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Novel techniques in Sensory and Consumer research applied to understand gluten-free products perception

TESIS DOCTORAL

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HACEMOS CONSTAR QUE:

El trabajo de investigación titulado **"Novel techniques in Sensory and Consumer research applied to understand gluten-free products perception"** que presenta Dª Patricia Puerta Gil por la Universidad Politécnica de Valencia, ha sido realizado en el Instituto de Agroquímica y Tecnología de alimentos (IATA-CSIC) bajo nuestra dirección y que reúne las condiciones para ser defendida por su autora.

Valencia, Noviembre de 2021

Fdo: Dra. Amparo Tárrega Guillem

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A todos los que han tenido el valor
de empezar una tesis… y acabarla.

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Resumen

El trabajo de investigación realizado en esta Tesis se ha centrado en la aplicación de técnicas recientes e innovadoras en el estudio de la percepción de productos sin gluten.

En primer lugar, se estudió cómo recopilar y tratar la información que hay disponible en Twitter para conocer las opiniones y preocupaciones de los consumidores sobre el tema "sin gluten". El análisis de los mensajes de Twitter mostró que los aspectos más relevantes para la gente que habla sobre “sin gluten” fueron cinco categorías de productos (pan, pastel, galleta, pizza y cerveza), situaciones de consumo, recomendaciones para preparar alimentos sin gluten en casa o lugares donde conseguirlos, y también aspectos relacionados con la enfermedad celíaca y con seguir una dieta sana o vegana.

Para explorar de forma automática la información recopilada de Twitter, se estudió la posibilidad de utilizar redes de co-ocurrencia. Estas redes resultaron ser útiles para interpretar el contenido de los tuits, ya que representan los aspectos más relevantes mencionados por los usuarios (ocurrencia de los términos), ayudan a poner en contexto estos aspectos, y al mismo tiempo, a relacionarlos con otros términos (co-ocurrencia). Además, se evaluó si es necesario un pre-tratamiento del texto de los tuits mediante análisis cualitativo. Para ello, se compararon las redes de co-ocurrencia obtenidas de datos previamente procesados por análisis cualitativo manual, y de datos procesados de forma automática. Ambas redes mostraron que la información obtenida era similar, lo que demostró que el proceso puede automatizarse, sin la necesidad de un pre-tratamiento manual del texto, y permitiendo analizar de forma efectiva la gran cantidad de información que hay disponible en la red.

En segundo lugar, se estudiaron diferentes panes comerciales sin gluten en relación al comportamiento en boca durante su consumo para entender mejor los factores que influyen en la percepción de la textura. Se caracterizaron cinco panes comerciales sin gluten y dos panes con gluten en cuanto a sus propiedades mecánicas, estructura, fragmentación durante la masticación, la

saliva incorporada y la consistencia y adhesividad del bolo formado. Las sensaciones de textura durante el consumo de los panes se registraron con la técnica TDS. La percepción de la textura varió a lo largo del proceso de masticación de los panes, que dependió a su vez de la estructura inicial, las propiedades mecánicas, la fragmentación, la formación del bolo o la actividad oral. Las sensaciones de duro, blando, esponjoso o seco, percibidas al principio de la masticación, estuvieron relacionadas con la estructura inicial y las propiedades mecánicas de los panes, como dureza y elasticidad. Las sensaciones de desmigabilidad y arenosidad se percibieron en aquellos panes que se fragmentaron en muchas partículas de pequeño tamaño. La sensación de compacto estuvo relacionada con una baja incorporación de saliva al formar el bolo, y las sensaciones de pastoso o de tener partículas pegadas, con un bolo más cohesivo o adhesivo, respectivamente. Las diferencias en las sensaciones percibidas parecen estar explicadas en base a las diferencias en la composición de los panes sin gluten. Posteriormente, se estudió cómo los cambios en la estructura de los panes sin gluten obtenidos por modificaciones en el proceso de panificación (tiempo de fermentación e hidratación) afectan al procesado oral, actividad oral y las sensaciones de textura percibidas durante el consumo. El comportamiento oral y la percepción de la textura variaron principalmente según el tiempo de fermentación. Especialmente al principio del consumo, las diferencias en las sensaciones de textura se explicaron en base a las diferencias en la estructura del pan y cómo se fragmentó durante la masticación. Al aumentar el tiempo de fermentación, estos panes, que eran menos densos y presentaban celdas de aire más grandes en la miga, fueron percibidos como aireados y menos secos al inicio de la masticación. En las etapas intermedias y finales de la masticación, todos los panes generaron las sensaciones de desmigabilidad, arenosidad, dificultad para formar el bolo y tener partículas pegadas.

En la última parte de la Tesis, se estudió la respuesta de los consumidores celíacos a distintos envases de alimentos sin gluten mediante la combinación de las técnicas de eye-tracking y de respuesta auto-reportada. El objetivo del primer trabajo fue estudiar la atención visual y la respuesta de los consumidores celíacos al envase de distintos panes sin gluten, así como el efecto del tipo de marca (marcas específicas, que solo fabrican productos sin gluten o marcas normales, no específicas de productos sin gluten), y de la presencia del logotipo de la certificación sin gluten. La atención visual se registró mediante eye-tracking, y se evaluó la intención de compra de los consumidores, la expectativa de aceptabilidad y la confianza que les confieren los paquetes de pan. Tanto el tipo de marca como la presencia del logo de la certificación, afectaron al comportamiento visual de los consumidores, siendo la lista de ingredientes el elemento que recibió mayor número de fijaciones. Todos los panes mostraron dar confianza a estos consumidores. La presencia del logo de la certificación sin gluten no afectó a la confianza, sino que condicionó lo que miraban: cuando no estaba presente, los consumidores celíacos se fijaron más en la lista de ingredientes o la información nutricional, especialmente en los panes de marcas no específicas. El tipo de marca afectó a la confianza y también la aceptabilidad esperada. Las marcas específicas de productos sin gluten dieron más confianza a estos consumidores. La expectativa de aceptabilidad fue mayor para los panes de marcas específicas, pero también estuvo explicada por otras características específicas de cada pan, como ser un pan blanco, blando y esponjoso, o tener buen sabor, semillas o diferentes cereales, mientras que los descritos como secos, quebradizos, duros, o no ser el paquete transparente, fueron los que mostraron una expectativa de aceptabilidad menor.

En un segundo trabajo, realizado en un supermercado simulado, se estudió la atención visual y las motivaciones de los niños celíacos y sus padres a la hora de comprar galletas en comparación con niños y padres no celíacos. La técnica de eye-tracking mostró que el patrón de las fijaciones sobre los distintos elementos de los paquetes de galletas varió según la condición celíaca, y ser o no padre de un niño celíaco. En comparación con los no celíacos, los niños celíacos se fijaron más en los ingredientes y en las palabras y símbolos que mencionan “sin gluten”, y menos en la imagen de la galleta. Los padres de niños celíacos, en comparación con los otros padres, prestaron más atención a los ingredientes y al símbolo de la certificación sin gluten, y menos a la imagen de la galleta, el nombre del producto, los dibujos y la información nutricional. El estudio de las razones de compra reveló que todos los niños estuvieron motivados por el placer como valor final, pero solo los niños celíacos mostraron interés por la marca y por probar un producto nuevo. También para los padres, la razón más importante para elegir una galleta fue que les gustara a sus hijos. Otra motivación importante para los padres de niños celíacos y no celíacos en su elección, fue la salud, pero los atributos que asociaron a este valor final fueron distintos: los padres de niños celíacos, buscaron garantizar la seguridad de sus hijos, mencionando atributos como la presencia del símbolo de la certificación sin gluten o tener una lista corta de ingredientes, mientras que los padres del grupo no celíaco, buscaron un contenido bajo en azúcar o grasa. Otros factores como el precio de las galletas o la confianza fueron motivaciones relevantes solo para los padres de niños celíacos.

En general, esta Tesis ha aportado conocimiento sobre el uso y la practicidad de técnicas o enfoques recientes en la ciencia sensorial y del consumidor. Esta investigación confirma que se puede conseguir una comprensión plena de la compleja respuesta del consumidor recabando información desde perspectivas muy distintas. Sin embargo, para responder a cuestiones específicas en investigación, cada una de estas técnicas diferentes (el análisis de las redes sociales, el estudio del procesado oral de los alimentos o la técnica de eye-tracking) puede contribuir de forma individual a entender mejor la aceptabilidad o las elecciones de alimentos del consumidor.

Resum

El treball de recerca realitzat en aquesta Tesi s'ha centrat en l'aplicació de tècniques recents i innovadores en l'estudi de la percepció de productes sense gluten.

En primer lloc, es va estudiar com recopilar i tractar la informació que hi ha disponible en Twitter per a conéixer les opinions i preocupacions dels consumidors sobre el tema "sense gluten". L'anàlisi dels missatges de Twitter va mostrar que els aspectes més rellevants per a la gent que parlava sobre "sense gluten" van ser cinc categories de productes (pa, pastís, galeta, pizza i cervesa), situacions de consum, recomanacions per a preparar aliments sense gluten a casa o llocs on aconseguir-los, i també aspectes relacionats amb la malaltia celíaca i seguir una dieta sana o vegana.

Per a explorar de manera automàtica la informació recopilada de Twitter, es va estudiar la possibilitat d'utilitzar xarxes de co-ocurrència. Aquestes xarxes van resultar ser útils per a interpretar el contingut dels tuits, ja que representen els aspectes més rellevants esmentats pels usuaris (ocurrència dels termes), ajuden a posar en context aquests aspectes, i al mateix temps, a relacionar-los amb altres termes (co-ocurrència). A més, es va avaluar si és necessari un pre-tractament del text dels tuits mitjançant anàlisi qualitativa. Per a això, es van comparar les xarxes de co-ocurrència obtingudes de dades prèviament processades per anàlisi qualitativa manual, i de dades processades de manera automàtica. Totes dues xarxes van mostrar que la informació obtinguda era similar, la qual cosa va demostrar que el procés pot automatitzar-se, sense la necessitat d'un pre-tractament manual del text, i permetent analitzar de manera efectiva la gran quantitat d'informació que hi ha disponible en la xarxa.

En segon lloc, es van estudiar diferents pans comercials sense gluten en relació al comportament en boca durant el seu consum per a entendre millor els factors que influeixen en la percepció de la textura. Es van caracteritzar cinc pans comercials sense gluten i dos pans normals quant a les seues propietats mecàniques, estructura, fragmentació durant la masticació, saliva incorporada i

consistència i adhesivitat de la bitla formada. Les sensacions de textura durant el consum es van registrar amb la tècnica TDS. La percepció de la textura va variar al llarg del procés de masticació dels pans, que va dependre al seu torn de l'estructura inicial, propietats mecàniques, fragmentació, formació de la bitla o l'activitat oral. Al principi de la masticació, les sensacions de duro, bla, esponjós o sec es van relacionar amb l'estructura inicial i les propietats mecàniques dels pans, com a duresa i elasticitat. Les sensacions que el pa s'esmolla i arenositat es van percebre en aquells pans que es van fragmentar en moltes partícules de xicoteta grandària. La sensació de compacte es va relacionar amb una baixa incorporació de saliva en formar la bitla, i les sensacions de pastós o de tindre partícules pegades es van relacionar amb una bitla més cohesiva o adhesiva, respectivament. Les diferències en les sensacions percebudes semblen estar explicades sobre la base de les diferències en la composició dels pans sense gluten. Posteriorment, es va estudiar com els canvis en l'estructura dels pans sense gluten obtinguts per modificacions en el procés de panificació (temps de fermentació i hidratació) afecten el processament oral, activitat oral i les sensacions de textura percebudes durant el consum. El comportament oral i la percepció de la textura van variar principalment segons el temps de fermentació. Especialment al principi del consum, les diferències en les sensacions de textura es van explicar sobre la base de les diferències en l'estructura del pa i com es va fragmentar durant la masticació. Un major temps de fermentació va fer que aquests pans, menys densos i amb majors cel·les d'aire, es perceberen airejats i menys secs a l'inici del consum. En les etapes intermèdies i finals de la masticació, tots els pans van generar les sensacions de que s’esmolla, arenositat, dificultat per a formar la bitla i tindre partícules pegades.

En l'última part de la Tesi, es va estudiar la resposta dels consumidors celíacs a diferents envasos d'aliments sense gluten mitjançant la combinació de tècniques de eye-tracking i de resposta acte-reportada. L'objectiu del primer treball va ser estudiar l'atenció visual i la resposta dels consumidors celíacs a l'envàs de diferents pans sense glútens, així com l'efecte de la mena de marca (marques específiques, que només fabriquen productes sense gluten o marques normals,

no específiques de productes sense gluten) i la presència del logotip de certificació sense gluten. L'atenció visual es va registrar mitjançant eye-tracking, i també es va avaluar la intenció de compra dels consumidors, la seua acceptabilitat esperada i la confiança que els confereixen els paquets de pa. Tant el tipus de marca com la presència del logo de certificació van afectar el comportament visual, sent la llista d'ingredients l'element que va rebre major nombre de fixacions. Tots els pans van mostrar donar confiança a aquests consumidors. La presència del logo de certificació sense gluten no va afectar la confiança, sinó que va condicionar el que miraven: quan no era present, els consumidors celíacs es van fixar més en la llista d'ingredients o la informació nutricional, especialment en els pans de marques no específiques. El tipus de marca va afectar la confiança i també l'acceptabilitat esperada. Les marques específiques de productes sense gluten van donar més confiança a aquests consumidors. L'expectativa d'acceptabilitat va ser major per als pans de marques específiques, però també va estar explicada per altres característiques específiques de cada pa, com ser un pa blanc, bla i esponjós, o tindre bon sabor, llavors o diferents cereals, mentre que els descrits com a secs, trencadissos, durs, o no ser el paquet transparent, van ser els que van mostrar una expectativa d'acceptabilitat menor.

En un segon treball, realitzat en un supermercat simulat, es va estudiar el comportament visual i les motivacions dels xiquets celíacs i els seus pares a l'hora de comprar galetes en comparació amb xiquets i pares no celíacs. El comportament visual va mostrar que les fixacions de la mirada canviaven segons la condició celíaca, i ser o no pare d'un xiquet celíac. En comparació amb els no celíacs, els xiquets celíacs es van fixar més en els ingredients i les paraules i els símbols esmentant “sense gluten”, i es van fixar menys en la imatge de la galeta. Els pares de xiquets celíacs, en comparació amb els altres pares, van prestar més atenció als ingredients i al símbol del certificat sense gluten, i menys a la imatge de la galeta, el nom del producte, els dibuixos animats i la informació nutricional. L'estudi de les raons de compra va revelar que tots els xiquets van estar motivats pel plaer com a valor final, però només els xiquets celíacs van

mostrar interés per la marca i per provar un producte nou. També per als pares, la raó més important per a triar una galeta va ser que els agradara als seus fills. Una altra motivació important per als pares de xiquets celíacs i no celíacs en la seua elecció, va ser la salut, però els atributs que van associar a aquest valor final van ser diferents: els pares de xiquets celíacs, van buscar garantir la seguretat dels seus fills, esmentant atributs com la presència del símbol de la certificació sense gluten o tindre una llista curta d'ingredients, mentre que els pares del grup no celíac, van buscar un contingut baix en sucre o greix. Altres factors com el preu de les galetes o la confiança van ser motivacions rellevants solo per als pares de xiquets celíacs.

En general, aquesta Tesi ha aportat coneixement sobre l'ús i la practicitat de tècniques o enfocaments recents en la ciència sensorial i del consumidor. Aquesta investigació confirma que es pot aconseguir una comprensió plena de la complexa resposta del consumidor recaptant informació des de perspectives molt diferents. No obstant això, per a respondre a qüestions específiques en investigació, cadascuna d'aquestes tècniques diferents (l'anàlisi de les xarxes socials, l'estudi del processament oral dels aliments o la tècnica de eye-tracking) pot contribuir de manera individual a entendre millor l'acceptabilitat o les eleccions d'aliments del consumidor.

Abstract

The research of this Thesis has focused on the application of recent and innovative techniques to study the perception of gluten-free products

First, it was studied how to gather and manage the information available on Twitter to get consumers' opinions and concerns about the topic “gluten-free”. The exploration of Twitter messages showed that the most relevant aspects for people talking about gluten-free were five product categories (bread, cake, cookie, pizza and beer), situations of consumption, recommendations for preparing gluten-free foods at home and places for getting them, and also aspects related to the coeliac condition and following a healthy or vegan diet.

To automatically explore the gathered information from Twitter, the possibility to use co-occurrence networks was studied. It was found that the co-occurrence networks were useful for interpreting the content of tweets, as they represent the most relevant aspects mentioned by users (occurrence of terms) and help to put these aspects into context and in relation to other terms (co-occurrence). In addition, the need of a pre-treatment of the text of tweets through qualitative analysis was addressed. For that purpose, co-occurrence networks obtained from either data processed by manual qualitative analysis and from data processed automatically were compared. Both networks showed that the information obtained was similarly meaningful, which proved that the process can be automated without the need for manual pre-treatment of the text, and allowing an efficient analysis of huge amounts of data available online.

Secondly, different commercial gluten-free breads were studied in terms of in-mouth behaviour during consumption to better understand the factors involved in texture perception. Five commercial gluten-free and two regular breads were characterised regarding mechanical properties, structure, fragmentation pattern during eating, saliva incorporated and consistency and adhesiveness of the bolus formed. Texture sensations elicited during consumption were registered with TDS technique. Texture perception showed to vary along the mastication process of the breads, which depended on their specific initial structure, mechanical properties, fragmentation pattern, bolus formation or oral activity. At the beginning, hard, soft, spongy or dry sensations were related to the initial structure and the mechanical properties of the breads such hardness and springiness. Crumbliness and sandiness were perceived in those breads that were fragmenting into a high number of particles of small size. Compact sensation was related with a low incorporation of saliva when forming the bolus, and pasty or sticky sensations were related with a more cohesive or adhesive bolus, respectively. Differences in the sensations perceived seem to be explained by the differences in composition of gluten-free breads. Subsequently, it was studied how changes in the structure of gluten-free breads achieved by modifications in breadmaking process (fermentation time and water hydration) affect oral processing, oral activity and texture sensations elicited during consumption. Oral behaviour and texture perception showed to vary mostly according to the time of fermentation. Especially at the beginning of consumption, differences in texture sensations were explained by the differences in structure and how it fragmented. A longer time of fermentation made that these breads, which were less dense and with bigger air cells, were perceived as aerated and less dry at the beginning of consumption. In middle and final stages of mastication, all breads elicited the sensations of crumbliness, grittiness, difficulty to form the bolus and having sticky particles.

In the last part of the Thesis, coeliac consumers’ response to different gluten-free food packages was studied through the combination of eye-tracking and self-reported techniques. A first work aimed to study the visual attention and response of coeliac consumers towards the package of gluten-free breads, as well as the impact of the type of brand (either specific brands only producing gluten-free products or a regular brand, non-specific of gluten-free) and the presence of gluten-free certification logo. Visual attention was registered through eye-tracking, while consumers evaluated purchase intention, expected acceptability, and trust conferred by the bread packages. Both the type of brand and presence of certification logo showed to affect the visual behaviour, and the list of ingredients was the element receiving the highest number of fixations. All breads were perceived as trusty to consume. The presence of a gluten-free certification logo did not affect the trust conferred, but conditioned what they looked at: when not present, coeliac consumers fixated more on the list of ingredients or nutritional facts, especially in breads of non-specific brands. The type of brand affected the trust and also expected acceptability. The brands specific of gluten-free products did confer more trust to these consumers. Expectations about liking were higher for this type of brands, but also were explained by other individual characteristics of breads as being a white bread, soft, and spongy, or having a good taste, seeds or different cereals, while those described as dry, brittle, hard, or not having a transparent package, were the less accepted.

In a second work, carried out in a simulated supermarket, the visual behaviour and motivations of coeliac children and their parents when purchasing biscuits were studied in comparison to non-coeliac ones. Eye-tracking technique showed that the fixation pattern on the elements of the biscuit packages changed according to suffering or not coeliac disease, and being or not a parent of a coeliac child. In comparison with the non-coeliac children, coeliac children fixated more on the ingredients, gluten-free words and symbols, and fixated less on the biscuit image. Parents of coeliac children, in comparison with parents of non-coeliac group, put more attention on the ingredients and the certified gluten-free symbol, and less attention on the biscuit image, product name, cartoon, and nutritional information. The study of their purchasing motivations revealed that all children looked for pleasure as the final value, but only coeliac children showed interest in the brand and in unknown products. For parents also, liking was the most important reason for choosing a biscuit for their children. Another important motivation for parents of celiac and non-celiac children was health, but the attributes associated to this final value were different: for parents of coeliac children, their motivations when purchasing were to ensure safety, mentioning attributes such as the gluten-free certification symbol and or short list of ingredients, while parents of non-coeliac group, searched for low sugar or fat contents. Other factors such as the price of cookies or trust were relevant motivations only for parents of celiac children.

On overall, this Thesis has provided knowledge about the usage and practicality of recent developed techniques or approaches in sensory and consumer science. This investigation confirms that a full understanding of complex consumer's response can be achieved by gathering consumer's information from very different perspectives. However, for answering specific research questions, these different tools (social media exploration, food oral processing approach or eye-tracking technique) can individually contribute to better understand consumer acceptability or food choice.

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Introduction

INTRODUCTION

1. Understanding consumers' food choice and factors involved

Eating is a vital and universal activity that comprises both physiological and psychosocial dimensions. The decisions that people routinely make regarding food are one of the most frequent human behaviours, dealing with different aspects to decide what to consume, when, where, how, what with, how much, why or who with. Food choice may seem simple, but it is the result of complex behaviour and diverse brain processes integrating multiple types of information learned from many interacting factors (Jaeger, 2006; Köster, 2009; Motoki & Suzuki, 2020).

The factors affecting the decision-making of food choice in consumers are of different nature, and can be classified into separate categories as the product itself, the consumer, and also the context in which consumption occurs. These factors interact to conform the perception that the consumer has about the product regarding the liking, the healthiness, the satiety of the trust conferred, which altogether will determine the food choice. Mojet presented in 2001 an overview of the many factors and disciplines involved in food choice behaviour (Figure 1). According to this, the factors affecting consumer choice can be structured based on the product, the consumer, or the context and situational factors (see Figure 2).

