2015) evaluated the influence of sweeteners and pseudocereals (amaranth and quinoa) on the sweetness and bitterness of gluten-free bread using the time-intensity method. Given the often perceived dry and crumbly texture of gluten-free bread described in literature (Pagliarini et al., 2010), it is anticipated that temporal methods may have particular value to describe the human perception of gluten-free products. Changes in oral processing parameters (e.g. time required to chew a product in anticipation of swallowing, or the ease of development of the bolus) of different products can affect consumption, texture perception and even feelings of satiety. Vvan Bommel et al., (2019) showed that evaluation of the developing sensations provided important additional information about food perception. Products with the same ingredients, same composition and same caloric content may vary in oral processing properties due to textural changes. This property may be the driver of different expectations of satiety and satiation of the breads.

2.3.1.3. Test method tools to interact with consumers

Sensory analysis integrates many different sciences to better understand the sensory properties of products and consumers' responses to these properties. In commercial settings, research methods to effectively measure consumer responses to new and reformulated products are essential. However, liking is not the only aspect that can be measured. Sensory and consumer scientists are nowadays tasked to collect a variety of information from consumers in order to obtain insight and a more comprehensive understanding of experiences with products. The interaction of consumers with products with a view of predicting food choice can be studied affectively, conceptually, or perceptually (Vidal et al., 2019).

Affective or hedonic tests measures how much pleasure (or dislike) the product conveys to consumers. The level of pleasure or satisfaction that a product delivers (or its sensory performance) is measured by asking consumers to indicate their opinion on a scale. The classic 9-point hedonic scale with word categories ranging from like extremely to dislike extremely is one of the most widely used preference scales. However, many other scales may also be used. See (Cardello, 2017; Lim, 2011) for a review of assumptions, contexts and frames of reference for hedonic scaling. Examples of other scales are the just-about-right scale, line scales with verbal anchors at the ends (''I dislike it very much''/''I like it very much'') or category or interval scales supplemented with frowning/smiling faces (Kihlberg et al., 2005).

Many researchers add value to liking measurements by obtaining additional information especially focusing on conceptual views of consumers e.g. appropriateness of a product for certain uses (for breakfast, school lunch packs, parties) (Giacalone and Jaeger, 2019), willingness to eat or purchase a

product, willingness to compromise on sensory quality in view of a health or other perceived or real benefit, and evaluation of post-ingestive measures (e.g. feelings of hunger or satiation) (Andersen et al., 2017) as well as demographical information (gender, age, family status, etc.). This additional information can be particularly useful to gluten-free food liking studies.

Kihlberg et al., (2005) studied liking of bread as a function of perceived sensory properties in combination with providing product information. Information was provided on the ingredients - flour origin (from conventional versus organic farming system), health effect (cholesterol-reducing effect), and addition of novel/less familiar ingredients to produce a neophobic reaction (with added amaranth). Interestingly, the results for samples that scored high for liking were affected differently by the information than were less well-liked samples. For example, when the information was given that a product was made with organic flour, liking of the product was enhanced compared to when the consumer was made to believe that the product was made with conventional flour. This finding was related to the consumers' ideas and attitudes about organic ingredients. This demonstrates that perceptual information may have an effect on contextual or conceptual insights and vice versa.

Studies have suggested that gluten-free products have a "health halo" effect and that consumers believe them to be healthier than products containing gluten (Christoph et al., 2018; Prada et al., 2019). In contrast to research on other food claims e.g. organic and low fat, experimental research examining the impact of gluten-free claims on food perception and specifically expected taste (sensory properties) is still limited. In Portugal, Prada et al., (2019) examined how including a gluten-free label on food packaging images impacted the evaluation (n= 202 consumers) of different aspects (healthfulness, caloric content, expected taste and level of processing) of the products depicted in the images. Gluten-free (vs. control) products were perceived by the participants as healthier, as having fewer calories and as being less processed. Interestingly, the consumers did not expect a difference in taste if the products were labeled gluten-free or not. In general, the participants held positive beliefs toward gluten-free diets, but low self-reported knowledge about gluten-free products was also identified. The effect of a gluten-free label claim on the taste expectations of products was positive for some types of products e.g. rice crackers but negative for others e.g. cooked rice. Consumer sensory studies to determine acceptance of gluten-free products may need to consider the motivations for consuming gluten-free products.