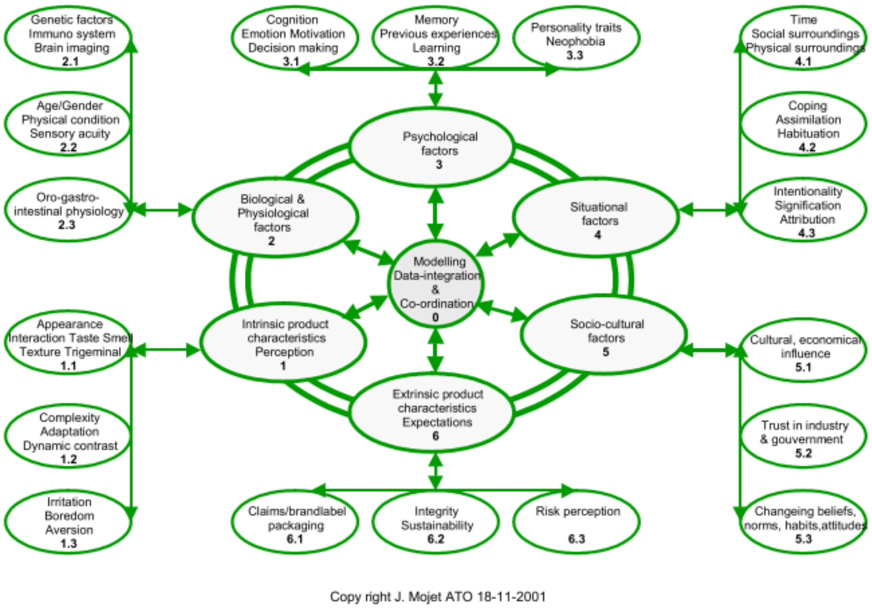

Figure 1. Factors involved in eating and drinking behaviour and food choice. From Mojet (2001), personal communication (Köster, 2009).

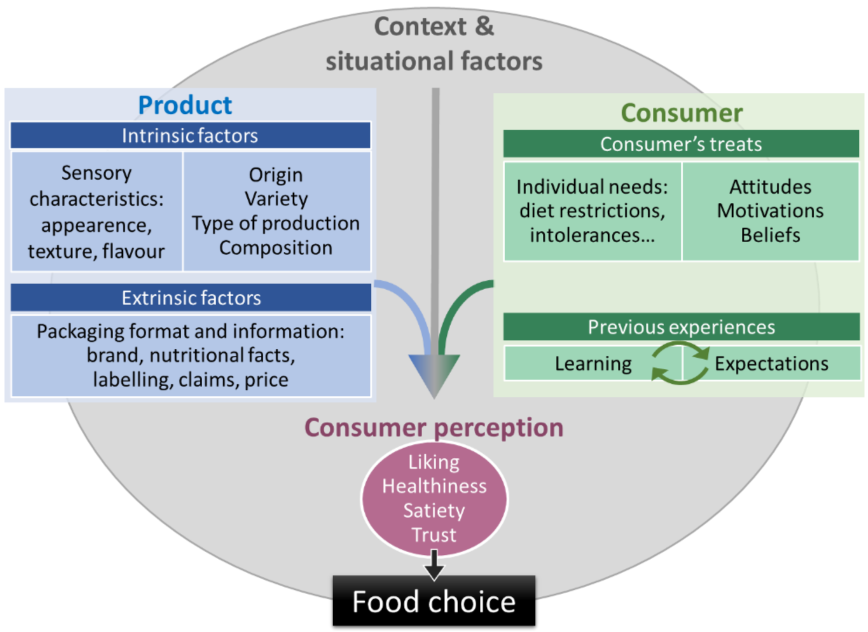

Figure 2. Factors affecting consumer food choice.

a) Product-related factors:

- *Intrinsic factors*:
  - Sensory characteristics of food as the appearance, texture, aroma or taste, are experienced and evaluated throughout the human senses when the consumer interacts with the product, and play an important role in the overall perception of food by the consumer. Perception of sensory characteristics, and particularly taste, are regarded as the main drivers of liking a food product. The term *liking* refers to the immediate experience of pleasure from the orosensory stimulation of eating a food, corresponding to the hedonic response or ‘‘palatability’’ of the sensory properties.
  - Other factors as the origin, variety, the type of production, or the composition also characterises the product. These features can influence consumers’ perception in two manners: i) affecting its sensory characteristics and subsequent liking; and ii) if the consumer knows these features, they can affect the perception of quality. For example, the same variety of a vegetable can vary in its sensory properties if its grown in different areas or soils or under different environmental conditions; and likewise, the same vegetable can be grown following a traditional or organic production method. This can be a valuable characteristic for the consumer, resulting in either acceptance or rejection of the product.
- *Extrinsic factors:*

  The format of the package in which the product is presented, the displayed information, nutritional facts, labelling or the price are product-related characteristics that do not physically belong to the product itself, but influence the consumer when choosing. The brand also has a direct implication on consumer perception of a product. Depending on the type of food product, the brand can substantially impact the hedonic liking (Guerrero, Colomer, Guàrdia, Xicola, & Clotet, 2000; Hubbard, Jervis, & Drake, 2016), having a strong influence on wines (Priilaid, 2006), beers

(Guinard, Uotani, & Schlich, 2001), orange-flavoured powdered drinks (Varela, Ares, Giménez, & Gámbaro, 2010) or chocolate (Torres-Moreno, Tarrega, Torrescasana, & Blanch, 2012). Additional information often included on the label such as sensory claims, can affect the expectations of the consumer regarding liking and also the perception of healthiness, satiety or trust conferred.

b) Consumer-related factors:

The decision to accept or reject a food product can be also conditioned by consumers' own treats, as their attitudes, motivations and beliefs, or more importantly, by their individual needs for consuming a product or not, as diet restrictions, intolerances o food allergies. Consumers usually take into account previous experiences with a food product to create sensory and hedonic expectations, leading them to believe that the product will have certain sensory features and forming an impression about how much they would like it. Subsequent confirmation or disconfirmation of these sensory and hedonic expectations after consumption, can lead to the acceptance or rejection of a product, and therefore, affect their choices and repeated consumption (Costell, Tárrega, & Bayarri, 2010; Li, Jervis, & Drake, 2015; Piqueras-Fiszman & Spence, 2015).

c) Context and situational factors:

The context in which a product is evaluated refers to the situation, the environment and surrounding setting, and has shown to be crucial for consumers' perception of a product, and therefore, for the process of food choice (Köster, 2009).

To achieve and maintain success in the market, a food product needs to meet consumers' expectations and fully satisfy their requirements. The study and knowledge of these factors affecting food choice results in great relevance when developing or improving products, as consumers are the final arbiters for choosing and consuming them (Tarancón, Sanz, Fiszman, & Tárrega, 2014). No food or beverage is worth producing, distributing or marketing without evidence indicating that consumers would accept it. In this sense, consumers can be considered co-creators of the new food products, playing a key role in the ideation, concept design and early stages of the development of products that result suitable for them (Lorenzo-Romero, Constantinides, & Brunink, 2014; Sawhney, Verona, & Prandelli, 2005).

Knowing the mechanisms of consumers' perception is also a valuable resource for the industry when a product is launched or modified in the market. If the factors that affect the choice of a specific group of consumers are understood, it is possible to adapt the product-related information to what consumers are demanding. Also, this would help policy makers to better transmit messages for a safer, healthier and more sustainable consumption.

In view of all these aspects mentioned coming into play, consumer research can result complex and challenging, requiring the application of methodologies that make possible to have an integrated view of consumers' behaviour and response with respect to food and drink.

2. Methods in sensory evaluation and consumer science

The field of sensory and consumer science emerged during the second half of the twentieth century in parallel to the growth of food industry to provide support to the emerging products. Since then, this field has rapidly expanded and evolved becoming increasingly interdisciplinary and relying upon other disciplines as biology, physiology, psychology or statistics (Jaeger, et al., 2017; Kemp, Hollowood, & Hort, 2009).

Sensory evaluation has been defined as a scientific method used to evoke, quantify, analyse and interpret the human responses to products which are perceived through the senses of sight, smell, touch, taste and hearing (Anonymous, 1975).

The use of sensory and consumer testing is of great importance in food research, both in industrial and academic fields. For food industry, it represents a powerful tool in new product development or optimization to guide business decisions, evaluate new concepts of products, check the effect of replacing ingredients or processes, monitor changes in food characteristics over time, or for quality control purposes. It is also helpful for identifying different sensory-based target consumer segments and for analysing product characteristics from competitors in market assessment. In the research field, it has helped to gain insights into the comprehension of the main mechanisms operating sensory perception of food (Kemp et al., 2009; Lawless & Heymann, 2010; Varela & Ares, 2012), to detect relevant factors for consumers in their food choice, to adapt nutritional messages and labelling for a better understanding by consumers to meet their real needs, and also to promote changes in consumption for healthier and more sustainable habits.

Traditionally, methods for sensory evaluation have been divided into well-defined categories according to who performed the evaluation: i) sensory characterization with trained assessors; and ii) consumer studies. Currently, it is widely recognised that there is no such obvious division between both approaches, and the methods available for food evaluation can be classified according to the information intended to be obtained and the aspects to be measured (Figure 3).

2.1. Methods for sensory evaluation

Sensory evaluation test methods can be classified as follows:

- *Tests to determine if there exists any sensory difference among products*.
  - To detect overall differences or similarities among products: triangle, tetrads duo-trio, same-different, or difference from control tests.
  - To detect attribute-specific differences: paired comparison or ranking tests.

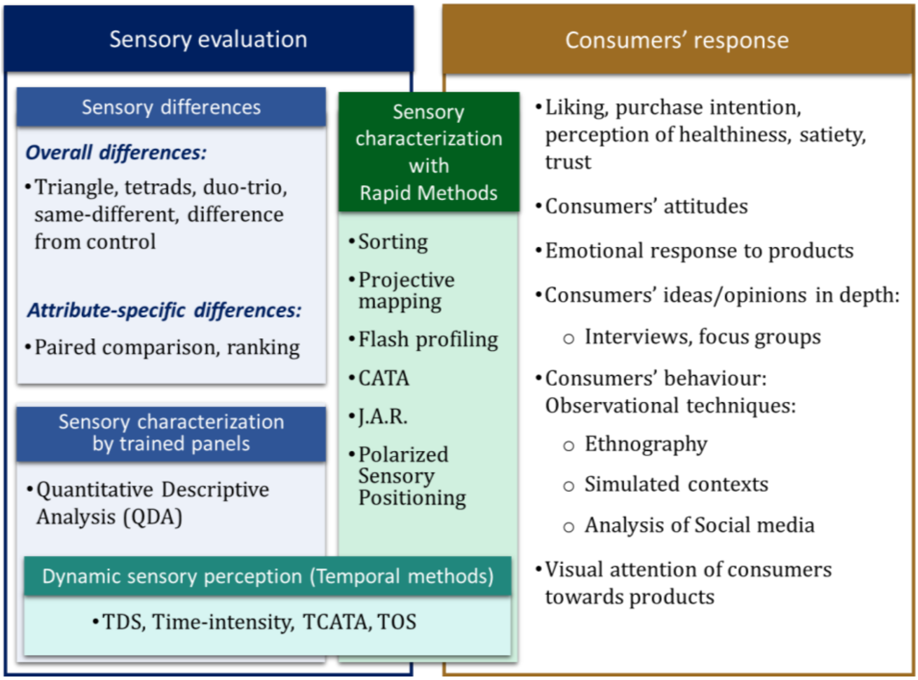

Figure 3. Methods used in sensory evaluation and consumers' response.

- *Tests to describe product characteristics*.
  - Sensory characterization by trained panels. The attributes of a product are analysed and evaluated by a trained panel selected according to their ability to detect, identify, discriminate and describe the sensory characteristics of products in a reliable way.
    - Quantitative Descriptive Analysis (QDA) is a powerful and precise tool to determine the sensory profile of a product, quantify the intensity of attributes and also understand the sensory drivers of liking when linked to data from consumer hedonic tests.
  - Sensory characterization with Rapid Methods. From a classical perspective, consumers have been regarded as not capable to provide objective information about the sensory properties of a product, devoted only to provide hedonic data. However, in the last two decades, there is an

increasing trend to use non-trained to analyse the sensory characteristics of the product. Novel test methodologies have been developed and adapted since then to get reliable and direct information about the sensory characteristics of a food product without the need of training, saving considerable time and resources and obtaining a global perception of the product experienced. The different Rapid Methods available allow assessors to express with their vocabulary how they perceive sensory properties, and can be classified according to their final purpose:

- To analyse global differences or similarities among products: sorting and projective mapping or Napping.
- To analyse specific attributes: Flash Profiling, Check-All-That-Applies (CATA) and Just About Right scales (J.A.R.).
- To compare with a reference product as Polarized Sensory Positioning.

- Temporal methods to describe the dynamics of sensory perception. Food sensations are elicited as a result of the evolving processes of mastication, breathing, salivation, movements of the tongue and swallowing, and vary from moment to moment. Temporal methods are used to describe the changes in perception of specific attributes over time in-mouth, providing key information about the temporal dimension of consumption.

  - Time-intensity (TI) methodology records how the perceived intensity of an attribute evolves over the time of consumption of a food or drink, providing information about the duration of sensation, the maximum intensity perceived, or the rate of the increase and decrease in perception. TI methodology has been widely used in last decades, but still presents some limitations that make it difficult to apply in industry or research fields, such as the long time that the experiment takes and the possible dumping effect derived from evaluating only one attribute at a time (Clark & Lawless, 1994; Varela & Ares, 2014).

- The Temporal Dominance of Sensations (TDS) method provides additional information to traditional TI approaches, as it monitors the most dominant sensation over time (Labbe, Schlich, Pineau, Gilbert, & Martin, 2009; Pineau et al., 2009). This method results of great utility for picturing the dynamics of perceived sensations that might be critical during oral processing, as the characteristics of food vary throughout mastication. Since its development in 1999, at the ‘‘Centre Européen des Sciences du Goût” in the LIRIS lab (Pineau et al., 2009), it has been increasingly applied to assess the dynamic aspects of sensory perception of different foods and beverages. Fiszman & Tárrega (2017) exhaustively reviewed the use of TDS method in relation to texture perception of hard solid foods. Table 1 shows a list of works for different product categories, including those reviewed by these authors.
- More recently, other temporal methods as Temporal Check-All-That-Apply (TCATA) or Temporal Order of Sensations (TOS) have been developed to also measure dynamic of sensations using a different set-up.

Table 1. Studies using TDS method for evaluating dynamics of sensory perception in different food and drink product categories.

Food category	Product	Reference
Dairy	Cheese	Ares, et al., 2015 Bemfeito, et al., 2016 de Loubens, et al., 2011 Deegan, et al., 2013 Saint-Eve, et al., 2015
	Cheese pie	Hutchings, et al., 2014a Marcano, et al., 2015
	Yoghurt	Bruzzone, et al., 2013
Cereal	Biscuits	Hutchings, et al., 2014a Laguna, et al., 2013 Cheong, et al., 2014 Young, et al., 2016 Young, et al., 2013 Lepage, et al., 2014
	Bread	Jourdren, et al., 2016b Panouillé, et al., 2014
	Breakfast cereals	Peyron, et al., 2011 Lenfant, et al., 2009
Meat	Sausages	Devezeaux de Lavergne, et al., 2015a Braghieri, et al., 2016
	Salami	Ares, et al., 2015
	Dry cured ham	Lorido, et al., 2016
	Cooked ham	Rizo, et al., 2018
Gels	Gelatine-agar gel	Tang, et al., 2017 Devezeaux de Lavergne, et al., 2015c
	Agar gels	di Monaco, et al., 2016a
	Gelatine gels	Hutchings, et al., 2014a
Other	Polenta sticks	di Monaco, et al., 2016b
	Fish sticks	Albert, et al., 2012
	Nuts	Hutchings, et al., 2014b
	Peanuts	Rosenthal & Share, 2014
	Potato crisps	Hutchings, et al., 2017
	Dark chocolate	Visalli, et al., 2016
	Milk chocolate melt	Hutchings, et al., 2014a
	Olive oil	Dinnella, et al., 2012
Drinks	Wine	Meillon, et al., 2009, 2010 Sokolowsky & Fisher, 2012
	Beer	Vázquez-Araújo, et al., 2013
	Coffee	Dinnella, et al., 2013
	Water	Teillet, et al., 2010

2.2. Methods for studying consumers' response to foods

In subjective consumer-based approaches, the appreciation of hedonic properties and other aspects of the product are measured by consumers. The acknowledgement of the multi-disciplinary nature of consumer behaviour has contributed to include other disciplines like psychology, marketing or sociology, besides sensory evaluation to obtain more complete and detailed information about the decision-making process and food choices. The different techniques available for consumers' response can be classified according to the type of information intended to be obtained:

- *Measurement of consumers' liking and preferences, purchase intention, and perception of aspects like healthiness, satiety or trust*. The magnitude of these aspects is quantified with structured scales using short and clear questions. The data obtained with these methods also help to understand the behaviour of different segments of consumers with clustering and classification techniques. Usually, a high number of consumers (generally 60 as minimum), is required to gain meaningful insights from the data collected, and ideally, consumers should be representative enough of the general population.
- *Measurements of consumers' attitudes and interests.* Multi-item scales are usually applied to measure attitudes towards food neophobia, health aspects (Roininen, Lähteenmäki, & Tuorila, 1999), environmental concerns or sociological and psychological aspects for meat consumption (Tarrega, Rizo, Murciano, Laguna, & Fiszman, 2020), among others, and classify consumers according to these attitudes.
- *Emotional response to products*. The emotions associated with food choices and the context of consumption are key in the decision-making process, modulate the perception of the eating experience and go beyond hedonic aspects. The measurement of emotional response is complex, and can be performed through explicit methods, with self-reported answers of consumers using words, pictures or emojis; or through implicit methods, with the analysis of physiological reactions registering the emotions and behaviour, using

techniques such as electroencephalography, galvanic skin response or reading of facial expressions.

- *Methods for gathering consumers' ideas and opinions in depth.* They are mainly used to generate and describe ideas from consumers, which results especially useful for identifying market opportunities, develop new concepts and explore consumers' impressions:
  - Personal interviews as laddering provide the underlying motives of individuals for choosing a product. It is based on the means-end chain theory, which determines the linkages between particular attributes of the product, consequences of consumption and important life values for the individual.
  - In focus group discussions, the researcher acts as a moderator to raise questions and stimulate the participation and interaction of participants to freely express their spontaneous opinions about a specific topic. The analysis of data obtained from these techniques is subjective, non-statistical, and usually is obtained from few participants (ideally among 7 and 12, as suggested by Guerrero & Xicola, 2018).
- *Observational techniques.* They are considered implicit methods that try to avoid the possible biased usually derived from conscious responses of self-reported (or explicit) answers from subjects obtained with direct questions or personal interviews. Observational techniques help to explore the behaviour of consumers in a situation as close to reality as possible.
  - Ethnography. In a real-life context, it helps to reveal what consumers do rather than what they express they would do.
  - Simulated context. It consists of a setting-up of a real environment, but under controlled conditions. In comparison with an evoked context (in which consumers are asked to imagine a scenario of consumption or purchasing), simulated contexts can achieve better ecological validity to understand consumers' response. For example, the display of a variety of

products available to choose allows the participants to act as they would normally do at the supermarket when deciding what to buy, which has shown to be helpful in the study of purchase intention and the influencing factors (O'Brien, et al., 2015; van Herpen, van den Broek, & van Trijp, 2016). As suggested by different studies (Bangcuyo, et al., 2015; Galiñanes Plaza, Delarue, & Saulais, 2019; Miele, Giboreau, & Almli, 2021; Sinesio et al., 2019), a re-creation of natural environments in laboratory settings would create a simulated context to approximate reality to consumers and mimic real-life situations. These approaches can be combined with methods based on direct asking, which can provide complementary information and a more comprehensive view of consumers' response.

3. Recent and innovative approaches to understand consumers' response

3.1. Study of food oral processing as a new approach for the understanding of dynamic sensory perception

The field of food oral processing is recently arising as a new approach to study the changes of food structure through mastication in relation to many other areas such as sensory evaluation, dentistry or dysphagia pathologies. During oral consumption, the food is deconstructed through mastication, undergoing physical and chemical transformations: food structure is dynamically broken down into particles, which are mixed with saliva and agglomerated to form a bolus suitable to be swallowed. The dynamic process of continuous modifications in the structure of food material during the oral trajectory are responsible for the texture perception and appreciation, which is complex and highly dynamic, changing from the first bite to the final swallow (Chen, 2009; Devezeaux de Lavergne, van de Velde, & Stieger, 2017; Varela, Salvador, & Fiszman, 2009).

The direct link between the mechanical properties of a food product derived from its structure and the texture perceived was first established by Friedman, Whitney, & Szczesniak (1963), and Hutchings & Lillford (1988) stated that texture perception depends on oral processing.

The traditional perspective for the study of texture sensations focused on the study of the initial structure and mechanical properties of the food product, and was based on instrumental analysis of textural properties such as hardness, springiness, cohesiveness or stickiness, among others, or other fundamental tests such as viscosity or lubrication (Chen, 2014). This approach bases on linking the sensory attributes perceived to the initial characteristics of the product through *in vitro* analysis and without processing in mouth. However, the specific mechanisms responsible for the perception of food oral properties differ greatly from those operating in instrumental measurements, which do not consider the dynamic nature of oral processing (Assad-Bustillos, 2019). For this reason, the focus of attention is recently being moved to study how the initial structure of foods is transformed during mastication, and how these changes can explain the variations in the sensations of texture perceived over time (Fiszman, & Tárrega, 2018; Foegeding, Stieger, & van de Velde, 2017; Rizo, et al., 2018). These studies focus on both the properties of bolus formed during eating and also on the oral activity of the individual.

a) Study of bolus properties

In the last years, different methodologies have been adapted and applied to study the bolus properties in bakery products, and particularly in breads. Table 2 shows the works that have addressed the study of different oral processes as the fragmentation of food structure, bolus formation and saliva incorporation during mastication of breads, through the analysis of different parameters of bolus applying multiple methodologies.

Table 2. Works addressing the study of oral processes during mastication of breads through the application of methodologies that analyse different parameters of bolus.

Oral process	Parameter analysed in bolus		Method		Reference
Food fragmentation	Particle size characterization		Image analysis		Tournier, et al., 2012 Le Bleis, et al., 2013 Pentikäinen, et al., 2014 Tournier, et al., 2014 Gao, et al., 2015 Jourdren, et al., 2016a Jourdren, et al., 2016b Le Bleis, et al., 2016 Gao, et al., 2018 van Eck, et al., 2019
Bolus formation	Particle size characterization		Laser diffraction techniques		Hoebler, et al., 1998 Hoebler, et al., 2000 Gao, et al., 2015
Bolus formation	Mechanical properties	Rheology	Rheometry	Capillary	Le Bleis, et al., 2013 Le Bleis, et al., 2016
Bolus formation	Mechanical properties	Rheology	Rheometry	Oscillatory	Le Bleis, et al., 2013 Panouillé, et al., 2014 Jourdren, et al., 2016a
Bolus formation	Mechanical properties	Texture (Hardness Adhesiveness Cohesiveness Springiness)	Double compression tests (TPA)		Jourdren, et al., 2016a Jourdren, et al., 2016b
Bolus formation	Mechanical properties	Texture (Hardness Adhesiveness Cohesiveness Springiness)	Penetration tests		Gao, et al., 2015 Gao, et al., 2017 Gao, et al., 2018 van Eck, et al., 2019 Puerta, et al., 2020 Puerta, et al., 2021
Bolus formation	Mechanical properties	Tribology	Tribometry		van Eck, et al., 2020
Saliva incorporation	Water content		Gravimetry		Le Bleis, et al., 2013 Motoi, et al., 2013 Panouillé, et al., 2014 Pentikäinen, et al., 2014 Tournier, et al., 2014 Gao, et al., 2015 Jourdren, et al., 2016a Jourdren, et al., 2016b Le Bleis, et al., 2016 Gao, et al., 2017 Gao, et al., 2018 van Eck, et al., 2019 van Eck, et al., 2020

- Particle size characterization. The measurement of particle of the bolus obtained from *in vivo* mastication is helpful for studying the fragmentation pattern of the food, which largely depends on the initial characteristics and structure of the product. Techniques as image analysis of bolus particles or laser diffraction are usually applied to provide information about the fragmentation degree of food and also about bolus formation and agglomeration mechanisms during chewing and before swallowing.

- Bolus mechanical properties. Measurement of texture through texture profile analysis (TPA: hardness, adhesiveness, springiness), rheological or lubrication properties through tribology can provide knowledge about the physics of bolus formation and evolution.
- Water content of bolus. This measurement contributes to elucidate the process of saliva incorporation to food, which is essential in the formation of a bolus suitable to be swallowed and strongly depends on the type of food matrix.

b) Individuals' oral activity

Other aspects not related to the bolus formed are also relevant for the understanding of oral transformations of food during consumption:

- Chewing behavior can be characterized through electromyography, image recording or self-reported measures of chewing activity.
- Salivation can be characterized through the study of salivary flow rate and composition of saliva produced during eating.

Taking into account the highly dynamic nature of texture perception of food during oral processing, sensory evaluation has been performed applying temporal analysis methods as TDS. The study of the relationship between oral processing of food structure and dynamics of texture perception been explored in products such as gels (Devezeaux de Lavergne, et al., 2015c), meats (Devezeaux de Lavergne, et al., 2015a; Rizo et al., 2018), biscuits (Cheong, Foster, Hedderley, Morgenstern, & James, 2016, Young, Cheong, Hedderley, Morgenstern, & James, 2013), and also in breads (Gao, Ong, Henry, & Zhou, 2017; Jourdren, et al., 2016a; Jourdren, et al., 2016b; Panouillé, Saint-Eve, Déléris, Le Bleis, & Souchon, 2014; Tournier, Grass, Septier, Bertrand, & Salles, 2014).

In a recent review, Gao & Zhou (2021), highlighted the importance of the initial structure characteristics and oral processing for the understanding of sensory perception during consumption of bread. These authors claimed for a holistic and deeper analysis of the link between the transformation of bread to bolus and texture perception when re-designing traditional bread products with improved health properties. Figure 4 shows an integrated view of bread structure and subject oral physiology, in relation to bread oral processing process involving three major components: chewing behaviour, bolus formation and sensory perception (adapted from the review by Gao & Zhou, 2021).

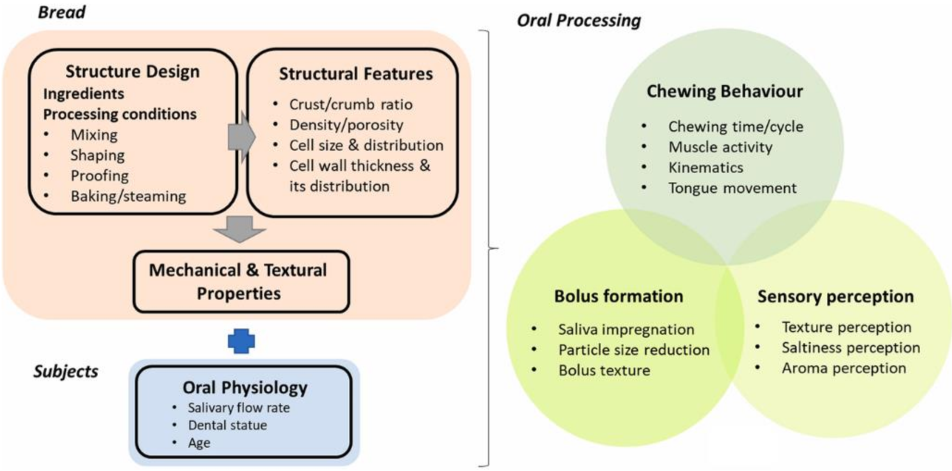

Figure 4. Integration of bread structure and subject oral physiology in relation to bread oral processing process, involving three major components: chewing behaviour, bolus formation and sensory perception (adapted from Gao & Zhou, 2021).

3.2. Social media as a source of information for consumer research

From the beginning of the 21st century, the use of the Internet has meant a revolution in social life and has become a part of our daily routines. Internet users in 2020 reached 4.66 billion across the globe (59.5% of total global population), which is supposed to increase by more than 60% since 2015. Currently, the Internet can be accessed via devices such as computers, PDAs, games machines, digital TVs or mobile phones, being these latter the most used for connecting (Kemp, 2020). As a result of this generalised access, a wide variety of activities that we habitually perform depend on the Internet, as information requests, shopping, supply of entertainment and leisure, banking transactions, or teleworking, among others.

The use of the Internet has also revolutionised the way we communicate with each other and has brought new ways to interact with other people, express ourselves and share experiences. The different platforms and applications that the Internet offers for communicating are social media, instant messaging, video calling systems, e-mail, videoconferencing and virtual classroom software. Some examples of each type are shown in Figure 5.

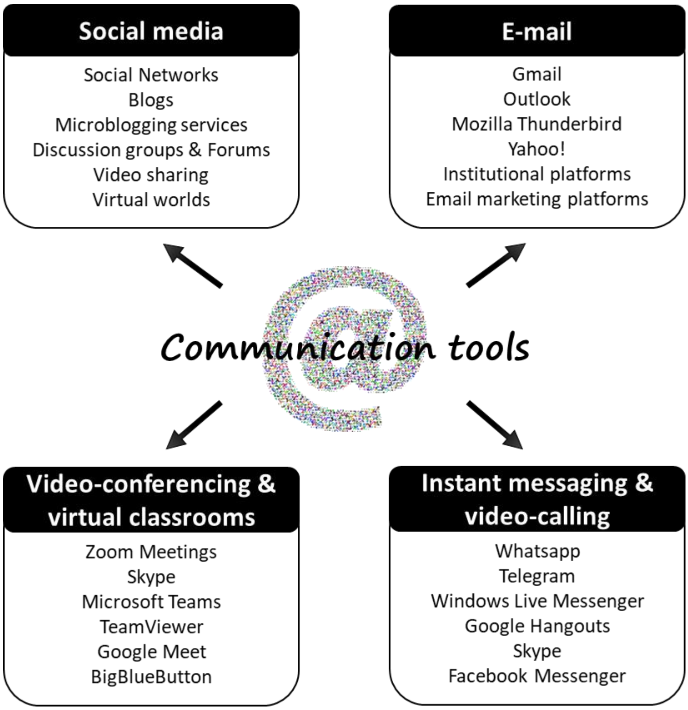

Figure 5. Most known tools for communication in the Internet

Among them, social media are of special interest for conducting consumers research, and according to Kaplan & Haenlein (2010), are Internet-based applications that allow the creation and exchange of User Generated Content.

Social media are a virtual environment where users reflect their opinions, interests, lifestyle, and experiences. Through a personal account, users can manage a public or semi-public profile to interact with a personalised list of contacts and share content in different formats (text, pictures, videos, emoticons and emojis). Social media are also used by companies and institutions for marketing purposes to interact with their customers or advertise brands and products. Table 3 describes the characteristics of the most frequently used social media.

Table 3. Characteristics of the most frequently used social media.

Social media	Characteristics
Twitter	Main platform of microblogging service for publishing messages ("tweets") up to 280 characters. It allows contacts ("followers") to interact with each other. Descriptive keywords ("hashtags") are often included in the tweet.
Facebook	Allows to communicate and share users' content posted (in any format) on the personal profile with their contacts and interact with them.
Instagram	Allows to take, share or edit mainly pictures, but also videos with contacts ("followers"). Besides short descriptions in text formats, the content is commonly accompanied by a list of keywords ("hashtags") that detail the picture or video posted.
Pinterest	Allows to storage and classify mainly pictures, but also videos or links to external webpages. Users can also interact with their list of contacts and share contents.
LinkedIn	Social network for professional purposes, focused on business and commercial activities. Personal profile shows the current occupation, professional trajectory and *Curriculum Vitae*.
YouTube	Platform for video watching that also allows the interaction among users. Having a personal account is not required for watching, but it is mandatory for interacting with other users.
TikTok	Video-sharing platform to create and share musical content with an entertaining purpose through short musical videos from 15 seconds to 1 minute long.

Social media represent a potential source of information to study different aspects of human behaviour. The following characteristics make them especially suitable for conducting consumer research:

- Its use has been widespread in the last years.
- A huge amount of information is available.
- Posting of messages is spontaneous (the content is freely generated).
- The language is informal and colloquial.
- People usually share experiences in the context of consumption.
- Different eating habits are importantly present in the posts (food choices, restaurants, healthy food, eating situations, emotional responses).

The fact of being freely generated content by the users in a context that has not been established by the researcher avoids any possible bias related to direct questioning or interviewing. Given the great potential, researchers of different fields have made use of these posts to gather insights on a variety of topics, as ethnic and cultural identities (Ichau, Frissen, & d'Haenens, 2019), health issues (Yin, Song, Clayton, & Malin, 2020), dietetic practice and weight management (Dumas, Lapointe, & Desroches, 2018; Liu & Yin, 2020), epidemics (Culotta, 2010), drugs (Bian & Topaloglu, 2012), tourism (Akehurst, 2009), analysis of emerging markets around the globe (Thoumrungroje, 2014) or political trends (Tumasjan, Sprenger, Sandner, & Welpe, 2010).

The content obtained from different social media has been explored to analyse topics related to food and drink (Table 4). In particular, Twitter has attracted the attention of many researchers for gathering valuable information for consumers' studies. It is one of the most popular microblogging services, with more than 340 million active users and 500 million messages, which are known as “tweets”, posted per day, as of October 2020 (Aslam, 2021). Twitter users are in general more likely to spontaneously post opinions and comments than other social media users about products, brands or experiences regarding food.

Table 4. Studies that analyse the content of different social media through different approaches

Social media	Type of content	Topic explored	Type of analysis	Reference
Twitter Facebook Forums Blogs	-Tweets: Text and keywords. -Facebook, forums and blogs: Text from posts	Impact of the cultural diversity associated to beer flavours on the perception of food and preferences across countries	Automatic word counting	Arellano-Covarrubias, et al., 2019
Twitter Facebook Instagram	Text from tweets, posts and messages	Messages posted by Spanish nutritionists with the highest engagement on social media	Manual content of the text	Arellano-Covarrubias, et al., 2019
Different social media (including Twitter and Facebook)	Text from posts	Identification of consumer insights regarding a food-related topic (coffee freshness) as a valuable source of consumer information for new product development	Automatic word counting	Carr, et al., 2015
Twitter	Text from tweets	Description of the content of food-related posts when people tweet about breakfast, lunch, dinner and snack	Manual content analysis of tweets and automatic word counting	Vidal, et al., 2015
Twitter	Text from tweets	Understanding how European retailers make use of social media for communicating and promoting healthy food	Manual content analysis of tweets	Samoggia, et al., 2019
Twitter	Text from tweets	Description of the content of food-related posts when people tweet about different eating situations, the foods and beverages they mention and the emotions they express	Manual content analysis of tweets and automatic word counting	Dondokova, et al., 2019
Twitter	Hashtags	Description of the type information regarding food shared on Twitter associated to different geographical areas of Italy	Manual content analysis of tweets and automatic word counting	Platania, & Spadoni, 2018
Twitter	Emojis	Analysis of the emojis and emoticons used to express emotions related to food when people tweet about breakfast, lunch, dinner and snack	Manual content analysis of emojis and emoticons	Vidal, et al., 2016
Instagram	Images	Consumption of drinks as a symbol of cultural identity	Visual analysis of images	Gómez-Corona, et al., 2019
Instagram	Hashtags	Consumers' perception of different cakes regarding appearance, flavour, texture and hedonic aspects	Automatic word counting of hashtags	Harun, et al., 2020
Instagram	Hashtags	Consumers' perceptions, feelings and motivations regarding organic production of food	Automatic word counting of hashtags	Pilař, et al., 2018
Instagram	Images	Analysis of brand engagements of bakeries establishments with consumers during COVID-19 lockdown period	Visual analysis of images	Fusté-Forné, & Filimon, 2021

According to Lipizzi, Iandoli, Ramirez Marquez (2015), Vidal, Ares, & Jaeger (2018) and Vidal, Ares, Machín, & Jaeger (2015), the basic steps for conducting social media research include:

- Searching and retrieving information of interest.
- Extracting and storing the relevant data in a suitable format.
- Pre-processing or cleaning of data.
- Analysis of the content for obtaining relevant conclusions.

The different types of analysis of the data that can be performed are resumed in Table 5.

One of the most common approaches is content analysis, which explores the messages and extracts relevant information expressed in form of text, images, videos, emojis and emoticons, and can be performed either manually or automatically. The main advantage of manual content analysis relies on that it is possible to obtain the full meaning of the message and interpretation of the context in which the information is expressed, but a full reading of the raw data is required, which is extremely time-consuming if the dataset is big. Automatic content analysis as word counting is based on registering the frequency of mention of terms present in the whole dataset, providing an idea about the relevant topics (Mostafa, 2013). Wordclouds graphically represent the frequency of occurrence of these terms, but they do not show the context in which each of those terms is mentioned. Algorithms-based techniques are computer-assisted methods that classify text units into categories or themes. However, specific skills for programming and developing algorithms are required, the topics identified can result unclear and the interpretation of data can be biased.

Table 5. Techniques for analysing data obtained from social media and main advantages and disadvantages of each.

Method	Type of analysis	Type of content	Procedure	Advantages	Disadvantages
Qualitative analysis	Manual	Text Images Videos Emoticons, emojis	Reading, coding and classification of the content into categories and themes	Full interpretation of meaning and context of the message	Laborious and time-consuming with big datasets.
Word counting	Automatic	Text	- Obtention of frequency of mention of terms - Graphical representation by wordclouds	Fast, easy and simple	Context of conversation is missing.
Algorithms (Computer-assisted method)	Automatic	Text	The algorithm recognises patterns in the data and assigns categories and themes to text units. External source of coded dataset required as a training sample for building the algorithm	Automatic classification of big datasets	Skills for programming required. Possible biased interpretation of data.

The challenge that still exists, is how to treat the huge amount of data available online to extract meaningful information feasibly and effectively, without investing lots of time or effort, and without the need of programming or developing algorithms. An approach that allows the efficient treatment of big volumes of information, which also includes the interpretation of the context, would be required to extract knowledge potentially useful for consumer research. In this scenario, the possibility to apply the co-occurrence technique arises for analysing the information available from social media. Co-occurrence networks are graphical representations showing the relevance of the terms present in a text and, at the same time, their relatedness. They have been widely applied for bibliometric studies, but no research has focused on the study of gluten-free by means of co-occurrences from information available on Twitter, which might be an appropriate tool to explore what is mentioned regarding this topic.

3.3. Eye-tracking as an implicit method for studying consumers' attention when observing or purchasing products.

Eye-tracking is an innovative technique that detects and analyses eye movements to investigate visual attention. Technological advancements offer the possibility to perform consumer research using new tools as eye-tracker devices for studying consumers' behaviour spontaneously and more naturally. This technique can be regarded as an implicit measurement capturing unconscious reactions, as long as participants are not informed about the experiment goal and the fact that their gaze is being captured. The interest in visual attention for studying consumer choice relies upon the importance of vision determining food selection, behaviour and choice decisions. It is a well-accepted fact that a product has to be visually noticed at least once on the supermarket shelf to be chosen, or as commonly known in Marketing, “not seen, not bought”. For these reasons, eye-tracking technique has proven to be a powerful tool to study consumers' choices of food products in relation to the visual attention paid to different elements of the product, and how the information is processed during the evaluation task (Ares, Mawad, Giménez, & Maiche, 2014; Bialkova, et al., 2014; Danner, et al., 2016; Gere, et al., 2016; Jantathai, Danner, Joechl, & Dürrschmid, 2013).

From a methodological point of view, the implementation of emerging technologies as eye-tracking, in combination with other techniques exploring consumers' behaviour in context and also the self-reported motivations behind their decisions, can provide a deeper understanding of their perceptions and response to food products.

4. Gluten-free products and coeliac consumers

Coeliac disease is a chronic autoimmune-mediated enteropathy triggered by exposure to dietary gluten, with a global prevalence of 0.7% (Singh et al., 2018). During last years, a higher prevalence of coeliac disease in children (1.4%) has been revealed thanks to the improvement in diagnosis tools (Rashid, et al., 2005; Sahin, 2021).

The ingestion of gluten causes in coeliac individuals an immune reaction, leading to intestinal inflammation, malabsorption syndrome and a broad range of symptoms affecting any organ or body system. Coeliac disease can be developed at any age, from early childhood to old age, and currently, the only effective treatment for these people is a lifelong avoidance of gluten from their diet (do Nascimento, Fiates, dos Anjos, & Teixeira, 2014a; Sahin, 2021; Vallons, Ryan, & Arendt, 2011), which implies the exclusion of gluten-containing cereals and derived products.

4.1. The challenge of gluten-free breads' texture

Gluten is a broad and complex group of prolamins (water-insoluble proteins) present in wheat (gliadin), rye (secalin), and barley (hordein) and other closely related grains as triticale, kamut or spelt. In bakery, gluten is the protein responsible for the structure forming of baked products, providing to dough its particular viscoelastic properties which will produce an elastic, extensible and cohesive crumb, with the capacity to retain moisture and gas during proof. Gluten removal represents a technological difficulty in bakery, especially in breadmaking, as it affects the rheology of dough, the leavening process and compromise the formation of crumb structure. In fact, gluten-free doughs are usually considered batters, as they are more liquid, less viscous, cohesive and elastic than gluten-containing doughs (Matos & Rosell, 2014). As a consequence, some post-baking defects appear in the resulting baked product, changing its properties and therefore, impacting the sensory perception when consumed. The loaf has been reported to result harder, with lower volume and a lighter colour than gluten-containing bread, and the crumb shows crumbling texture, insufficient elasticity and springiness, with poor mouthfeel, aroma and flavour (Gallagher, Gormley, & Arendt, 2004; Ronda Pérez-Quirce, & Villanueva, 2017; Stantiall & Serventi, 2018).

The constraints of gluten-free breadmaking have been addressed through different approaches in order to try to overcome these deficiencies (Brites, Schmiele, & Steel, 2018; Conte, Fadda, Drabińska, & Krupa-Kozak, 2019). Compositional-directed approaches usually imply the incorporation of addition of different fats, fibres, or several additives as emulsifiers, hydrocolloids, preservatives, acidifiers, leavening agents, among others. However, current trends in consumer behaviour point towards a preference for products with a short list of ingredients, which do not or scarcely include what they consider “artificial” additives or not-natural ingredients. Gluten-free products are not out of the scope of this trend in consumption patterns. For this reason, also processing approaches in the breadmaking process represent an interesting alternative for this current trend in consumer patterns.

During last years, a great number of research works have focused on the characterisation of the physical or mechanical properties of gluten-free dough or batter (Demirkesen, Mert, Sumnu, & Sahin, 2010; Mancebo, San Miguel, Martínez, & Gómez, 2015; Martínez & Gómez, 2017; Rocha-Parra, Ribotta, & Ferrero, 2015), or even of final product as the crumb (Espinosa-Ramírez, Garzon, Serna-Saldivar, & Rosell, 2018; Masure, Fierens, & Delcour, 2016; Moore, Schober, Dockery, & Arendt, 2004; Witczak, Ziobro, Juszczak, & Korus, 2016), on the characterisation of sensory aspects (Brites et al., 2018; Gallagher, Gormley, & Arendt, 2003; Korus, Witczak, Ziobro, & Juszczak, 2009; Machado-Alencar, Carvalho de Morais, Steel, & Bolini, 2017; Muggah, Duizer, & McSweeney, 2016) and also relating instrumental parameters and sensory attributes (Matos & Rosell, 2012) of different types of gluten-free breads.