It is also possible that the acceptance of naturally gluten-free products may be negatively influenced by gluten-free label information due to taste expectations based on the gluten-free concept. In another study, an interesting word association (WA) technique was used by Pontual et al., (2017) to investigate the perception two groups of consumers (72 coeliac and 78 non-coeliac individuals; 150 in total) have on pizza dough (thick or thin) and the raw material used at the manufacturer (cassava flour or rice flour). Using this technique it was found that gluten-free pizza should have a thin dough and use cassava flour or rice flour as the raw material.

Product sensory experiences can evoke wide-ranging emotional responses. A plethora of test methods focus on the measurement of emotional responses to foods (De Wijk et al., 2019; Deubler et al., 2019; Kaneko et al., 2018; King et al., 2015; Lagast et al., 2017). Dalenberg et al., (2014) showed that non-verbal food-evoked emotion scores improve food choice prediction over mere liking scores. Both explicit and implicit methods are widely used to gather data about consumers' perceptions. Explicit methods are either verbal or visual self-reported measurements where participants report their feelings or emotions upon evaluating food products (Lagast et al., 2017). Modern technology also allows for the measurement of more implicit consumer response measures such as facial expressions and physiological measurements of the autonomic nervous system to provide other types of information than explicitly verbalised responses (De Wijk et al., 2019).

While sensory evaluation most often focuses on the evaluation of the intrinsic quality attributes of products, the reality is that the cost and even brand information of a product and the perceived value for money have a significant effect on consumer opinion and behaviour. A variety of structured questionnaires or instruments have been published to study consumers with a view to gain insight in the factors that predict food choice. Such instruments are used to assess e.g. the importance of health, pleasure, convenience, price, familiarity and ethicality motives in the selection of items for consumption. Examples are the food choice questionnaire (Steptoe et al., 1995), food neophobia scale (Pliner and Hobden, 1992), health and taste attitudes scales (Roininen et al., 1999) and instruments to measure the impact of food environments on choice (see Ohri-Vachaspati and Leviton, 2010 for a review of instruments on this topic).

2.3.2. The test samples

Practical considerations regarding the best way to prepare and present products for evaluation by a judging panel are important aspects of sensory testing (Table 3). For example, when serving bread to a sensory panel, should they evaluate a product as presented for purchase on the shelf or as self-prepared? How much and what part/s of e.g. bread (crust, crumb or both) should be evaluated or not evaluated? Should a spread like butter or margarine, topping options or usual accompaniments (e.g. tea) be made available or not? These are important to consider because it may have an important effect on liking ratings during consumer evaluation. We compared consumer acceptability of the crumb of commercial gluten-free and gluten-containing bread by cutting out circles of crumb using a cookie cutter (Fig. 2). No significant difference in the liking of the appearance of the bread crumb samples was found, but it is fair to assume that the assessment would probably be very different if the consumers were aware, during the evaluation, of the substantial difference in size and crust properties of the bread loaves. This example emphasizes the importance of considering the format of sample presentation but also hidden information when interpreting sensory results.

Table 3 Practical aspects of product samples that need to be considered when planning sensory evaluation tests

Nature of samples to be tested	Sample set	Evaluation of the samples
Are the samples to be tested comparable e.g. equally fresh? Will the set of samples selected be suitable for the test objective/s? Are the samples safe for consumption? Are the samples to be tested palatable? What sort of preparation is required? How is the product type usually consumed?	How many different product types need to be evaluated? How many samples can be tested at any given time? How much sample is available for testing? The sampling protocol What constitutes a typical sample size? Is repeated-use evaluation necessary?	Are there any practical limits for the number of samples to be tested? What instructions (or information) are provided to evaluators? Palate cleansing materials Use of toppings and accompaniments Product serving, presentation, and handling protocol Serving utensils