Despite the attempts made trying to improve gluten-free baked goods, the texture dimension is still one of the main unresolved matters, especially in breads. The challenge remaining is to achieve bakery products that mimic the properties of gluten-containing products. For this reason, it results in great interest to identify those critical attributes perceived related to texture along with the oral processing in mouth. This would allow disentangling the target points to improve concerning the texture of gluten-free breads, compromised by the lack of gluten.

Because of the important impact that the variations in the structure of a product has on the texture perception, the question arises to know how the structure of gluten-free breads impacts the oral trajectory and on dynamics of sensations perceived during consumption. In gluten-free bread, in which the lack of gluten hinders the structure formation, the sensations that are desirable for such a product are difficult to emulate. Perception of texture sensations is a complex process in which various stimuli come into play. In order to ascertain where do these sensations come from, it is necessary to understand what happens in the mouth during oral processing, how the product behaves, how it breaks down and the dynamics of sensations that are elicited. The application of the innovative approaches of food oral processing described in the previous section rises as an interesting possibility to study and understand the critical points of the perceived texture of gluten-free breads in relation to oral processing and breakdown pattern.

4.2. Coeliac consumers

Beyond the sensory properties of products, consumers can be also influenced by other factors when choosing food. Package properties and information shown are decisive factors when deciding to buy a product. Coeliac individuals constitute a special group of consumers, who need that the food they consume is free of any trace of gluten. The increase in the number of diagnosed coeliac individuals in last years and subsequent rise in demand of gluten-free products, has led to manufacturers to look for gluten-free alternatives to satisfy the needs of this segment of consumers (Bogue & Sorenson, 2011; Xhakollari, Canavari, & Osman, 2019).

Previous studies have shown that the main constraints of coeliac consumers for diet adherence are the limited variety and availability of gluten-free products in the market, high prices, poor nutritional properties and social restrictions imposed by the gluten-free diet (do Nascimento, Fiates, dos Anjos, & Teixeira, 2014b; Villafuerte-Galvez et al., 2015; Xhakollari, et al., 2019). The strict restrictions of the lifelong adherence to the gluten-free diet are even more critical for children, and can affect their psychosocial wellbeing. Their involvement in daily activities, especially social events such as eating out, birthdays, parties, camping, or school coexistence represent additional challenges for them (MacCulloch & Rashid, 2014; Rashid et al., 2005), and school integration and self-esteem have shown to impact the adherence to the gluten-free diet during adolescence (Errichiello et al., 2010). Furthermore, this not only affects the children's daily life, but also their parents'.

However, there are not many studies exploring the response of coeliac consumers to particular gluten-free products or to the information on packages that can drive their decisions. For this reason, knowing the intrinsic and extrinsic factors that can influence the perceptions and food choices of coeliac consumers, both in adults and children, would be very helpful to cereal food industry and manufacturers for developing and improving gluten-free products that meet their needs and enhance their quality of life.

REFERENCES

Albert, A., Salvador, A., Schlich, P., & Fiszman, S. (2012). Comparison between temporal dominance of sensations (TDS) and key-attribute sensory profiling for evaluating solid food with contrasting textural layers: Fish sticks. *Food Quality and Preference, 24*, 111–118.

Akehurst, G. (2009). User generated content: The use of blogs for tourism organisations and tourism consumers. *Service Business*, *3*(1), 51–61.

Anonymous (1975). *Minutes of Division Business Meeting*. Institute of Food Technologists – Sensory Evaluation Division, IFT, Chicago, IL.

Arellano-Covarrubias, A., Gómez-Corona, C., Varela, P., & Escalona-Buendía, H. B. (2019). Connecting flavors in social media: A cross cultural study with beer pairing. *Food Research International, 115*, 303-310.

Ares, G., Giménez, A., & Gámbaro, A. (2008). Understanding consumers' perception of conventional and functional yogurts using word association and hard laddering. *Food Quality and Preference, 19*(7), 636-643.

Ares, G., Jaeger, S., Antúnez, L., Vidal, L., Giménez, A., Coste, B., Picallo, A., & Castura, J. (2015). Comparison of TCATA and TDS for dynamic sensory characterization of food products. *Food Research International, 78*, 148–158.

Ares, G., Mawad, F., Giménez, A., & Maiche, A. (2014). Influence of rational and intuitive thinking styles on food choice: Preliminary evidence from an eye-tracking study with yogurt labels. *Food Quality and Preference, 31*(1), 28–37.

Aslam, A. (2021, January 6). Twitter by the Numbers: Stats, Demographics & Fun Facts [Blog post]. Retrieved from https://www.omnicoreagency.com/twitter-statistics/

Assad-Bustillos, M. (2019). *Food oral processing and chewing mechanisms in the elderly applied to the development of soft cereal foods fortified with proteins*. Doctoral dissertation, Université de Nantes.

Bangcuyo, R. G., Smith, K. J., Zumach, J. L., Pierce, A. M., Guttman, G. A., & Simons, C. T. (2015). The use of immersive technologies to improve consumer testing: The role of ecological validity, context and engagement in evaluating coffee. *Food Quality and Preference*, *41*, 84–95.

Bemfeito, R. M., Rodrigues, J. F., e Silva, J. G., & Abreu, L. R. (2016). Temporal dominance of sensations sensory profile and drivers of liking of artisanal Minas cheese produced in the region of Serra da Canastra, Brazil. *Journal of Dairy Science, 99*(10), 7886-7897.

Bialkova, S., Grunert, K. G., Juhl, H. J., Wasowicz-Kirylo, G., Stysko-Kunkowska, M., & van Trijp, H. C. M. (2014). Attention mediates the effect of nutrition label information on consumers' choice: Evidence from a choice experiment involving eye-tracking. *Appetite, 76*, 66–75.

Bogue, J., & Sorenson, D. (2011). The marketing of gluten-free cereal products. In E. Arendt & F. Dal Bello (Eds.), *Gluten-free cereal products and beverages* (pp. 393–411). Elsevier Science & Technology Books.

Bian, J., Topaloglu, U., & Yu, F. Towards large-scale twitter mining for drug-related adverse events. In *Proc of the 2012 international workshop on Smart health and wellbeing*. 2012:25–32.

Braghieri, A., Piazzolla, N., Galgano, F., Condelli, N., De Rosa, G., & Napolitano, F. (2016). Effect of preservative addition on sensory and dynamic profile of Lucanian dry-sausages as assessed by quantitative descriptive analysis and temporal dominance of sensations. *Meat Science, 122*, 68–75.

Brites, L. T. G. F., Schmiele, M., & Steel, C. J. (2018). *Gluten-Free Bakery and Pasta Products*. In *Alternative and Replacement Foods 17*(2). Elsevier Inc. 385-410.

Bruzzone, F., Ares, G., & Giménez, A. (2013). Temporal aspects of yoghurt texture perception. *International Dairy Journal, 29*(2), 124-134.

Carr, J., Decreton, L., Qin, W., Rojas, B., Rossochacki, T., Yang, Y., & wen. (2015). Social media in product development. *Food Quality and Preference, 40*(PB), 354–364.

Chen, J. (2009). Food oral processing-A review. *Food Hydrocolloids*, *23*(1), 1–25.

Chen, J. (2014). Food oral processing: Some important underpinning principles of eating and sensory perception. *Food Structure*, *1*(2), 91–105.

Cheong, J. N., Foster, K. D., Morgenstern, M. P., Grigor, J. M. V., Bronlund, J. E., Hutchings, S. C., & Hedderley, D. I. (2014). The application of temporal dominance of sensations (TDS) for oral processing studies: An initial investigation. *Journal of Texture Studies, 45*, 409–419.

Clark, C. C., & Lawless, H. T. (1994). Limiting response alternatives in time-intensity scaling: an examination of the halo-dumping effect. *Chemical senses, 19*(6), 583-594.

Conte, P., Fadda, C., Drabińska, N., & Krupa-Kozak, U. (2019). Technological and nutritional challenges, and novelty in gluten-free breadmaking: A review. *Polish Journal of Food and Nutrition Sciences*, *69*(1), 5–21.

Costell, E., Tárrega, A., & Bayarri, S. (2010). Food acceptance: The role of consumer perception and attitudes. *Chemosensory Perception*, *3*(1), 42–50.

Culotta, A. Towards detecting influenza epidemics by analyzing Twitter messages. In *Proceedings of the first workshop on social media analytics*. 2010: 115-122.

Danner, L., De Antoni, N., Gere, A., Sipos, L., Kovács, S., & Dürrschmid, K. (2016). Make a choice! Visual attention and choice behaviour in multialternative food choice situations. *Acta Alimentaria, 45*(4), 515–524.

de Loubens, C., Panouillé, M., Saint-Eve, A., Déléris, I., Tréléa, I. C., & Souchon, I. (2011). Mechanistic model of in vitro salt release from model dairy gels based on standardized breakdown test simulating mastication. *Journal of Food Engineering, 105*(1), 161-168.

Deegan, K. C., Heikintalo, N., Ritvanen, T., Putkonen, T., Rekonen, J., McSweeney, P. L., Alatossava, T., & Tuorila, H. (2013). Effects of low-pressure homogenisation on the sensory and chemical properties of Emmental cheese. *Innovative Food Science & Emerging Technologies, 19*, 104-114.

Demirkesen, I., Mert, B., Sumnu, G., & Sahin, S. (2010). Rheological properties of gluten-free bread formulations. *Journal of Food Engineering, 96*(2), 295–303.

Devezeaux de Lavergne, M., Derks, J. A. M., Ketel, E. C., de Wijk, R. A., & Stieger, M. (2015a). Eating behaviour explains differences between individuals in dynamic texture perception of sausages. *Food Quality and Preference*, *41*, 189–200.

Devezeaux de Lavergne, M., van de Velde, F., van Boekel, M. A. J. S., & Stieger, M. (2015b). Dynamic texture perception and oral processing of semi-solid food gels: Part 2: Impact of breakdown behaviour on bolus properties and dynamic texture perception. *Food Hydrocolloids*, *49*, 61–72.

Devezeaux de Lavergne, M., van Delft, M., van De Velde, F., van Boekel, M. A. J. S., & Stieger, M. (2015c). Dynamic texture perception and oral processing of semi-solid food gels: Part 1: Comparison between QDA, progressive profiling and TDS. *Food Hydrocolloids*, 43, 207–217.

Devezeaux de Lavergne, M., van de Velde, F., & Stieger, M. (2017). Bolus matters: the influence of food oral breakdown on dynamic texture perception. *Food Funct.*, *8*(2), 464–480.

di Monaco, R., Galiñanes Plaza, A., Miele, N. A., Picone, D., & Cavella, S. (2016a). Temporal sweetness profile of MNEI protein in gelled model systems. *Journal of Sensory Studies, 31*, 382–392.

di Monaco, R., Miele, N. A., Volpe, S., Masi, P., & Cavella, S. (2016b). Temporal dominance of sensations and dynamic liking evaluation of polenta sticks*. British Food Journal, 118*, 749–760.

Dinnella, C., Masi, C., Naes, T., & Monteleone, E. (2013). A new approach in TDS data analysis: A case study on sweetened coffee*. Food quality and preference, 30*(1), 33-46.

Dinnella, C., Masi, C., Zoboli, G., & Monteleone, E. (2012). Sensory functionality of extra-virgin olive oil in vegetable foods assessed by Temporal Dominance of Sensations and Descriptive Analysis. Food Quality and Preference, 26(2), 141-150.

do Nascimento, A. B., Fiates, G. M. R., dos Anjos, A., & Teixeira, E. (2014a). Availability, cost and nutritional composition of gluten-free products. *British Food Journal*, *116*(12), 1842–1852.

do Nascimento, A. B., Fiates, G. M. R., dos Anjos, A., & Teixeira, E. (2014b). Gluten-free is not enough-perception and suggestions of celiac consumers. *International Journal of Food Sciences and Nutrition*, *65*(4), 394–398.

Dondokova, A., Aich, S., Kim, H. C., & Huh, G. H. (2018, July). A text mining approach to study individuals' food choices and eating behavior using Twitter feeds. In *International Conference on Frontier Computing* (pp. 520-527). Springer, Singapore.

Dumas, A. A., Lapointe, A., & Desroches, S. (2018). Users, uses, and effects of social media in dietetic practice: Scoping review of the quantitative and qualitative evidence. *Journal of Medical Internet Research*, *20*(2), 1–17.

Errichiello, S., Esposito, O., Di Mase, R., Camarca, M. E., Natale, C., Limongelli, M. G., Marano, C., Coruzzo, A., Lombardo, M., Strisciuglio, P., & Greco, L. (2010). Celiac disease: predictors of compliance with a gluten-free diet in adolescents and young adults. *Journal of pediatric gastroenterology and nutrition, 50*(1), 54-60.

Espinosa-Ramírez, J., Garzon, R., Serna-Saldivar, S. O., & Rosell, C. M. (2018). Functional and nutritional replacement of gluten in gluten-free yeast-leavened breads by using β-conglycinin concentrate extracted from soybean flour. *Food Hydrocolloids*, *84*, 353–360.

Fiszman, S., & Tarrega, A. (2018). The dynamics of texture perception of hard solid food: A review of the contribution of the temporal dominance of sensations technique. *Journal of texture studies, 49*(2), 202-212.

Foegeding, E. A., Stieger, M., & van de Velde, F. (2017). Moving from molecules, to structure, to texture perception. *Food Hydrocolloids*, *68*, 31–42.

Friedman, H. H., Whitney, J. E., & Szczesniak, A. S. (1963). The texturometer—a new instrument for objective texture measurement. *Journal of Food science, 28*(4), 390-396.

Fusté-Forné, F., & Filimon, N. (2021). Using Social Media to Preserve Consumers' Awareness on Food Identity in Times of Crisis: The Case of Bakeries. *International Journal of Environmental Research and Public Health, 18*(12), 6251.

Galiñanes Plaza, A., Delarue, J., & Saulais, L. (2019). The pursuit of ecological validity through contextual methodologies. *Food Quality and Preference*, *73*, 226–247.

Gallagher, E., Gormley, T. R., & Arendt, E. K. (2003). Crust and crumb characteristics of gluten free breads. *Journal of Food Engineering*, *56*(2–3), 153–161.

Gallagher, E., Gormley, T. R., & Arendt, E. K. (2004). Recent advances in the formulation of gluten-free cereal-based products. *Trends in Food Science and Technology*, *15*(3–4), 143–152.

Gao, J., Ong, J. J. X., Henry, J., & Zhou, W. (2017). Physical breakdown of bread and its impact on texture perception: A dynamic perspective. *Food Quality and Preference*, *60*, 96–104.

Gao, J., Tay, S. L., Koh, A. H. S., & Zhou, W. (2018). Dough and bread making from high- and low-protein flours by vacuum mixing: Part 3. Oral processing of bread. *Journal of Cereal Science*, *79*, 408–417.

Gao, J., Wong, J. X., Lim, J. C. S., Henry, J., & Zhou, W. (2015). Influence of bread structure on human oral processing. *Journal of Food Engineering, 167*, 147–155.

Gao, J., & Zhou, W. (2021). Oral processing of bread: Implications of designing healthier bread products. *Trends in Food Science & Technology, 112,* 720–734.

Gere, A., Danner, L., de Antoni, N., Kovács, S., Dürrschmid, K., & Sipos, L. (2016). Visual attention accompanying food decision process: An alternative approach to choose the best models. *Food Quality and Preference, 51*, 1–7.

Guerrero, L., Colomer, Y., Guàrdia, M. D., Xicola, J., & Clotet, R. (2000). Consumer attitude towards store brands. *Food Quality and Preference*, *11*(5), 387–395.

Guerrero, L., & Xicola, J. (2018). New Approaches to Focus Groups. In *Methods in Consumer Research, Volume 1* (pp. 49-77). Woodhead Publishing.

Guinard, J. X., Uotani, B., & Schlich, P. (2001). Internal and external mapping of preferences for commercial lager beers: Comparison of hedonic ratings by consumers blind versus with knowledge of brand and price. *Food Quality and Preference*, *12*(4), 243–255.

Harun, A. F., Ruslan, N., Adnan, W. A. W., Suliman, S. I., Ismail, J., & Baharin, H. (2020). Digitizing food experience: Food taste perception on digital image and true form using hashtags. *Bulletin of Electrical Engineering and Informatics, 9*(5), 2141-2153.

Hoebler, C., Devaux, M. F., Karinthi, A., Belleville, C., & Barry, J. L. (2000). Particle size of solid food after human mastication and in vitro simulation of oral breakdown. *International Journal of Food Sciences and Nutrition, 51*(5), 353–366.

Hoebler, C., Karinthi, A., Devaux, M.-F. F., Guillon, F., Gallant, D. J., Bouchet, B., Melegari, C., & Barry, J.-L. (1998). Physical and chemical transformations of cereal food during oral digestion in human subjects. *British Journal of Nutrition, 80*(5), 429–436.

Hubbard, E. M., Jervis, S. M., & Drake, M. A. (2016). The effect of extrinsic attributes on liking of cottage cheese. *Journal of Dairy Science*, *99*(1), 183–193.

Hutchings, S. C., Foster, K. D., Hedderley, D. I., & Morgenstern, M. (2014a). Differences between age groups in the use of the temporal dominance of sensations technique across a range of food textures. *Journal of Texture Studies, 45*, 206–219.

Hutchings, S. C., Foster, K. D., Grigor, J. M. V., Bronlund, J. E., & Morgenstern, M. P. (2014b). Temporal dominance of sensations: A comparison between younger and older subjects for the perception of food texture. *Food Quality and Preference, 31*, 106–115.

Hutchings, S. C., Horner, K. M., Dible, V. A., & Grigor, J. M. V. (2017). Modification of aftertaste with a menthol mouthwash reduces food wanting, liking, and a libitum intake of potato crisps. *Appetite, 108*, 57–67.

Hutchings, J. B., & Lillford, P. J. (1988). The perception of food texture - The philosophy of the breakdown path. *Journal of Texture Studies*, *19*(2), 103–115.

Ichau, E., Frissen, T., & d'Haenens, L. (2019). From #selfie to #edgy. Hashtag networks and images associated with the hashtag #jews on Instagram. *Telematics and Informatics*, *44*, 101275.

Jaeger, S. R. (2006). Non-sensory factors in sensory science research. *Food Quality and Preference, 17*(1–2), 132–144.

Jaeger, S. R., Hort, J., Porcherot, C., Ares, G., Pecore, S., & MacFie, H. J. H. (2017). Future directions in sensory and consumer science: Four perspectives and audience voting. *Food Quality and Preference, 56*, 301–309.

Jaeger, S. R. (2006). Non-sensory factors in sensory science research. *Food Quality and Preference*, *17*(1–2), 132–144.

Jantathai, S., Danner, L., Joechl, M., & Dürrschmid, K. (2013). Gazing behavior, choice and color of food: Does gazing behavior predict choice? *Food Research International, 54*(2), 1621–1626.

Jourdren, S., Panouillé, M., Saint-Eve, A., Déléris, I., Forest, D., Lejeune, P., & Souchon, I. (2016a). Breakdown pathways during oral processing of different breads: impact of crumb and crust structures. *Food Funct.*, *7*(3), 1446–1457.

Jourdren, S., Saint-Eve, A., Panouillé, M., Lejeune, P., Déléris, I., & Souchon, I. (2016b). Respective impact of bread structure and oral processing on dynamic texture perceptions through statistical multiblock analysis. *Food Research International*, *87*, 142–151.

Kaplan, A. M., & Haenlein, M. (2010). Users of the world, unite! The challenges and opportunities of social media. *Business Horizons, 53*, 59–68.

Kemp S. Digital 2020: Global Digital Overview. New York, NY: We Are Social and Hootsuite; 2020. URL: https://wearesocial.com/digital-2020 [accessed 2021-08-17].

Kemp, S. E., Hollowood, T., & Hort, J. (2009). *Sensory Evaluation. A practical handbook* (1st Edition). Wiley-Blackwell.

Kaplan, A. M., & Haenlein, M. (2010). Users of the world, unite! The challenges and opportunities of social media. *Business Horizons, 53,* 59–68

Korus, J., Witczak, M., Ziobro, R., & Juszczak, L. (2009). The impact of resistant starch on characteristics of gluten-free dough and bread. *Food Hydrocolloids*, *23*(3), 988–995.

Köster, E. P. (2009). Diversity in the determinants of food choice: A psychological perspective. *Food Quality and Preference*, *20*(2), 70–82.

Labbe, D., Schlich, P., Pineau, N., Gilbert, F., & Martin, N. (2009). Temporal dominance of sensations and sensory profiling: a comparative study. *Food Quality and Preference, 20*, 216-221

Laguna, L., Varela, P., Salvador, A., & Fiszman, S. (2013). A new sensory tool to analyse the oral trajectory of biscuits with different fat and fibre contents. *Food Research International, 51*(2), 544–553.

Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food: principles of good practice*. *Sensory Evaluation of Food*.

Le Bleis, F., Chaunier, L., Della Valle, G., Panouillé, M., & Réguerre, A. L. (2013). Physical assessment of bread destructuration during chewing. *Food Research International, 50*(1), 308–317.

Le Bleis, F., Chaunier, L., Montigaud, P., & Della Valle, G. (2016). Destructuration mechanisms of bread enriched with fibers during mastication. *Food Research International, 80*, 1–11.

Lenfant, F., Loret, C., Pineau, N., Hartmann, C., & Martin, N. (2009). Perception of food oral breakdown: The concept of sensory trajectory. *Appetite, 52*(3), 659–667.

Lepage, M., Neville, T., Rytz, A., Schlich, P., Martin, N., & Pineau, N. (2014). Panel performance for temporal dominance of sensations. *Food Quality and Preference*, 38,24–29.

Li, X. E., Jervis, S. M., & Drake, M. A. (2015). Examining Extrinsic Factors that Influence Product Acceptance: A Review. *Journal of Food Science*, *80*(5), R901–R909.

Lipizzi, C., Iandoli, L., & Ramirez Marquez, J. E. (2015). Extracting and evaluating conversational patterns in social media: A socio-semantic analysis of customers' reactions to the launch of new products using Twitter streams. *International Journal of Information Management*, *35*(4), 490–503.

Liu, Y., & Yin, Z. (2020). Understanding weight loss via online discussions: Content analysis of reddit posts using topic modeling and word clustering techniques. *Journal of Medical Internet Research*, *22*(6), 1–14.

Lorenzo-Romero, C., Constantinides, E., & Brunink, L. A. (2014). Co-creation: customer integration in social media based product and service development. *Procedia - Social and Behavioral Sciences*, *148*, 383–396.

Lorido, L., Hort, J., Estévez, M., & Ventanas, S. (2016). Reporting the sensory properties of dry-cured ham using a new language: Time intensity (TI) and temporal dominance of sensations (TDS). *Meat Science, 121*, 166–174.

MacCulloch, K., & Rashid, M. (2014). Factors affecting adherence to a gluten-free diet in children with celiac disease. *Paediatrics & child health, 19*(6), 305-309.

Machado-Alencar, N. M., Carvalho de Morais, E., Steel, C. J., & Bolini, H. M. A. (2017). Sensory characterisation of gluten-free bread with addition of quinoa, amaranth flour and sweeteners as an alternative for coeliac patients. *International Journal of Food Science and Technology*, *52*(4), 872–879.

Mancebo, C.M., San Miguel, M.A., Martínez, M.M., & Gómez, M., 2015. Optimisation of rheological properties of gluten-free doughs with HPMC, psyllium and different levels of water. *Journal of Cereal Science, 61*, 8-15.

Marcano, J., Varela, P., Cunha, L. M., & Fiszman, S. (2015). Relating dynamic perception of reformulated cheese pies to consumers' expectations of satiating ability. *Food Research International, 78*,369–377.

Martínez, M. M., & Gómez, M. (2017). Rheological and microstructural evolution of the most common gluten-free flours and starches during bread fermentation and baking. *Journal of Food Engineering, 197*, 78–86.

Masure, H. G., Fierens, E., & Delcour, J. A. (2016). Current and forward looking experimental approaches in gluten-free bread making research. *Journal of Cereal Science*, *67*, 92–111.

Matos, M. E., & Rosell, C. M. (2012). Relationship between instrumental parameters and sensory characteristics in gluten-free breads. *European Food Research and Technology*, *235*(1), 107–117.

Matos, M. E., & Rosell, C. M. (2014). Understanding gluten-free dough for reaching breads with physical quality and nutritional balance. *Journal of the Science of Food and Agriculture*, *95*(4), 653–661.

Meillon, S., Urbano, C., & Schlich, P. (2009). Contribution of the Temporal Dominance of Sensations (TDS) method to the sensory description of subtle differences in partially dealcoholized red wines. *Food Quality and Preference, 20*(7), 490-499.

Meillon, S., Viala, D., Medel, M., Urbano, C., Guillot, G., & Schlich, P. (2010). Impact of partial alcohol reduction in Syrah wine on perceived complexity and temporality of sensations and link with preference. *Food Quality and Preference, 21*(7), 732-740.

Miele, N. A., Giboreau, A., & Almli, V. L. (2021). The temporality of eating behavior as a discriminant tool to characterize consumers: Temporal Dominance of Behavior applied to bread consumption during a restaurant meal in France. *Food Quality and Preference, 92*, 104225.

Moore, M. M., Schober, T. J., Dockery, P., & Arendt, E. K. (2004). Textural comparisons of gluten-free and wheat-based doughs, batters, and breads. *Cereal Chemistry*, *81*(5), 567–575.

Mostafa, M. M. (2013). More than words: Social networks' text mining for consumer brand sentiments. *Expert Systems with Applications*, *40*(10), 4241–4251.

Motoi, L., Morgenstern, M. P., Hedderley, D. I., Wilson, A. J., & Balita, S. (2013). Bolus moisture content of solid foods during mastication. *Journal of Texture Studies, 44*(6), 468–479.

Motoki, K., & Suzuki, S. (2020). Extrinsic Factors Underlying Food Valuation in the Human Brain. *Frontiers in Behavioral Neuroscience, 14*, 1–7.

Muggah, E. M., Duizer, L. M., & McSweeney, M. B. (2016). A comparison of sensory properties of artisanal style and industrially processed gluten free breads. *International Journal of Gastronomy and Food Science*, *3*, 38–46.

O'Brien, M. C., McConnon, A., Hollywood, L. E., Cuskelly, G. J., Barnett, J., Raats, M., & Dean, M. (2015). Let's talk about health: Shoppers' discourse regarding health while food shopping. *Public Health Nutrition, 18*(6), 1001–1010.

Panouillé, M., Saint-Eve, A., Déléris, I., Le Bleis, F., & Souchon, I. (2014). Oral processing and bolus properties drive the dynamics of salty and texture perceptions of bread. *Food Research International*, *62*, 238–246.

Pentikäinen, S., Sozer, N., Närväinen, J., Ylätalo, S., Teppola, P., Jurvelin, J., Holopainen-Mantila, U., Törrönen, R., Aura, A. M., & Poutanen, K. (2014). Effects of wheat and rye bread structure on mastication process and bolus properties. *Food Research International, 66*, 356–364.

Peyron, M. A., Gierczynski, I., Hartmann, C., Loret, C., Dardevet, D., Martin, N., & Woda, A. (2011). Role of physical bolus properties as sensory inputs in the trigger of swallowing. *PLoS ONE, 6*(6), e21167.

Pineau, N., Schlich, P., Cordelle, S., Mathonnière, C., Issanchou, S., Imbert, A., Rogeaux, M., Etiévant, P., & Köster, E. (2009). Temporal Dominance of Sensations: Construction of the TDS curves and comparison with time-intensity. *Food Quality and Preference*, *20*(6), 450–455.

Piqueras-Fiszman, B., & Spence, C. (2015). Sensory expectations based on product-extrinsic food cues: An interdisciplinary review of the empirical evidence and theoretical accounts. *Food Quality and Preference*, *40*(PA), 165–179.

Platania, M., & Spadoni, R. (2018). How people share information about food: Insights from tweets regarding two Italian Regions. *International Journal on Food System Dynamics, 9*(2), 149–165.

Priilaid, D. A. (2006). Wine's placebo effect: How the extrinsic cues of visual assessments mask the intrinsic quality of South African red wine. *International Journal of Wine Marketing, (18)*1, 17–32.

Puerta, P., Garzón, R., Rosell, C. M., Fiszman, S., Laguna, L., & Tárrega, A. (2021). Modifying gluten-free bread's structure using different baking conditions: Impact on oral processing and texture perception. *LWT - Food Science and Technology, 140*, 110718.

Puerta, P., Laguna, L., Villegas, B., Rizo, A., Fiszman, S., & Tarrega, A. (2020). Oral processing and dynamics of texture perception in commercial gluten-free breads. *Food Research International, 134*, 109233.

Rashid, M., Cranney, A., Zarkadas, M., Graham, I. D., Switzer, C., Case, S., Molloy, M., Warren, R.E., Burrows, V., & Butzner, J. D. (2005). Celiac disease: evaluation of the diagnosis and dietary compliance in Canadian children. *Pediatrics, 116*(6), e754-e759.

Rizo, A., Peña, E., Alarcon-Rojo, A. D., Fiszman, S., & Tárrega, A. (2018). Relating texture perception of cooked ham to the bolus evolution in the mouth. *Food Research International*, *118*, 4-12

Rocha-Parra, A.F., Ribotta, P.D., & Ferrero, C., 2015. Apple pomace in gluten-free formulations: effect on rheology and product quality. *International Journal of Food Science and Technology, 50*, 682-690.

Roininen, K., Lähteenmäki, L., & Tuorila, H. (1999). Quantification of consumer attitudes to health and hedonic characteristics of foods. *Appetite, 33*(1), 71-88.

Ronda, F., Pérez-Quirce, S., & Villanueva, M. (2017). Rheological Properties of Gluten-Free Bread Doughs: Relationship With Bread Quality. In J. Ahmed (Ed.), *Advances in Food Rheology and its Applications* (pp. 297–334). Elsevier Ltd.

Rosenthal, A. J., & Share, C. (2014). Temporal dominance of sensations of peanuts and peanut products in relation to Hutchings and Lillford's "breakdown path". *Food Quality and Preference, 32*, 311–316.

Sahin, Y. (2021). Celiac disease in children: A review of the literature. *World Journal of Clinical Pediatrics, 10*(4), 53.

Saint-Eve, A., Panouille, M., Capitaine, C., Deleris, I., & Souchon, I. (2015). Dynamic aspects of texture perception during cheese consumption and relationship with bolus properties*. Food Hydrocolloids, 46*, 144-152.

Samoggia, A., Bertazzoli, A., & Ruggeri, A. (2019). Food retailing marketing management: Social media communication for healthy food. *International Journal of Retail and Distribution Management.*

Sawhney, M., Verona, G., & Prandelli, E. (2005). Collaborating to create: The internet as a platform for customer engagement in product innovation. *Journal of Interactive Marketing*, *19*(4), 4–34.

Sinesio, F., Moneta, E., Porcherot, C., Abbà, S., Dreyfuss, L., Guillamet, K., Bruyninckx, S., Laporte, C., Henneberg, S., & Mcewan, J. A. (2019). Do immersive techniques help to capture consumer reality? *Food Quality and Preference*, *77*, 123–134.

Singh, P., Arora, A., Strand, T. A., Leffler, D. A., Catassi, C., Green, P. H., Kelly, C. P., Ahuja, V., & Makharia, G. K. (2018). Global Prevalence of Celiac Disease: Systematic Review and Meta-analysis. *Clinical Gastroenterology and Hepatology*, *16*(6), 823-836.e2.

Sokolowsky, M., & Fischer, U. (2012). Evaluation of bitterness in white wine applying descriptive analysis, time-intensity analysis, and temporal dominance of sensations analysis*. Analytica Chimica Acta, 732*, 46-52.

Stantiall, S. E., & Serventi, L. (2018). Nutritional and sensory challenges of gluten-free bakery products: a review. *International Journal of Food Sciences and Nutrition*, *69*(4), 427–436.

Tang, J., Larsen, D. S., Ferguson, L., & James, B. J. (2017). Textural complexity model foods assessed with instrumental and sensory measurements. *Journal of Texture Studies, 48*(1), 9–22.

Tarancón, P., Sanz, T., Fiszman, S., & Tárrega, A. (2014). Consumers' hedonic expectations and perception of the healthiness of biscuits made with olive oil or sunflower oil. *Food Research International*, *55*, 197–206.

Tarrega, A., Rizo, A., Murciano, A., Laguna, L., & Fiszman, S. (2020). Are mixed meat and vegetable protein products good alternatives for reducing meat consumption? A case study with burgers. *Current Research in Food Science, 3*, 30-40.

Teillet, E., Schlich, P., Urbano, C., Cordelle, S., & Guichard, E. (2010). Sensory methodologies and the taste of water. Food Quality and Preference, 21(8), 967-976.

Thoumrungroje, A. (2014). The Influence of Social Media Intensity and EWOM on Conspicuous Consumption. *Procedia - Social and Behavioral Sciences*, *148*, 7–15.

Torres-Moreno, M., Tarrega, A., Torrescasana, E., & Blanch, C. (2012). Influence of label information on dark chocolate acceptability. *Appetite*, *58*(2), 665–671.

Tournier, C., Grass, M., Septier, C., Bertrand, D., & Salles, C. (2014). The impact of mastication, salivation and food bolus formation on salt release during bread consumption. *Food & Function*, *5*(11), 2969–2980.

Tournier, C., Grass, M., Zope, D., Salles, C., & Bertrand, D. (2012). Characterization of bread breakdown during mastication by image texture analysis. *Journal of Food Engineering, 113*(4), 615–622.

Tumasjan, A., Sprenger, T., Sandner, P., & Welpe, I. Predicting elections with twitter: What 140 characters reveal about political sentiment. In *Proceedings of the International AAAI Conference on Web and Social Media*. 2010:175-185.

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

van Eck, A., Fogliano, V., Galindo-Cuspinera, V., Scholten, E., & Stieger, M. (2019). Adding condiments to foods: How does static and dynamic sensory perception change when bread and carrots are consumed with mayonnaise? *Food Quality and Preference, 73*, 154–170.

van Eck, A., Franks, E., Vinyard, C. J., Galindo-Cuspinera, V., Fogliano, V., Stieger, M., & Scholten, E. (2020). Sauce it up: influence of condiment properties on oral processing behavior, bolus formation and sensory perception of solid foods. *Food & Function, 11*(7), 6186–6201.

van Herpen, E., van den Broek, E., van Trijp, H. C. M., & Yu, T. (2016). Can a virtual supermarket bring realism into the lab? Comparing shopping behavior using virtual and pictorial store representations to behavior in a physical store. *Appetite, 107*, 196–207.

Varela, P., & Ares, G. (2012). Sensory profiling, the blurred line between sensory and consumer science. A review of novel methods for product characterization. *Food Research International, 48*(2), 893-908.

Varela, P., & Ares, G. (2014). Novel techniques in sensory characterization and consumer profiling. In *Novel Techniques in Sensory Characterization and Consumer Profiling*. CRC Press

Varela, P., Ares, G., Giménez, A., & Gámbaro, A. (2010). Influence of brand information on consumers' expectations and liking of powdered drinks in central location tests. *Food Quality and Preference*, *21*(7), 873–880.

Varela, P., Salvador, A., & Fiszman, S. (2009). On the assessment of fracture in brittle foods II. Biting or chewing? *Food Research International, 42*(10), 1468–1474.

Vázquez-Araújo, L., Parker, D., & Woods, E. (2013). Comparison of temporal-sensory methods for beer flavor evaluation. *Journal of Sensory Studies, 28*, 387-395

Vidal, L., Ares, G., & Jaeger, S. R. (2016). Use of emoticon and emoji in tweets for food-related emotional expression. *Food Quality and Preference, 49*, 119–128

Vidal, L., Ares, G., & Jaeger, S. R. (2018). Application of Social Media for Consumer Research. In G. Ares & P. Varela (Eds.), *Methods in Consumer Research, Volume 1: New Approaches to Classic Methods* (pp. 125–155). Woodhead Publishing.

Vidal, L., Ares, G., Machín, L., & Jaeger, S. R. (2015). Using Twitter data for food-related consumer research: A case study on "what people say when tweeting about different eating situations." *Food Quality and Preference*, *45*, 58–69.

Villafuerte-Galvez, J., Vanga, R. R., Dennis, M., Hansen, J., Leffler, D. A., Kelly, C. P., & Mukherjee, R. (2015). Factors governing long-term adherence to a gluten-free diet in adult patients with coeliac disease. *Alimentary Pharmacology and Therapeutics*, *42*(6), 753–760.

Visalli, M., Lange, C., Mallet, L., Cordelle, S., & Schlich, P. (2016). Should I use touchscreen tablets rather than computers and mice in TDS trials? *Food Quality and Preference, 52*, 11–16.

Witczak, M., Ziobro, R., Juszczak, L., & Korus, J. (2016). Starch and starch derivatives in gluten-free systems - A review. *Journal of Cereal Science*, *67*, 46–57.

Xhakollari, V., Canavari, M., & Osman, M. (2019). Factors affecting consumers' adherence to gluten-free diet, a systematic review. *Trends in Food Science and Technology*, *85*, 23–33.

Yin, Z., Song, L., Clayton, E. W., & Malin, B. A. (2020). Health and kinship matter: Learning about direct-to-consumer genetic testing user experiences via online discussions. *PLoS ONE*, *15*, 1–15.

Young, A. K., Cheong, J. N., Foster, K. D., Hedderley, D. I., Morgenstern, M. P., & James, B. J. (2016). Exploring the Links Between Texture Perception and Bolus Properties Throughout Oral Processing. Part 1: Breakdown paths. *Journal of Texture Studies*, *47*(6), 461–473.

Young, A. K., Cheong, J. N., Hedderley, D. I., Morgenstern, M. P., & James, B. J. (2013). Understanding the link between bolus properties and perceived texture. *Journal of Texture Studies*, *44*(5), 376–386.

Objectives of Doctoral Thesis

OBJECTIVES OF DOCTORAL THESIS

The main objective of this Thesis is to understand perceptions in gluten-free products and the coeliac consumers' behaviour towards information of their package through the application of recent and innovative techniques.

To achieve this objective, the following specific objectives were proposed:

- To determine the aspects that are relevant for consumers about gluten-free products through the exploration of information from a social media as Twitter.
- To investigate methods for automated analysis of text messages from Twitter.
- To study the changes that commercial gluten-free bread undergoes during oral processing to understand the factors involved in texture sensations perceived.
- To study how modifications in breadmaking conditions impact on oral processing and texture perception of gluten-free breads during consumption.
- To investigate the visual attention of coeliac consumers towards the package of commercial gluten-free breads and their perceptions in relation to hedonic expectations and trust conferred.
- To better understand the factors driving purchasing decision of biscuits in coeliac children and their parents by measuring visual attention (through eye-tracking technique) and reported response (through laddering interview) in a simulated supermarket context.

Thesis outline

THESIS OUTLINE

The work performed in this Thesis has given rise to different scientific publications which are in line with the objectives proposed, and is presented in three separate chapters:

Chapter 1 is dedicated to study how to gather and treat the information available on social media, particularly from Twitter to obtain consumers' opinion. Also, it has addressed the study of what is relevant for people who talk about "gluten-free", and includes the following work:

> Puerta, P., Laguna, L., Vidal, L., Ares, G., Fiszman, S., Tárrega, A. (2020). Co-occurrence networks of Twitter content after manual or automatic processing. A case-study on "gluten-free". *Food Quality and Preference 86,* 103993. DOI: 10.1016/j.foodqual.2020.103993

Chapter 2 addresses the study of the changes occurrying during oral trajectory of gluten-free breads for a better understanding of texture sensations perceived during consumption, and includes the following works:

> Puerta, P., Laguna, L., Villegas, B., Rizo, A., Fiszman, S., Tarrega, A. (2020). Oral processing and dynamics of texture perception in commercial gluten-free breads. *Food Research International, 134,* 109233. DOI: 10.1016/j.foodres.2020.109233
>
> Puerta, P., Fiszman, S., Laguna, L., Tárrega, A. Impact of gluten-free bread's structure on oral processing and sensory perception. Adapted from the publication:
>
> > Puerta, P., Garzón, R., Rosell, C.M., Fiszman, S., Laguna, L., Tárrega, A. (2021). Modifying gluten-free bread's structure using different baking conditions: impact on oral processing and texture perception. *LWT – Food Science and Technology, 140,* 110718. DOI: 10.1016/j.lwt.2020.110718

Chapter 3 examines coeliac consumers' response to different gluten-free products as bread or biscuits through the application of eye-tracking and self-reported techniques in order to understand the factors involved in their purchasing decision, and includes the following works:

Puerta, P., Carrillo, E., Badia-Olmos, C., Laguna, L., Rosell, C. M., Tárrega, A. Visual attention and response of coeliac consumers towards packages of gluten-free breads. Impact of certification logo and brand. In preparation.

Puerta, P., Laguna, L., Tárrega, A., Carrillo, E. Relevant elements on biscuits purchasing decision for coeliac children and their parents in a supermarket context. Accepted for publication in *Food Quality and Preference*.

Chapter 1

Co-occurrence networks of Twitter content after manual or automatic processing. A case-study on “gluten-free”

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ABSTRACT

Gathering information from social networks such as Twitter has emerged to obtain spontaneous and direct opinions of users about a topic. This study focuses on using co-occurrence networks to analyse Twitter information. The objectives were to study the impact of text pre-treatment (codification based in qualitative analysis or just pre-cleaning) and to apply co-occurrence networks for analysing what is said on Twitter about specific topics like “gluten-free”. As such, 16,386 tweets in Spanish containing terms “sin-gluten” and “gluten-free” were collected. A subset of 3000 tweets was used to make co-occurrence networks two ways: i) from the manually coded text and ii) from pre-cleaned text. Results indicate that the co-occurrence network from pre-cleaned text provides meaningful information showing structure and relevance for terms like the network from coded text. The whole set of tweets was used to explore Twitter information on gluten-free, showing users share information about products, occasions, social situations, and places but also product characteristics, sensations, and diet or health issues related to the products. Five product categories, critical for the lack of gluten (bread, cake, cookie, beer, and pizza), occupied most tweets, and according to the related terms, were intended to recommend how to get (buying or cooking) these gluten-free products and to exhibit what (how, when, and where) they prepare and eat. These aspects were different among products, and separated co-occurrence networks allowed better identification.

Keywords: Gluten-free, Co-occurrence networks, Social media, Consumers, Twitter.

1. INTRODUCTION

1.1. Gluten-free consumers

In recent years, an increase in consumer demand has been observed for gluten-free products (Christoph, Larson, Hootman, Miller, & Neumark-Sztainer, 2018; Missbach et al., 2015; Molina-Rosell, 2013). Research on gluten-free products has focused on strategies dealing with the negative impact a lack of gluten has on the quality properties of these products. Manufacturing gluten-free cereal products is a challenging task for the food industry (Capriles, dos Santos, & Arêas, 2016; Houben, Höchstötter, & Becker, 2012). Besides, according to Naqash, Gani, Gani, & Masoodi (2017), most approaches include the addition of functional ingredients to the formulation (gluten-free flours, starches, hydrocolloids, proteins, fats, and fibres) or the adoption of alternative processing methods (high pressure, extrusion, and sourdough fermentation) to produce gluten-free products with good sensory quality, especially a texture comparable to those containing gluten (Marston, Khouryieh, & Aramouni, 2016; Matos & Rosell, 2012; O'Shea, Doran, Auty, Arendt, & Gallagher, 2013; Penjumras et al., 2019).

However, according to Do Nascimento, Fiates, & Teixeira (2017), consumers concerns for gluten-free products include sensory quality of products and the issues they experience trying to have a "normal life", especially in a social context. Still, information on the relevance of extrinsic properties of products, context aspects, and individual attitudes and opinions of gluten-free consumers is scarce. This is for the difficulty in finding coeliac participants for consumer studies, accounting for an estimated 1 to 2% of population (Sapone et al., 2012). Therefore, we believe what is said on social media networks may be a way to obtain opinions of this target group of consumers, allowing us to understand their motivations and interests when consuming gluten-free products.