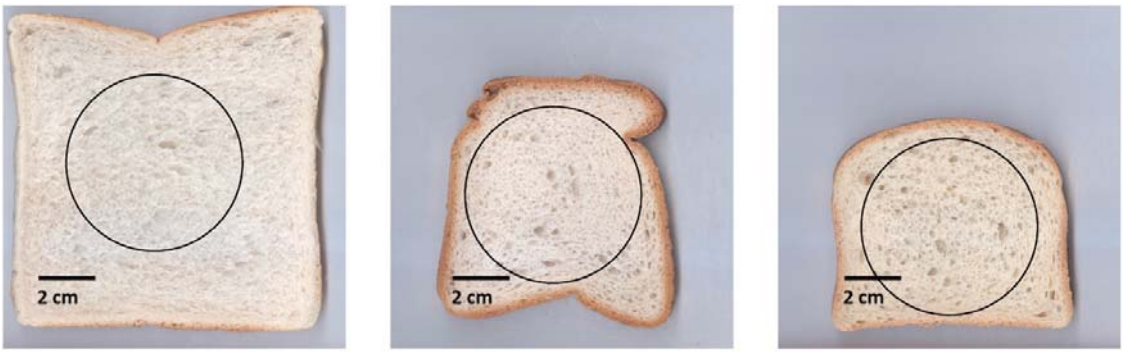


Figure 2 Illustration of the effect of a sampling method to focus the attention of the sensory panel on the crumb properties of bread samples while ignoring the visual differences of the products

The use of materials for palate cleansing or refreshing before and in between the evaluation of different samples also requires active thought. Test subjects usually drink or rinse with water for the purpose. However, Chueamchaitrakun et al., (2011) used water and unsalted crackers when evaluating butter cakes while Ari Akin et al., (2019) used raw cucumber in addition to water and unsalted crackers when evaluating sorghum bread. Prior testing of rinsing agent is essential to prevent carry over effects that may influence response variables.

2.3.3. The test panel

Humans with their five senses (sight, smell, taste, touch and hearing) are unique and very useful for judging food and materials. The aim of Sensory Evaluation is to characterise a food product and to obtain an understanding of how the end-user experiences the sensory properties of the food before, during and after consumption. The practical decision about who are the most suitable judges to evaluate the products and where and how to find them is part of the task of the sensory scientist. The use of specifically trained panellists but also untrained judges (consumers) to characterise and profile the sensory properties of foods are well documented.

Despite some journals still publishing research papers where a small number of trained judges is used to judge liking of food products, the opinion of such a small panel of trained judges or company employees should not be relied on to report on the level of acceptability of products nor to predict consumers' acceptance and preference of products. The opinions of trained product evaluators are usually not representative of regular consumers due to the analytical approach to evaluation enforced by the attribute training process that they are exposed to. Consumers are heterogeneous and vary considerably in their preferences for products and this is the main reason why consumer evaluation requires relatively large numbers of consumers, typically 80 or more, selected to be representative of a specifically defined consumer target market to evaluate the acceptance and/or preference of product options. The number of consumers to recruit for a test is a matter of statistical debate and practical aspects also play a role. For consumer panels, the criteria for inclusion of participants is very important and requires adequate motivation. In a study by Mazzeo et al., (2014), children between 6 and 12 years, diagnosed with coeliac disease, were recruited to evaluate the visual and taste

preferences for three commercial gluten-free products. The motivation for choosing this group was due to research findings indicating that childhood and adolescence was the most difficult stage to manage a strict gluten-free diet. Overall, the results of this study with a small number of respondents (n=28) showed that the majority of the children liked the appearance but were less satisfied with the taste of the gluten-free products evaluated.

Engaging humans as test instruments requires serious consideration of ethical requirements as part of the interaction with the participants, the information supplied, data handling and reporting etc. While most sensory tests do not represent risks beyond 'the ordinary risks of daily life,' the use of coeliac consumers may require additional care and all aspects of the test (information supplied to and collected from participants, nature of test and control samples, choice of mouth cleansers etc.) should be carefully contemplated. The provision and signing of a consent form by all test participants is a standard procedure. Volunteering participants need to be fully informed of the potential risks of participation in accordance with the Declaration of Helsinki (Prescott et al., 2014). As sensory tests with consumers often also apply tools from psychology, the risk for emotional/psychological distress should not be ignored. While participation in sensory testing is always voluntary, participants are often incentivized and/or thanked for the time spent using monetary or other means (e.g. vouchers to spend at stores, participation in raffles). Care should be exercised to ensure that the lure of the incentive does not become more important to participants than the purpose of the task.

2.3.4. The test environment

The environment where sensory data is collected can have a huge effect on the responses obtained (De Wijk et al., 2019) and should be considered with great care. External influences (e.g. sounds and information, images, odours) create perceptions that can influence the perception of the acceptability of the products tested. For analytical sensory evaluation, a sensory laboratory or dedicated sensory area, including a sample preparation area *is recommended* so that conditions can be controlled, and distractions are kept to a minimum. The physical setting, including individual sensory booths or test stations, must be set up in such a manner that minimises panellists' biases, maximises evaluation sensitivity and eliminates external variables. The setting should allow panellists to perform tasks free from distractions in a neutral and generally comfortable, quiet, preferably temperature-controlled environment. The testing area should be free of crowding and confusion. Easy access to the area (centrally located for panellists) saves time and frustration. Panellists should not be able to observe activities in the sample preparation area. No odours from food preparation or foreign odours should be present in the testing area, as this may influence the judgments of panellists. Conditions must be conducive to concentration. Off-white or light grey walls, lighting and fittings that do not influence the appearance of the products being judged are essential.

For consumer testing, different types of test areas are used. If total control of external variables is desired, a sensory laboratory is perfect to use. Nowadays, there is much support for conducting consumer product testing in more natural consumption locations with the aim of better-predicting consumers' views of products as consumed in the real world. Kihlberg et al., (2005) conducted a consumer test in a supermarket to allow for the effect of retail information on the liking of a selection of bread types. The test area allowed to reach the broadest group of the target market, food-buying consumers. The current theory emphasis is to include meaningful contextual (visual, auditory and olfactory) test environment cues to inform consumer perceptions, liking and behaviors when making product decisions (Bangcuyo et al., 2015). The motive for the choice of a test set up is to improve the reliability of consumer data, thereby providing food and consumer product companies significant savings on product development costs and failed launches.

The availability of specialised sensory software e.g. *Compusense, Fizz, RedJade, Eye Question* has enabled researchers and companies to utilise fast and easy test setup capability, experimental designs, test methods and other functional tools such as product blind coding, serving order design, panel recruitment and monitoring functions and also statistical analyses. Data is collected via direct online user/panellist interaction and analysed using the built-in software capacity.

2.4. Step 4: Run the sensory evaluation test

Detailed planning with dedicated staff (sensory analysts) and following good sensory practices (European Co-operation for Accreditation, 2003; Lawless and Heymann, 2010) is the key to running a successful sensory test. It is vital to make sure that all the necessary samples, containers and utensils are available prior to set up the test. The testing area should be prepared and spotlessly clean. The time and labour required to prepare samples especially for large panel tests, should not be underestimated. Keeping samples warm/cold, hygienic and free from drying-out/softening, and ensuring that the samples are presented in the correct orders to the right persons are pre-requisites and requires attention and enough helpers. Panellists become demotivated and distracted when they are kept waiting or sense confusion. A neat and professional-looking reception area where panellists can register for a test and with a friendly person to welcome them, as well as a comfortable waiting area, is indispensable. Practical considerations for scheduling test sessions should consider the expected level of hunger of participants and the availability of judges. Scheduling early morning, or after working hours sessions may be more convenient for those that work.

2.5. Step 5: Analyse the sensory test results

Once the sensory and/or consumer data is collected analysis tools are applied to interpret the effect of one variable on another, to search for noteworthy trends and to assess sets of data in order to reach conclusions regarding its meaning. The diversity of data types from sensory and consumer research allows for the application of a variety of powerful statistical analysis techniques. The academic discipline of sensometrics has evolved due to the requirement of specific methodology and statistical methods for sensory and consumer science (sensometric.org). The choice of an analysis method to use depends on the question to answer, the type of data collected but also on the statistical data handling skills of the researcher.

One of the most powerful functions that sensory evaluation provides is the identification of the drivers of liking/disliking by relating descriptive characteristics of products to consumers' opinions (Kihlberg et al., 2005). For example, partial least squares regression was used by (Heenan et al., 2008) to investigate the relationships between consumers' perceptions of bread freshness and descriptive sensory data. Perception of bread freshness varied among consumers. Heenan et al., (2008) identified three consumer segments that were homogeneous in their perceptions of bread freshness. Positive drivers of bread freshness for consumers in one of the cluster groupings were ''porous" appearance, and ''floury" odour, while positive drivers for another cluster were ''malty" odour, and ''sweet", ''buttery", ''oily" flavour. The third group of consumers were positively driven by ''porous" appearance, ''floury", ''toasted" odour and ''sweet" aftertaste. Using sensory profiling by a trained panel and consumer testing with coeliacs, Morais et al., (2014) found the drivers of liking of gluten-free breads to be apparent softness, the intensity of traditional bread aroma, sweetness and the crumb color while hardness, chewiness, and yeast aroma were drivers of disliking. Using this information, the researchers were able to identify the formulations with the highest acceptability among a range of prototypes. When comparing alternative quinoa varieties, Wu et al., (2017) concluded that overall acceptance of quinoa was driven by higher intensities of grassy aroma, and firm and crunchy texture. In addition, the researchers concluded that consumers could be segmented into four groups based on their acceptance of specific attributes, particularly texture. Such information

enables food companies to develop and market different products to suit different consumer preferences.