1.2. Using Twitter as a source for gathering consumers' opinion

Among social media platforms, Twitter is one of the most popular and dynamic microblogging services, with 500 million text-based messages, called "tweets", generated by active users per day (Chae, 2015; Da Silva, Hruschka, & Hruschka Jr, 2014; Mention, 2018; Vidal et al., 2015). The informal and colloquial nature of tweets, together with the ease and instant access of the platform make its use widespread, giving rise to a huge volume of rapidly generated data (Fried, Surdeanu, Kobourov, Hingle, & Bell, 2015; Moe & Schweidel, 2017). Unlike other opinion gathering methods for consumers (surveys), social media users spontaneously post what they want when they want, avoiding forced biases to express their opinion.

Food represents one of the key themes discussed on Twitter (Platania & Spadoni, 2018) and consequently, tweets are potentially valuable data sources for gaining insight on food-related consumer studies. To date, the exploration of user-generated content on Twitter has been useful to study food-related topics (food in general, influence of food choices, language of food, food chains, health food, different eating situations, and emotional responses to food and beverages) (Chen & Yang, 2014; Fried et al., 2015; He, Zha, & Li, 2013; Platania & Spadoni, 2018; Samoggia, Bertazzoli, & Ruggeri, 2019; Vidal, Ares, & Jaeger, 2016; Vidal et al., 2015). However, no study has addressed the exploration and interpretation of a topic like gluten-free.

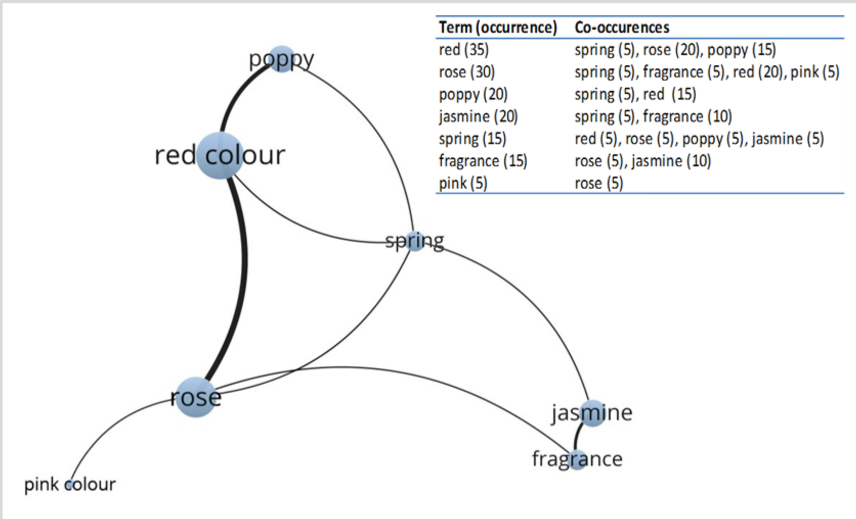
Different approaches have been made to analyse tweets; automatic word counting is the simplest method of gathering information from users. Calculating the frequency or occurrence of mentions for an individual word, is simple and rapid for summarising the text according to the terms that are frequently mentioned. Nevertheless, the frequency of occurrence of individual words has several important limitations. It may not represent the meaning of the word isolated in the dataset and can lead to misleading conclusions because of the loss of the words' context (Hsieh & Shannon, 2005; Vidal et al., 2015; Zhao, Zhang, Qian, & Zhou, 2013). Therefore, previous qualitative analysis of tweet contents, with individual reading, was proposed to analyse tweets in the context of which the words are mentioned. Thus, the content was classified into themes and sub-themes related to the specific topic (Nguyen et al., 2019; Platania & Spadoni, 2018; Samoggia et al., 2019; Vidal et al., 2015). Although implementing manual content analysis can be tedious and time consuming for the large amounts of text to be read, it proved to be successful at gaining better interpretation of Twitter content (He et al., 2017; He et al., 2013; Vidal et al., 2015). As an automatic alternative, text analysis based on machine learning algorithms have been used to extract meaningful information from the textual data, recording themes already established or commonly studied (Constantinides & Holleschovsky, 2016; Sengupta & Ghosh, 2020; van Zoonen & van der Meer, 2016). However, for the correct performance of these models, machine learning algorithms usually require a large external source of coded dataset to analyse the text units (Vidal, Ares, & Jaeger, 2018). Thus, the development and adjustment of the algorithms for new topics is complex or require added information.

1.3. Co-occurrence networks technique

Co-occurrence networks have been proposed as an approach to facilitate the understanding and visualisation of the structure of different text items and their content. Co-occurrence networks graphically represent the relevance of terms and the relatedness among them, identifying and displaying patterns of co-occurrence within the text (Ruiz & Barnett, 2015; Su & Lee, 2010). Although broadly applied in studies of bibliometric analysis, to identify and visualise the existing connections among data (Skaf, Buonocore, Dumontet, Capone, & Franzese, 2020; van Eck & Waltman, 2018; Wen, Horlings, van der Zouwen, & van den Besselaar, 2017), co-occurrence networks can also be used for exploring connections of terms in different text documents.

Co-occurrence networks can be obtained by specific software as VOSviewer and Gephi or by using the Python programming language. In the VOSviewer software used in this study, the construction of a map comprises three steps: i) A similarity matrix (association strength as a measure of similarity) is obtained from a co-occurrence matrix (van Eck & Waltman, 2007; van Eck, Waltman, van den Berg, & Kaymak, 2006). The similarity between two terms is calculated as the ratio: the number of co-occurrences of two terms i and j divided by the product of the total number of co-occurrences of i and the total number of co-occurrences of j. ii) The visualisation of similarities (VOS) mapping technique constructs a two-dimensional map in which the items are located in such a way that the distance between any pair of items reflects their similarity. The base for doing so is minimising a weighted sum of the squared Euclidean distances between all pairs of items. The higher the similarity between two items the higher the weight of their squared distance in the sum. iii) The obtained map is translated, rotated, and reflected to obtain consistent results (always the same map) regardless of the different solutions that can be reached in the optimisation process.

In the obtained network, the size of the label representing a term is proportional to its frequency of appearance in the text (occurrence). The thickness of the line connecting two terms indicates how often they co-occur within the same text unit. The distance between two terms offers an approximate indication of the relatedness of the terms (Cunillera & Guilera, 2018; Marinho, Hirst, & Amancio, 2017; Sharma, Bairwa, Gowthamghosh, Gupta, & Mangal, 2018; van Eck, Waltman, Noyons, & Buter, 2010). A dataset of 70 text documents describing flowers has been created to illustrate the explanation (Figure 1). The table in the figure includes the occurrences and co-occurrences of the seven terms. Each term is represented in the network as a circle of size proportional to the number of occurrences; for example, the labels and circles of terms *red colour* and *pink colour* are the largest and the smallest because they are the most and least mentioned terms, respectively. Distribution of terms on the map responds to the relationships between items. *Spring* was a general term, co-mentioned with many terms (*red*, *rose*, *poppy*, and *jasmine*) and thus, appears located in the centre. The links with the four terms have the same thickness because the number of co-occurrences is the same (five). Terms that do not show co-occurrences among them are separated in the extremes, and close to the terms with higher co-occurrence. In the top-left appears the term *poppy* related to *red*, while in the bottom right, the term *jasmine* relates to *fragrance*. *Rose* shows a strong link with *red* and *fragrance,* and appears in the bottom-left. The term *pink* links to *rose* but does not show co-occurrence with any other term, appearing separated on the bottom-left extreme of the network.



Term (occurrence)	Co-occurences
red (35)	spring (5), rose (20), poppy (15)
rose (30)	spring (5), fragrance (5), red (20), pink (5)
poppy (20)	spring (5), red (15)
jasmine (20)	spring (5), fragrance (10)
spring (15)	red (5), rose (5), poppy (5), jasmine (5)
fragrance (15)	rose (5), jasmine (10)
pink (5)	rose (5)

Figure 1. Example of a co-occurrence network from a dataset created from 70 documents describing flowers and containing seven terms whose occurrence and co-occurrences are indicated in the table.

In this study, we propose using co-occurrence networks as a tool for analysing terms in tweets to give more structured information than word counting. Using of raw text directly from tweets would make the analysis almost automatic, however, a previous qualitative analysis of tweets and the corresponding coding of text could be necessary to provide the relevance of ideas expressed in many different terms to avoid misunderstanding of the text.

Therefore, the first aim was to study how pre-processing of tweet text (coding through qualitative analysis or just pre-cleaning) influences co-occurrence networks to determine if the process can be automated without losing relevant information. The second aim was to analyse tweets about “gluten-free” to gather information about the aspects that are relevant for this specific group of consumers, in general and in relation to specific products.

2. MATERIALS AND METHODS

2.1. Retrieval of tweets

A total of 16,386 tweets containing “sin-gluten” or “gluten-free” terms posted by users writing in Spanish, between September 2017 and January 2018, were retrieved with the *rtweet* package (Kearney, 2018) from R software (R Core Team, 2017) via the Twitter’s Application Programming Interface (API). Re-tweets and repeated tweets were removed. Each retrieved tweet included an ID number, username of the person posting and the date and time when the tweet was published, among other information. Gender and age of Twitter users was not provided by *rtweet* package, and geographical location data was shown when specified by users in their personal profiles. Finally, the tm package (Feinerer & Hornik, 2017) was used for automatically lowering character case, removing punctuation, numbers, and stop words in the tweets text.

2.2. Qualitative analysis of tweets and manual coding

Because of time restrictions, a subset of the first 3,000 tweets was extracted. This subset was used for comparing networks obtained from coded and un-coded tweets and to determine the need of previous qualitative analysis when obtaining co-occurrence networks.

By a first independent reading, two researchers identified, by consensus, the most relevant and frequent type of terms (sub-themes). Considering both the type of terms and the meaning in the sentence, these sub-themes were grouped into main themes. For example, the tweet “Gluten-free party with school friends” was coded into the sub-themes: “social event” and “family-friends”, both belonging to the “Social context” main theme.

2.3. Co-occurrence networks

VOSviewer software (Version 1.6.7, Centre for Science and Technology Studies, Leiden University, The Netherlands) was used to obtain networks based on the frequency of mentioned terms (occurrence) and on their co-occurrence within the same tweet (i.e., when both terms occur together in one tweet). Based on the interconnection of terms within each tweet, this tool constructed, analysed, and visualised keyword networks by using the visualisation of similarities (VOS) technology (van Eck & Waltman, 2010; van Eck et al., 2010). The VOSviewer software created a two-dimensions map where distance between terms can be interpreted as an indication of their relatedness.

For evaluating the impact of pre-treatment of tweets, two different co-occurrence networks were obtained from the subset of 3,000 tweets. A first network was obtained from the coded text. Here, the database uploaded comprised the sub-themes identified after manually coding the tweets. A second network was obtained from directly the same 3,000 tweets text after just a pre-cleaning process, which included steps: i) Bi-grams (i.e. words that co-occur together and need to be treated as a single entity (e.g. "lactose" and "free" are converted into "lactose_free") were identified using an N-gram analyser tool (http://guidetodatamining.com/ngramAnalyzer/), to be later replaced by the corresponding single word unit. ii) NVivo software (Version 12, QSR International Pty Ltd., Victoria, Australia) was used for identifying related words sharing a common stem (e.g. different forms of the same verb), to be later replaced by a single word selected as representative. Replacements of both bi-grams and stem words were performed by including a thesaurus list in the VOSviewer software when creating the co-occurrence networks. Alternatively, these steps can be performed automatically using the *tm* and *ngram* packages in R software.

Finally, to analyse Twitter content on gluten-free, the co-occurrence networks for the 16,386 tweets and those mentioning specific products (*bread*, *cookie*, *cake*, *beer*, and *pizza*) were obtained using the pre-cleaned text of the tweets.

3. RESULTS

3.1. Themes and sub-themes in tweets on gluten-free

Table 1 shows the content of the subset of 3,000 tweets summarised into nine main themes: products, places, culinary preparations, product-related characteristics, ingredients, occasions, social context, diet / health, and sensory characteristics / sensations. Tweets relating to the themes product, places, and culinary preparation were the most frequent (> 30%). Although with lower frequency (< 10%), other themes related to diet or health issues and sensory characteristics / sensations were also found. The sub-theme *positive_sensation* referred to expressions of positive ideas and opinions such as *good*, *like*, *well*, *excellent*, and *enjoy*. The sub-theme *negative_sensation* referred to expressions of negative ideas and opinions such as *bad*, *worse*, and *awful*.

Within each theme, four to fifteen sub-themes were identified. Product was the category with the highest number of sub-themes (15): *cookie*, *bread*, *pizza-dough-patty*, *beer*, *cereal*, *pasta*, *cake-pastry*, *meat*, *fish-seafood*, *fruit-vegetable*, *dairy*, *drink*, *mix*, *snack*, and *others*. Within the themes places and ingredients, a high number of sub-themes were also identified (12 each). For places, the sub-themes were *city*, *country*, *restaurant*, *chain*, *bakery*, *supermarkets*; *Carrefour*; *Lidl*; and *Mercadona*, *bar*, and *home*. Culinary aspects included *recipe*, *meat meal*, *fish_meal*, *vegetable-rice-legume_meal*, *pasta-meal*, *creams-soup-sauce*, *drinks*, and *eggs*. Tweets referring to ingredients contained *fruits-vegetable*, *cocoa*, *flour*, *cereal* as *corn*, *rice* or *wheat*, *nut*, *dairy products*, *sweetener*, and *meat*. The most relevant moments were eating occasions along the day, and the name of the days. Social themes referred to family, friends, and events. For diet and health, the sub-themes were *coeliac* and other disease aspects.

Table 1. Themes and sub-themes identified in Twitter messages on gluten-free by qualitative analysis of a subset of 3000 tweets. For each sub-theme, frequency of mention is indicated in brackets.

Theme	Sub-themes	Frequency (%)
Products	*cake-pastry* (14.4), *bread* (7.2), *fruit-vegetable* (4.7), *cookie* (4.5), *pizza-dough-patty* (4.1), *cereal* (3.8), *snack* (2.5), *dairy* (1.7), *beer* (1.5), *meat_product* (1.4), *pasta* (1.4), *mix* (0.6), *fish-seafood* (0.5), *drink* (0.2)	48.7
Places	*city* (9.1), *bakery* (4.4), *restaurant* (3.7), *chain* (2.3), *country* (1.0), *supermarket* (1.0), *Mercadona* (0.7), *bar* (0.4), *home* (0.4), *Lidl* (0.3), *Carrefour* (0.1)	32.1
Culinary preparations	*recipe* (11.6), *vegetable-rice-legume_meal* (2.6), *meat_meal* (1.9), *cream-soup-sauce* (1.9), *pasta_meal* (1.4), *fish_meal* (0.7), *eggs* (0.1)	31.8
Product-related characteristics	*brand* (5.7), *eco* (1.9), *bio-organic* (0.8), *craft* (0.7), *natural-home-made* (0.6), *price* (0.4)	19.9
Ingredients	*fruit-vegetable* (4.7), *cereal* (3.8), *flour* (2.3), *dairy* (1.7), *cocoa/chocolate* (1.4), *nut* (1.1), *sweetener* (0.7), *corn* (0.3), *rice* (0.2), *wheat* (0.2)	16.9
Occasions	*weekend* (3.4), *breakfast* (2.9), *weekday* (2.2), *snack_time* (1.3), *lunch* (1.1), *month-season* (1.0), *dinner* (0.6), *day_moment* (0.3)	13.0
Social context	*family-friends* (3.1), *social_event* (1.3), *professional_event* (2.7), *platform* (0.8), *professional_area* (0.4), *social_policy* (0.3), *association* (0.2)	12.8
Diet / Health	*coeliac* (6.6), *diet* (1.5), *drug-treatment* (0.3), *coeliac_disease* (0.2), *associated_diseases* (0.1)	9.8
Sensory characteristics / Sensations	*positive_sensation* (6.2), *complaint* (1.5), *negative_sensation* (0.8), *craving-hunger* (0.5)	9.1

3.2. Comparison of co-occurrence networks from coded and pre-cleaned text

Figures 2 and 3 show the co-occurrence networks for coded and just pre-cleaned text from the subset of 3,000 tweets. In this plot, the size of circles represents the frequency of mentioned terms (or sub-themes, in the case of coded text). Co-occurrence is shown by the line connecting two terms, which is thicker when more times are co-mentioned together within the same tweet. Furthermore, the position of a term in the network is determined by the co-occurrence regarding all the other terms. Printed versions of the network make it difficult to see the connections, still the VOSviewer software can show every single term and the connections they have with others by just clicking on the word. For example, Figure 4 shows the highlighted connections of the term *flour* with its co-mentioned words (in the same network of Figure 3).

Co-occurrence networks from coded text showed, in agreement with Table 1, the most frequent sub-themes (bigger circles) were related to products (*cake-pastry*, *bread*, *cookie* and *pizza-dough-patty*), culinary preparations (*recipe*), places (*city*, *bakery* and *restaurant*), and product associated characteristics (*brand*). Finally, although the theme sensory / sensation was one of the least mentioned, *positive* was one of the most frequently mentioned sub-themes.

Relationships among sub-themes and their position show products at the ‘nodes’ of the network structure. The products *cake-pastry*, *bread*, and *cookie* appeared separated from the others and related to *recipe* and *flour,* which was connected to different cereals and other flour sources like *wheat*, *spelt*, *corn*, *chickpea*, *carob*, *rice*, *brown_rice* and *almond*. Few ingredients (*cocoa / chocolate* and *fruit-vegetables*) also appeared connected with these three products. P*izza-dough-patty* and *beer* appeared related to occasions (*weekend* and *snack_time*), places (*restaurant*, *city*, *food chain* and *supermarket*), social (*family-fiend*), and with *brand* and *coeliac.* Besides, *coeliac* was related to *restaurant*, *city*, *food chain*, and *diet. Pasta* related to places (*restaurant* and *city*), social aspects (*family-friend*), the word *coeliac* and to other groups of sub-themes like ingredients (*fruit-vegetable* and *fish-seafood*) and occasions (*dinner* and *weekday).* Sub-themes *positive sensations, brand*, and *bakery* appeared in the central area of the network indicating that they were equally related to most other sub-themes.

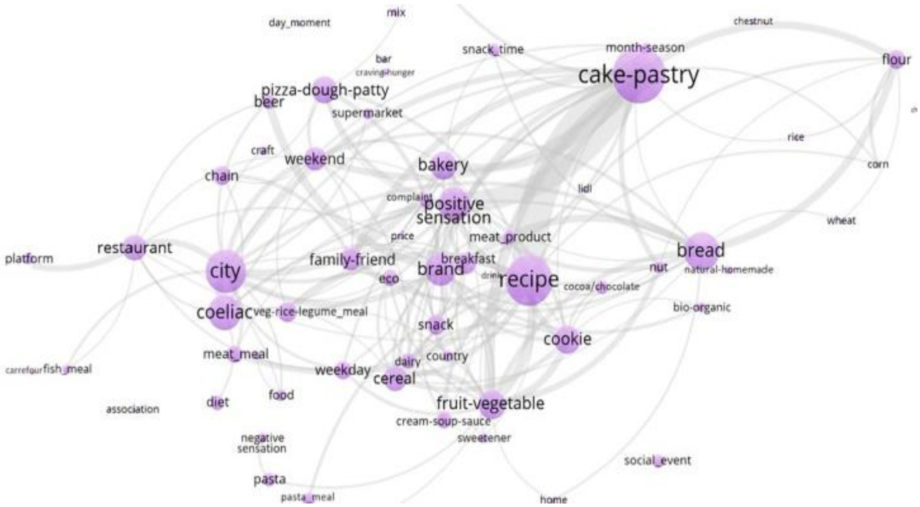


Figure 2. Co-occurrence network of Twitter information on "gluten-free" obtained from manually coded text of the subset of 3000 tweets.

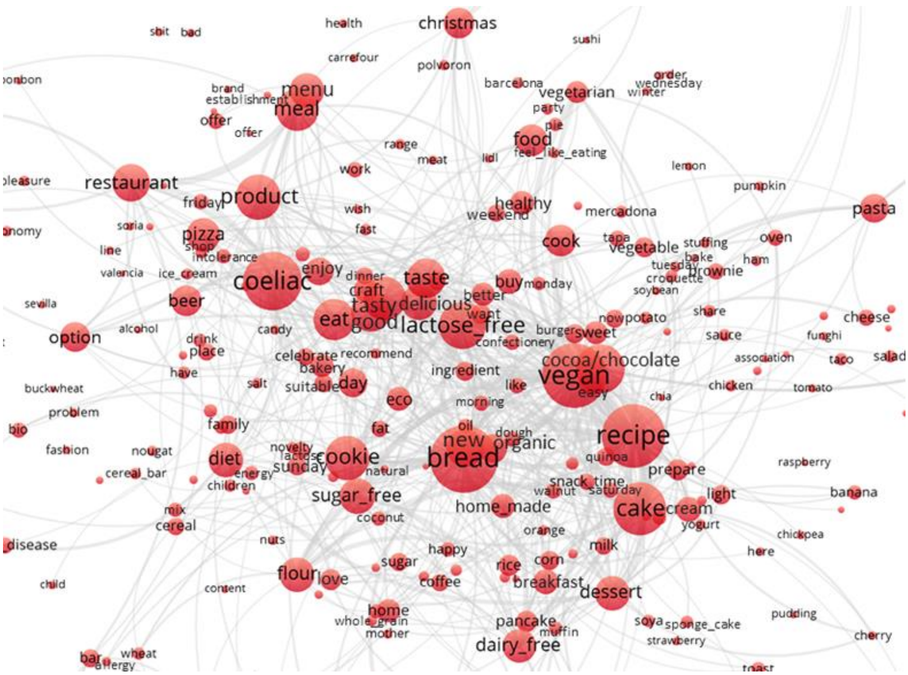


Figure 3. Co-occurrence network of Twitter information on "gluten-free" obtained from pre-cleaned text of the subset of 3000 tweets.

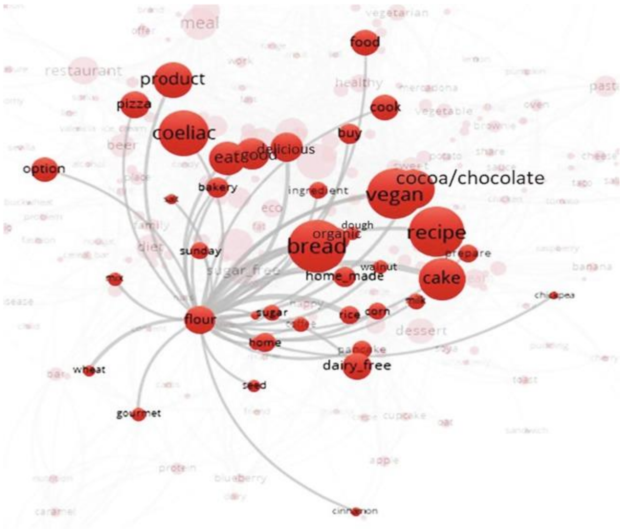


Figure 4. Connections for the term *flour* in the co-occurrence network (pre-cleaned text, Figure 3) highlighted by VOSviewer software when clicking on the term.

The co-occurrence network obtained from the pre-cleaned text of the same 3,000 tweets (Figure 3) showed many terms represented by circles of intermediate size. The frequency of mention (also indicated in Table 2) was high for products (*bread*, *cake*, *cookie*, *beer*, *pizza* and *pasta*), ingredients (*cocoa / chocolate*, *flour*, *cream*, *rice* and *sugar*), product-related features (*vegan*, *lactose_free*, *new*, *sugar_free* and *organic*), positive sensations (*tasty*, *good*, *delicious* and *enjoy*) and other terms related to different aspects like *recipe*, *coeliac*, *meal*, *eat*, *restaurant*, *dessert*, *diet* and *cook.*

Figure 3 shows that products like *cookie*, *bread*, and *cake* were frequently co-mentioned with *recipe* and *vegan*. *Bread* and *cake* were also co-mentioned with *flour,* which related to different cereals and flour sources. Many small-size terms comprising fruits, nuts, and condiments related to *cake*. *Pasta* also related to *recipe*, *vegan*, *flour,* and specific ingredients such as *cheese*, *sauce*, *ham,* and *fungi*. *Coeliac* was related to *restaurant*, *product*, *diet*, *meal / menu* and *suitable*.

Here, the terms *tasty*, *taste*, *delicious*, *enjoy*, *lactose-free* and *eat* were in the centre of the network (equally related to most other terms).

Table 2. Frequency of terms mentioned on Twitter when talking about gluten-free obtained from the subset of 3000 tweets.

Term	Frequency (%)	Term	Frequency (%)	Term	Frequency (%)
bread	7.2	dessert	2.4	buy	1.4
vegan	6.7	flour	2.4	eco	1.3
recipe	6.6	menu	2.4	healthy	1.3
coeliac	5.8	diet	2.4	craft	1.3
cake	4.9	dairy_free	2.3	easy	1.3
cocoa/chocolate	4.3	pizza	2.3	home_made	1.3
lactose_free	4.0	food	2.1	bakery	1.3
product	3.7	cook	2.0	home	1.2
cookie	3.6	beer	2.0	better	1.2
tasty	3.5	christmas	2.0	sweet	1.2
meal	3.4	option	1.8	vegetarian	1.1
eat	3.3	organic	1.8	rice	1.1
good	3.0	day	1.7	pancake	1.1
taste	3.0	enjoy	1.7	love	1.0
new	2.7	pasta	1.7	prepare	1.0
restaurant	2.7	cream	1.4	vegetable	1.0
delicious	2.6	breakfast	1.4	want	1.0
sugar_free	2.5				

Only frequencies higher than 1% are listed.

3.3. Co-occurrence networks from tweets on "gluten-free" in general and from tweets on specific products

The co-occurrence network (Figure 5) was obtained for the totality of tweets (16,386) after just the pre-cleaning step. In this network, more mentioned terms and connections were the same as the subset of pre-cleaned text of 3,000 tweets (Figure 3). However, two main effects were observed when increasing the number of tweets in the analysis. First, the differences in frequency (label size) among terms were more evident in the network with totality of tweet. Second, some terms that initially showed low frequency (some specific ingredients and brand and company names) became relevant, showing more detailed information.

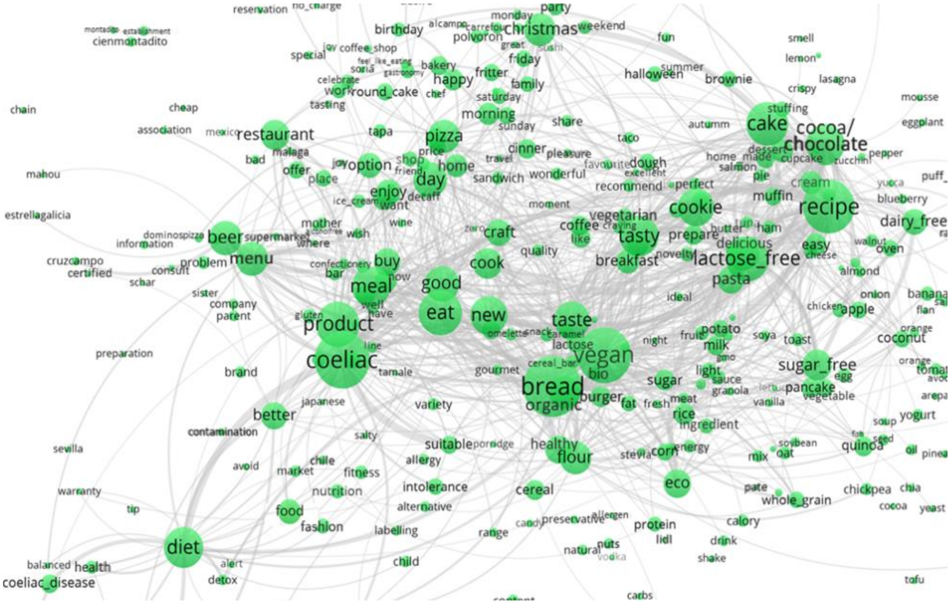


Figure 5. Co-occurrence network of Twitter information on “gluten-free” obtained from pre-cleaned text of the totality of tweets (16,386).

Individual co-occurrence networks were obtained for the products *bread, cake, cookie, beer*, and *pizza.* Frequencies of mention for terms related to these products are shown in Table 4*.* These products were selected given the relevance of the presence of gluten in their composition and for their high frequencies of mention in the totality of tweets (Table 3).

Table 3. Frequency of terms mentioned on Twitter when talking about gluten-free obtained from the totality of 16,386 tweets.

Term	Frequency (%)	Term	Frequency (%)	Term	Frequency (%)
bread	6.7	day	2.4	craft	1.5
coeliac	6.0	beer	2.4	enjoy	1.4
vegan	5.7	delicious	2.3	better	1.4
recipe	5.3	menu	2.3	dairy_free	1.4
eat	3.9	pizza	2.2	option	1.3
product	3.8	christmas	2.2	breakfast	1.2
cake	3.7	flour	2.1	want	1.2
lactose_free	3.7	organic	2.1	home	1.2
cocoa/chocolate	3.2	sugar_free	1.9	sweet	1.1
tasty	3.2	cook	1.9	dessert	1.1
meal	3.1	restaurant	1.8	now	1.1
diet	3.1	food	1.6	cream	1.1
new	2.9	healthy	1.6	easy	1.1
cookie	2.8	eco	1.6	morning	1.0
taste	2.7	pasta	1.5	happy	1.0
good	2.5	buy	1.5		

Only frequencies higher than 1% are listed.

Table 4. Frequency of terms mentioned on Twitter when talking about gluten-free obtained from the totality of 16,386 tweets), related to different products.

Bread		Cake		Cookie		Beer		Pizza	
Term	F (%)	Term	F (%)	Term	F (%)	Term	F (%)	Term	F (%)
recipe	6.2	cocoa/chocolate	15	recipe	13	craft	11	dough	8.3
eat	5.5	recipe	13	cocoa/chocolate	12	cruzcampo	8.2	dominospizza	8.1
coeliac	5.1	cupcake	10	vegan	9.1	alcoholfree	8	telepizza	6.8
flour	4.9	lactose_free	7.4	christmas	6.9	coeliac	7	vegan	6.5
tasty	4.7	vegan	6.4	tasty	6.7	taste	7	taste	4.3
day	3.8	tasty	5.1	delicious	6.5	new	4.6	eat	4
burger	3.7	dessert	4.8	lactose_free	5.8	burger	3.9	recipe	4
vegan	3.6	delicious	4.4	taste	5.2	good	3.4	flour	3.8
dairy_free	2.8	apple	4.2	new	4.1	estrellagalicia	3.1	lactose_free	3.8
good	2.8	flour	4.2	buy	3.5	better	2.8	new	3.5
home_made	2.8	sugar_free	3.9	sugar_free	3.5	bar	2.6	tuesday	3.5
delicious	2.8	birthday	3.8	eat	3.2	daura	2.6	bread	3.3
lactose_free	2.8	cream	3.8	good	3.2	day	2.6	want	3.3
taste	2.6	coeliac	3.5	sweet	3.2	enjoy	2.6	coeliac	3
sweet	2.3	sweet	3	flour	2.8	novelty	2.6	good	3
buy	2.2	dairy_free	2.9	coconut	2.6	now	2.6	vegetarian	2.8
dough	2.1	taste	2.9	cream	2.6	bread	2.3	dinner	2.5
easy	2.1	prepare	2.7	healthy	2.6	mahou	2.3	home_made	2.5
wheat	2.1	carrot	2.6	prepare	2.4	drink	2.1	menu	2.5
milk	2	cheesecake	2.3	sugar	2.4	menu	2.1	lactose	2.3
		coconut	2.3	want	2.4	tasty	2.1	promo	2.3
		christmas	2.1	apple	2.2			tasty	2.3
		celebrate	2	coeliac	2.2			craft	2
		easy	2	rice	2.2			enjoy	2
		eat	2	snack_time	2.2			friday	2
		halloween	2						

F (%): Frequency of mention of terms.
Only frequencies higher than 2% are listed.

In the network for *bread* (Figure 6), the terms *recipe* and *flour* were highly mentioned, and also others related to many relevant different types of flours (*chickpea, teff, quinoa, linseed, rice, buckwheat, seed, yucca, wheat, corn, spelt, rye* and *whole_grain*). Other terms like *breakfast*, bread for *burger* and *home_made* (relating to *delicious* and *oven*) were also relevant.

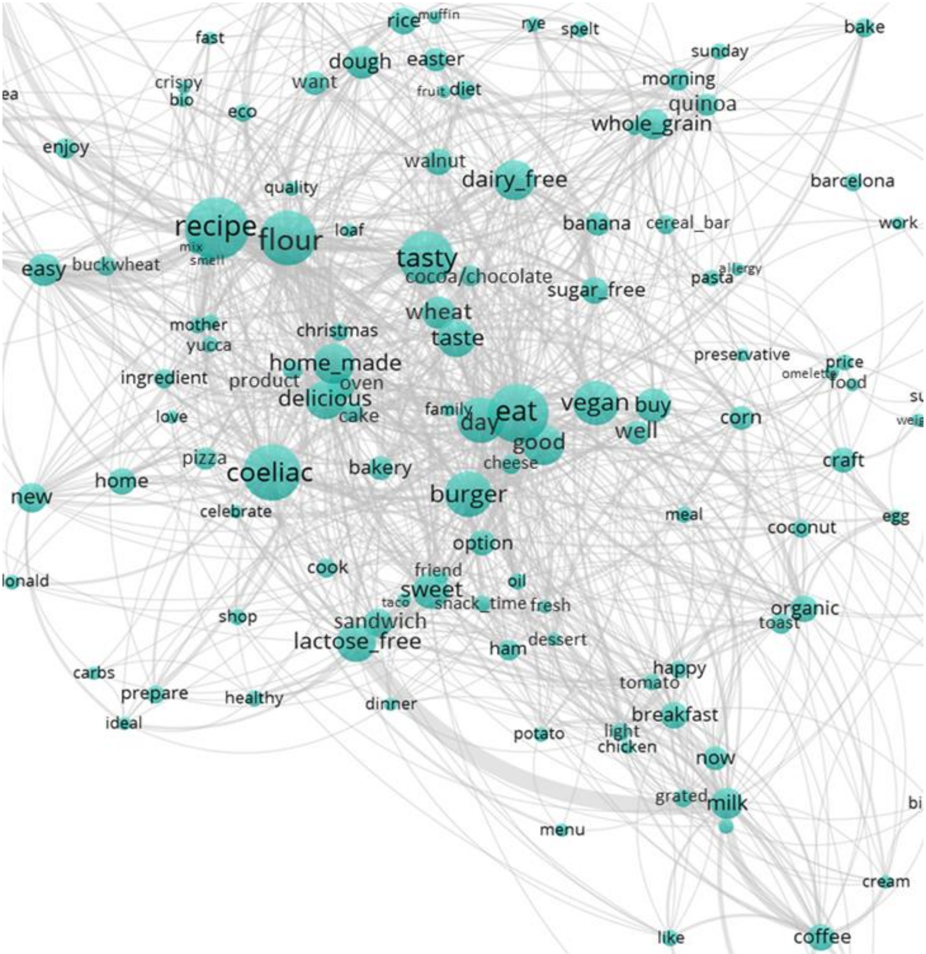


Figure 6. Co-occurrence network of Twitter information on “gluten-free” and “*bread*”.

For *cake* (Figure 7) and *cookie* (Figure 8), networks were similar. *Recipe* and *cocoa / chocolate* were the most relevant terms and many types of ingredients, mostly fruits and nuts (*carrot, apple, strawberry, cherry, orange, walnut,* and *blueberry*) became relevant. Terms relating to context such as celebrations (*Christmas* and *Halloween*) and *sugar_free* were associated to both products. *Birthday* was importantly mentioned in the *cake* network, while *snack_time* was mentioned in the *cookie* network.

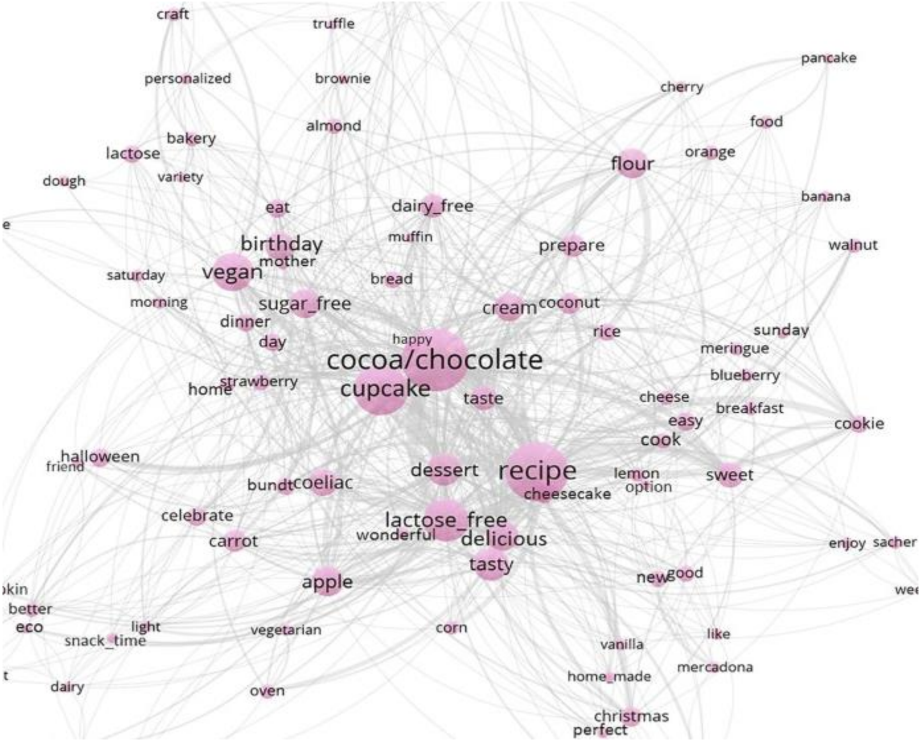


Figure 7. Co-occurrence network of Twitter information on “gluten-free” and “*cake*”.

For *beer* (Figure 9), the relevant terms were *craft* (relating to *burger* and *taste*), *alcohol_free* (relating to *new*), and many different brands and types of beer (*Estrella Galicia, Cruzcampo, Daura, Ambar, Mahou, IPA,* and *Pilsen*). Terms like *bar, restaurant, Saturday, home, day, have* and *now*, appeared related to *enjoy*, *delicious, good, taste* and *happy*. Regarding places, *bars* and *restaurants* were mentioned (places to drink), also *supermarkets* and *shops* (places to buy beer) were named.

For *pizza* (Figure 10), *dough* was the most mentioned term, while others related to *recipe*, *home_made,* and different ingredients were shown in this network. Restaurants, food chains (*Tele Pizza, Pizza Hut* and *Domino’s Pizza*) and aspects related to buying and supermarkets (*promo, new* and *novelty*) were also relevant.

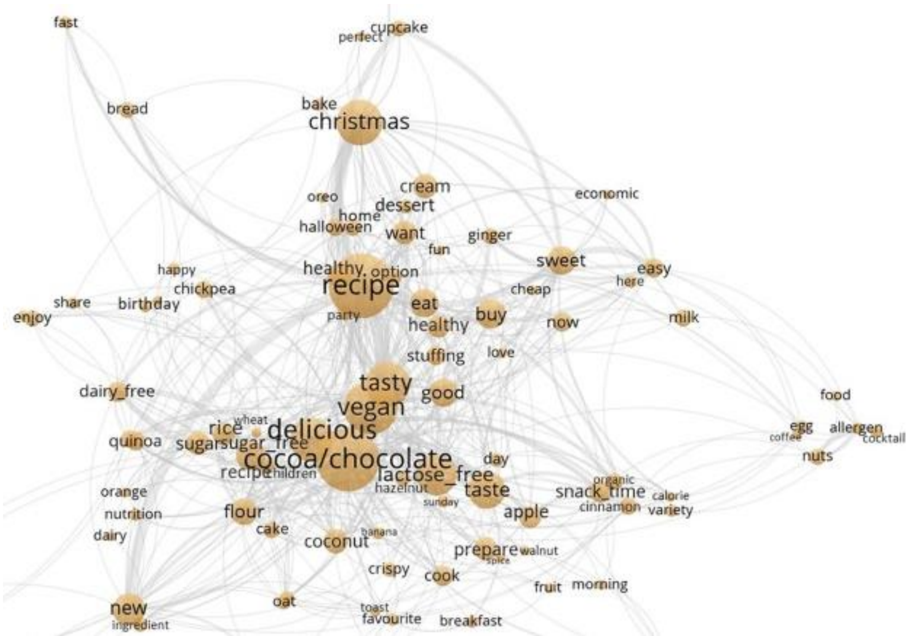


Figure 8. Co-occurrence network of Twitter information on "gluten-free" and "*cookie*".

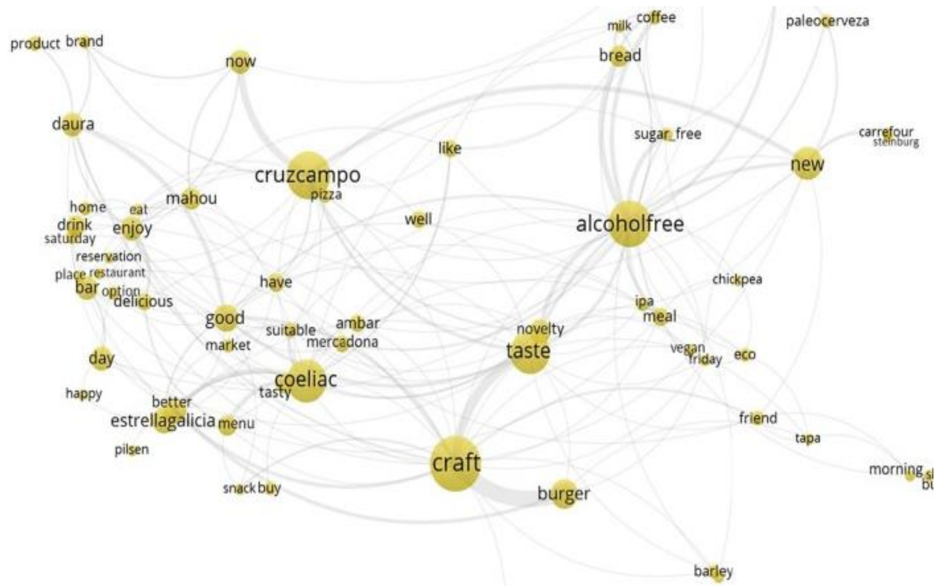


Figure 9. Co-occurrence network of Twitter information on "gluten-free" and "*beer*".