2.6. Step 6: Take action

The last step in sensory testing is to interpret the results obtained and to take appropriate action based on the question identified at the start, the objective defined for the test, the specific conditions under which the test results were obtained, and the methods applied for analysis of the test results.

3. Some suggestions for future sensory studies on gluten-free bakery products

It is the intention that the discussion in this review would stimulate ideas for application of appropriate and where necessary more advanced sensory tools to further understanding to enhance development of gluten-free foods and ingredients.

More research on the acceptance and perception of the sensory properties of gluten-free product options by both coeliac and non-coeliac consumers at different life stages is needed. Food products are often eaten in combination with other products, with accompaniments and as part of meals. Research to determine the evaluation of the sensory properties of gluten-free products in such contexts is limited or non-existing. The utilization of more immersive testing environments for evaluating gluten-free products e.g. at the market, health shop or other points of purchase, in a bakery, restaurant environment, school tuck shop could be investigated. To accommodate the requirements of a coeliac member in a family , it may be more practical and safer for all to purchase and consume strictly gluten-free options in the home setting. In the foodservice environment (e.g. airline, hospitals), sensory optimized product options that could satisfy the perceived or real needs of more customers (e.g. inclusive of those seeking gluten-free) are very sought after as it reduces the need for maintaining a variety of stock-keeping units.

Due to technological challenges and their niche market status, gluten-free products are often relatively expensive. Evaluation of the sensory properties of a product with its specific gluten-free benefit(s) in relation to the price premium expected to pay could yield very valuable insights for manufacturers. Determining consumers' willingness to pay more or willingness/reluctance to compromise on sensory expectations or perception is an under-researched area.

For technological reasons, gluten-free products tend to have substantially different sensory characteristics compared to gluten-containing products. Yet, in the bakery category, most product development efforts are focused on matching or closely resembling the sensory properties of gluten-containing product options. In a recent study of the acceptability of the sensory properties of commercial gluten-free bread in South Africa, we found that some traits of a commercial gluten-free bread product (roasted sweet aroma, visually perceived texture) were very desirable to consumers. A question to consider is whether a better understanding by consumers of the role and contribution of gluten, or in fact the lack thereof, in bakery products will not lead to greater appreciation and acceptance of gluten-free products? This may, for example, be achieved by on-pack consumer education or social media information strategies. When measuring the acceptability of gluten-free products, product developers may need to reconsider the usual comparison against wheat-based or other gluten-containing products as the "control or standard" (Pagliarini et al., 2010).

Much more research to describe the unique sensory properties of naturally gluten-free bakery products, as well as studies to determine consumer acceptance and preferences for these in wider consumer markets, are urgently needed. For these products, gluten-free is a mere additional benefit and not the main marketing feature. Traditional Mexican tortillas (Herrera-Corredor et al., 2007), Ethiopian injera (Yetneberk et al., 2004), Italian taralli (Barbieri et al., 2018), ancient whole grain

gluten-free flatbreads (Kahlon and Chiu, 2014) and sorghum biscuits (Serrem et al., 2011) are examples of gluten-free bakery products with potential universal appeal. There is space and opportunity for gluten-free products to be established and appreciated for their unique characteristics without having to compare them to wheat-containing alternatives.

4. Conclusions

The sensory properties of gluten-free bakery foods are instrumental in guiding people to choose and consume such foods. Methodologies to compare differences or similarities among product options, to describe the sensory properties and to gain insight on consumers' views on products are critical to the development of suitable products. Sensory and consumer research offers various useful tools that can, in addition to physicochemical analyses and assessment using instrumental devices, provide valuable perspectives on gluten-free ingredients and product options. The application of the tools in a systematic manner based on the six steps to sensory testing process presented here will assist researchers to obtain powerful results to answer research questions.

Declarations of competing interest

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