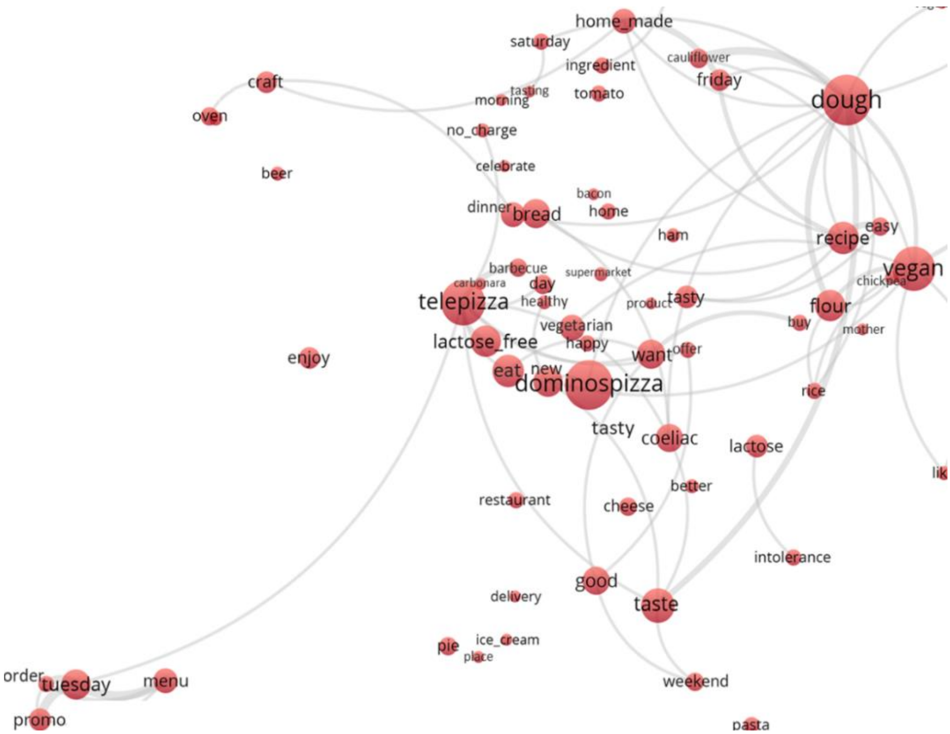


Figure 10. Co-occurrence network of Twitter information on “gluten-free” and “*pizza*”.

All products showed connections to positive ideas and concepts, like *good, enjoy, delicious, tasty,* and *happy. Vegan* and *lactose-free* were terms that appeared frequently for all products except for *beer*.

4. DISCUSSION

4.1. Treatment of the information obtained from Twitter

In this study, the analysis of tweet information was conducted using co-occurrence networks. The tweets were pre-processed in two ways, either manually coding the content of tweet or using direct raw tweet text (after just a pre-cleaned step). The networks from the manual coded and pre-cleaned text from the subset of 3,000 tweets revealed similar main ideas about the topic "gluten-free" but they were differently represented. When coding the information after reading, concepts and ideas were grouped into the same term in the network from coded text, increasing the frequency of mention and, as it was intended, highlighting the differences in the relevance of sub-themes.

In many cases, the terms and sub-themes with a high frequency of mention were the same in both networks. However, few sub-themes highly cited in the coded text network were not found in the pre-cleaned text network because the frequency was split into different terms. This is observable for the names of weekdays, cities, and countries and for positive sensations. Therefore, manual reading and coding text into themes, organises the information more and structures separate topics together; however, can lead to a loss of detailed or meaningful information for interpretation.

Notably, the network obtained from pre-cleaned text of the totality of 16,386 tweets showed a structure and size distribution of terms that resembled those observed for the coded text network. Seemingly increasing the sample size (tweets) for analysis, highlighted the differences in the relevance of terms, like what was achieved by manually coding the text of the tweets. In this study, with a large volume of tweets, only a cleaning of text is needed to obtain co-occurrence networks with relevant and meaningful terms, representing what people tweet about for a given topic. Furthermore, using pre-cleaned text avoids limitations of coding, subjectivity bias, and mistakes. Here, both *vegan* and *lactose_free* terms showed a high frequency of mention in the pre-cleaned text network and were not found in the coded text. This mistake in coding (*vegan* and *lactose_free* were not considered when reading the tweets and identifying the relevant themes) made that this information was not considered and therefore lost. In addition, interpreting the information provided by coded text, without knowing the coding criteria, can be complex. Finally, saving time is also an advantage as manual coding of 3,000 tweets took around 120 hours of work of two researchers and the text pre-cleaning process, in turn, takes only 2-4 hours of one researcher, regardless of the volume of tweets used for the analysis.

To date, co-occurrence networks had been scarcely applied in the analysis of Twitter than other methods (Eriksson-Backa, Holmberg, & Ek, 2016; He et al., 2017; Kang et al., 2017). The most direct and simplest method to analyse tweets' content is the study of the frequencies of mentioned words and using wordclouds to visualise its relevance (Carr et al., 2015; Fried et al., 2015; Le & Worch, 2014; Vidal et al., 2018). However, as demonstrated by Vidal et al. (2015) qualitative analysis of text is necessary to interpret each word in its context, avoiding misinterpretation and providing full meaning of ideas. Thus, co-occurrence networks that show the frequency of mentions of a word and the connections with the co-mentioned words, can play the role of qualitative analysis and place words into their context automatically. Text mining techniques based on machine learning algorithms are also used to analyse Twitter text, using themes already established or commonly studied (Mishra & Singh, 2016; Shah et al., 2016). In contrast, co-occurrence networks are less complex and do not require the adjustment of algorithms for new topics.

4.2. Information found on Twitter about gluten-free

Twitter exploration using co-occurrence networks has been useful to gather knowledge about what is relevant, in general, for a specific target of consumers, in this case gluten-free consumers. However, from an industry perspective, it is sometimes interesting to get more detailed information on what consumers say about a topic regarding a specific product category, brand, or attribute. Here, obtaining the individual networks from tweets, including "gluten-free" and the specific product, allowed better visualisation of the more relevant topics for each of the products.

When tweeting about gluten-free, people mainly talk about five product categories, which are critical for the lack of gluten (*bread, cake, cookie, beer*, and *pizza*), share information about how to prepare food (recipes and ingredients), where to get food (restaurants, supermarkets, food chains), describe the context of consumption (social events, places, and occasions), or talk about diet and health aspects related to coeliac disease.

Bakery goods and pizza are essential products for the people tweeting about gluten-free. The large amount of information about recipes, ingredients, and culinary preparations suggest that people commonly prepare these categories of products at home. The importance of recipe sharing in online communities has also been highlighted by Blackburn, Yilmaz, & Boyd (2018), who observed that the process of cooking, sharing instructions for recipes, and the ingredients used are key topics of discussion on the social networking site Reddit.

The mention of occasions, together with people; places; and positive sensations indicated that describing the eating / drinking situation was also a frequent topic in tweets. People associated the consumption of *pizza* or *beer* to a given time (weekend) or place (restaurant / bar / home), while the consumption of *bread, cake*, and *cookie* was linked to breakfast, and *cake* was especially related to celebrations. The importance of context of consumption has also been reported by previous works in other product categories and situations. Beyond the scope of social media, Spinelli et al. (2017) found that coffee consumers focus more on the pleasantness of the related social situation in which the coffee is consumed rather than on the experience of enjoying the product by itself. When exploring food topics on Twitter, Vidal et al. (2015) observed, agreeing with our findings, that people usually mention the food they consume, places, or the people they share the meal with when tweeting about different eating situations like breakfast, lunch, dinner, and snack. Here, the eating situation and social context was a relevant part of the information obtained, but for people tweeting about gluten-free, it was of great importance how and where to find the products for this specific population with restrictions in their diet.

The high frequencies of mention found for positive sensations in this study reveals that people talk positively, avoiding negative aspects or complaints about gluten-free. These observations are in line with other studies showing a positive attitude when mentioning or remembering specific eating situations (Vidal et al., 2015) or “memorable” meals (Piqueras-Fiszman & Jaeger, 2015), especially those involving family, friends, good food, and positive emotions.

The presence of terms like *bio*, *organic*, *natural*, *artisan*, *vegan*, *sugar-free* and *eco* in central areas of the network reveals that people tweeting about gluten-free are especially interested in these aspects. Regardless of the reasons behind this, people associate gluten-free diet to a particular style of food, evoking a sense of natural foods and lifestyle.

Regarding the essential importance of avoiding gluten in disorders related to this protein, concepts associated to diet, health, and food intolerances revealed the special concern of people about these aspects. Previous studies showed the importance, among consumers with special requirements in their diet, of consulting the available information online regarding food allergies and intolerances (Hamshaw, Barnett, & Lucas, 2018). Therefore, sharing information about food chains for eating or ordering *pizza* was especially relevant. Given that eating out presents a particular challenge for people suffering food allergies and / or intolerances (Begen et al., 2016), they pay special attention to the places where they can eat, limiting the potential risk to their health and where they can find a tasty and compatible gluten-free product.

Other social networks have been used for exploring consumer behaviour using different approaches depending on the type o information that users share. For example, the visual analysis of images on Instagram, related to food products posted by users, showed more detailed information about the context surrounding consumption, and also the brand, type, and flavour of the product (Gómez-Corona, Ares, Spinelli, Veflen, & Stathopoulou, 2019). Other Instagram studies have focused on the analysis of the hashtags posted associated to a particular topic. Pilař, Balcarová, Rojík, Tichá, & Poláková (2018) explored the farmers’ market context, which showed customer clusters according to their attitudes or motivations, finding segments oriented by product, emotions, and social aspects. The same authors also explored Instagram interactions and hashtags to study consumer perceptions and feelings regarding organic food production; also they identified communities of users motivated by areas like healthy living, vegetarian diets, clean eating, and active healthy living (Pilař, Stanislavská, et al., 2018). Arellano-Covarrubias, Gómez-Corona, Varela, & Escalona-Buendía (2019) studied the relationship between flavours in beer pairings across different cultures and countries, using Synthesio® for retrieving data from Twitter, Facebook, forums, and blogs. This pay-platform allows access to geographical information (as well as gender and age when specified by users in their public profile) of the messages posted, which made possible to perform the study by country. In this study, it would be interesting to analyse potential differences across countries, gender, and age groups. However, the *rtweet* package did not show this information from the users.

5. CONCLUSIONS

Co-occurrence networks allow the understanding of the information on Twitter showing the relevance of terms and how they are structured through co-occurrence connections.

This study shows that co-occurrence networks can be used, almost directly, from pre-cleaned data without losing relevant information. Furthermore, the study highlighted the importance of the number of tweets when making relevant and dependable information.

This approach almost automatic based on co-occurrence networks from pre-cleaned text can be a tool for analysing, in an easy and fast manner, the massive information continuously available and updated from online platforms like Twitter. This would enable monitoring of what people think, feel, and talk about regarding product categories, services, and topics and how they evolve.

This strategy allows exploration of topics concerning a certain group of consumers. Here, people talking about gluten-free in Twitter mentioned five categories of products (*bread*, *cake*, *cookie*, *beer,* and *pizza*) plus the context of consumption and purchasing. Tweets were posted to share eating or preparing food situations and also to recommend how to get gluten-free products: with bakery goods, recipes and ingredients for preparing them; while for beer and pizza, recommendations were related to brands, supermarkets and restaurants.

REFERENCES

Arellano-Covarrubias, A., Gómez-Corona, C., Varela, P., & Escalona-Buendía, H. B. (2019). Connecting flavors in social media: A cross cultural study with beer pairing. *Food Research International*, *115*(July 2018), 303–310.

Begen, F. M., Barnett, J., Payne, R., Roy, D., Gowland, M. H., & Lucas, J. S. (2016). Consumer preferences for written and oral information about allergens when eating out. *PLoS ONE*, *11*(5), 1–12.

Blackburn, K. G., Yilmaz, G., & Boyd, R. L. (2018). Food for thought: Exploring how people think and talk about food online. *Appetite*, *123*, 390–401.

Capriles, V. D., dos Santos, F. G., & Arêas, J. A. G. (2016). Gluten-free breadmaking: Improving nutritional and bioactive compounds. *Journal of Cereal Science*, *67*, 83–91.

Carr, J., Decreton, L., Qin, W., Rojas, B., Rossochacki, T., & Yang, Y. wen. (2015). Social media in product development. *Food Quality and Preference*, *40*(PB), 354–364.

Chae, B. (2015). Insights from hashtag #supplychain and Twitter analytics: Considering Twitter and Twitter data for supply chain practice and research. *International Journal of Production Economics*, *165*, 247–259.

Chen, X., & Yang, X. (2014). Does food environment influence food choices? A geographical analysis through “tweets.” *Applied Geography*, *51*, 82–89.

Christoph, M. J., Larson, N., Hootman, K. C., Miller, J. M., & Neumark-Sztainer, D. (2018). Who Values Gluten-Free? Dietary Intake, Behaviors, and Sociodemographic Characteristics of Young Adults Who Value Gluten-Free Food. *Journal of the Academy of Nutrition and Dietetics*, *118*(8), 1389–1398.

Constantinides, E., & Holleschovsky, N. I. (2016). Impact of online product reviews on purchasing decisions. *WEBIST 2016 - Proceedings of the 12th International Conference on Web Information Systems and Technologies*, *1*(Webist), 271–278.

Cunillera, T., & Guilera, G. (2018). Twenty years of statistical learning: from language, back to machine learning. *Scientometrics*, *117*(1), 1–8.

Da Silva, N. F., Hruschka, E. R. E. R., & Hruschka, E. R. E. R. (2014). Tweet sentiment analysis with classifier ensembles. *Decision Support Systems*, *66*, 170–179.

do Nascimento, A. B., Fiates, G. M. R., & Teixeira, E. (2017). We want to be normal! Perceptions of a group of Brazilian consumers with coeliac disease on gluten-free bread buns. *International Journal of Gastronomy and Food Science*, *7*(January), 27–31.

Eriksson-Backa, K., Holmberg, K., & Ek, S. (2016). Communicating diabetes and diets on Twitter - a semantic content analysis. *International Journal of Networking and Virtual Organisations*, *16*(1), 8.

Feinerer, I., & Hornik, K. (2017). Package ‘tm’: Text Mining Package. Version 0.7-1. CRAN.R-Project. URL: https://cran.r-project.org/web/packages/tm/index.html

Fried, D., Surdeanu, M., Kobourov, S., Hingle, M., & Bell, D. (2015). Analyzing the language of food on social media. *Proceedings - 2014 IEEE International Conference on Big Data, IEEE Big Data 2014*, (Section II), 778–783.

Gómez-Corona, C., Ares, G., Spinelli, S., Veflen, N., & Stathopoulou, N. (2019). Social media in sensory and consumer research: What do we know so far and how can we shape the future? In 13th Pangborn Sensory Science Symposium. Edinburgh Scotland, UK. July 28-August 1.

Hamshaw, R. J. T., Barnett, J., & Lucas, J. S. (2018). Tweeting and Eating: The Effect of Links and Likes on Food-Hypersensitive Consumers' Perceptions of Tweets. *Frontiers in Public Health*, *6*(April), 1–12.

He, W., Tian, X., Tao, R., Zhang, W., Yan, G., & Akula, V. (2017). Application of social media analytics: A case of analyzing online hotel reviews. *Online Information Review*, *41*(7), 921–935.

He, W., Zha, S., & Li, L. (2013). Social media competitive analysis and text mining: A case study in the pizza industry. *International Journal of Information Management*, *33*, 464–472.

Houben, A., Höchstötter, A., & Becker, T. (2012). Possibilities to increase the quality in gluten-free bread production: An overview. *European Food Research and Technology*, *235*(2), 195–208.

Hsieh, H.-F., & Shannon, S. E. (2005). Three Approaches to Qualitative Content Analysis. *Qualitative Health Research*, *15*(9), 1277–1288.

Kearney, M. (2017). Package 'rtweet': Collecting Twitter Data. Version 0.4.0. CRAN.R-Project. URL: https://cran.r-project.org/web/packages/rtweet/index.html

Kang, G. J., Ewing-Nelson, S. R., Mackey, L., Schlitt, J. T., Marathe, A., Abbas, K. M., & Swarup, S. (2017). Semantic network analysis of vaccine sentiment in online social media. *Vaccine*, *35*(29), 3621–3638.

King, S. C. (2016). Emotions elicited by foods. In Emotion measurement (pp. 455-472). Woodhead Publishing.

Le, S., & Worch, T. (2014). *Analyzing Sensory Data with R - CRC Press Book*.

Marinho, V. Q., Hirst, G., & Amancio, D. R. (2017). Authorship Attribution via Network Motifs Identification. *Proceedings - 2016 5th Brazilian Conference on Intelligent Systems, BRACIS 2016*, 355–360.

Marston, K., Khouryieh, H., & Aramouni, F. (2016). Effect of heat treatment of sorghum flour on the functional properties of gluten-free bread and cake. *LWT - Food Science and Technology*, *65*(2016), 637–644.

Matos, M. E., & Rosell, C. M. (2012). Relationship between instrumental parameters and sensory characteristics in gluten-free breads. *European Food Research and Technology*, *235*(1), 107–117.

Mention. (2018). *The Twitter Engagement Report*. Retrieved September 2019, from https://mention.com/en/reports/twitter/

Mishra, N., & Singh, A. (2016). Use of twitter data for waste minimisation in beef supply chain. *Annals of Operations Research*, 1–23.

Missbach, B., Schwingshackl, L., Billmann, A., Mystek, A., Hickelsberger, M., Bauer, G., & König, J. (2015). Gluten-free food database: The nutritional quality and cost of packaged gluten-free foods. *PeerJ*, *2015*(10).

Moe, W. W., & Schweidel, D. A. (2017). Opportunities for Innovation in Social Media Analytics. *Journal of Product Innovation Management*, *34*(5), 697–702.

Molina-Rosell, C. (2013). Alimentos sin gluten derivados de cereales. In L. Rodrigo & A. Peña (Eds.), *Enfermedad celíaca y sensibilidad al gluten no celíaca* (pp. 447–461). Barcelona, España: OmniaScience.

Naqash, F., Gani, A., Gani, A., & Masoodi, F. A. (2017). Gluten-free baking: Combating the challenges - A review. *Trends in Food Science and Technology*, *66*, 98–107.

Nguyen, T. T., Criss, S., Allen, A. M., Glymour, M. M., Phan, L., Trevino, R., … Nguyen, Q. C. (2019). Pride, love, and twitter rants: Combining machine learning and qualitative techniques to understand what our tweets reveal about race in the us. *International Journal of Environmental Research and Public Health*, *16*(10), 1–19.

O’Shea, N., Doran, L., Auty, M., Arendt, E., & Gallagher, E. (2013). The rheology, microstructure and sensory characteristics of a gluten-free bread formulation enhanced with orange pomace. *Food & Function*, *4*(12), 1856.

Penjumras, P., Janmeesup, C., Umnat, S., Chokeprasert, P., Wattananapakasem, I., & Phaiphan, A. (2019). Development of gluten-free cream puff with the addition of carboxymethylcellulose and carrageenan. *Food Research*, *3*(2), 138–144.

Pilař, L., Balcarová, T., Rojík, S., Tichá, I., & Poláková, J. (2018). Customer experience with farmers’ markets: What hashtags can reveal. *International Food and Agribusiness Management Review*, *21*(6), 755–770.

Pilař, L., Stanislavská, L. K., Rojík, S., Kvasnička, R., Poláková, J., & Gresham, G. (2018). Customer experience with organic food: Global view. *Emirates Journal of Food and Agriculture*, *30*(11), 918–926.

Piqueras-Fiszman, B., & Jaeger, S. R. (2015). Emotions associated to mealtimes: Memorable meals and typical evening meals. *Food Research International*, *76*(P2), 243–252.

Platania, M., & Spadoni, R. (2018). How people share information about food: Insights from tweets regarding two Italian Regions. *International Journal on Food System Dynamics*, *9*(2), 149–165.

R Core Team. (2016). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing, 860–864.

Ruiz, J. B., & Barnett, G. A. (2015). Exploring the presentation of HPV information online: A semantic network analysis of websites. *Vaccine*, *33*(29), 3354–3359.

Samoggia, A., Bertazzoli, A., & Ruggeri, A. (2019). Food retailing marketing management: social media communication for healthy food. *International Journal of Retail and Distribution Management*.

Sapone, A., Bai, J. C., Ciacci, C., Dolinsek, J., Green, P. H. R., Hadjivassiliou, M., … Fasano, A. (2012). Spectrum of gluten-related disorders: Consensus on new nomenclature and classification. *BMC Medicine*, *10*.

Sengupta, A., & Ghosh, A. (2020). Mining social network data for predictive personality modelling by employing machine learning techniques. *Lecture Notes in Electrical Engineering*, *575*, 113–127.

Shah, S., Kumar, K., & Saravanaguru, R. K. (2016). Sentimental analysis of twitter data using classifier algorithms. *International Journal of Electrical and Computer Engineering*, *6*(1), 357–366.

Sharma, N., Bairwa, M., Gowthamghosh, B., Gupta, S. D., & Mangal, D. K. (2018). A bibliometric analysis of the published road traffic injuries research in India, post-1990, 1–11.

Skaf, L., Buonocore, E., Dumontet, S., Capone, R., & Franzese, P. P. (2020). Applying network analysis to explore the global scientific literature on food security. *Ecological Informatics*, *56*(January), 101062.

Spinelli, S., Dinnella, C., Masi, C., Zoboli, G. P., Prescott, J., & Monteleone, E. (2017). Investigating preferred coffee consumption contexts using open-ended questions. *Food Quality and Preference*, *61*, 63–73.

Su, H. N., & Lee, P. C. (2010). Mapping knowledge structure by keyword co-occurrence: A first look at journal papers in Technology Foresight. *Scientometrics*, *85*(1), 65–79.

van Eck, N. J., & Waltman, L. (2007). VOS: A new method for visualizing similarities between objects. *Advances in Data Analysis*, (April 2006), 299–306.

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523–538.

van Eck, N. J., & Waltman, L. (2018). VOSviewer Manual version 1.6.9. *Universiteit Leiden*, (August), 1–51.

van Eck, N. J., Waltman, L., Noyons, E. C. M., & Buter, R. K. (2010). Automatic term identification for bibliometric mapping. *Scientometrics*, *82*(3), 581–596.

van Eck, N. J., Waltman, L., van den Berg, J., & Kaymak, U. (2006). Vizualizing the computational intelligence field. *IEEE Computational Intelligence Magazine*, *1*(4), 6–10.

van Zoonen, W., & van Der Meer, T. G. L. A. (2016). Social media research: The application of supervised machine learning in organizational communication research. *Computers in Human Behavior*, *63*, 132–141.

Vidal, L, Ares, G., & Jaeger, S. R. (2018). Application of Social Media for Consumer Research. In G. Ares & P. Varela (Eds.), *Methods in Consumer Research, Volume 1: New Approaches to Classic Methods* (pp. 125–155). Woodhead Publishing.

Vidal, L., Ares, G., & Jaeger, S. R. (2016). Use of emoticon and emoji in tweets for food-related emotional expression. *Food Quality and Preference*, *49*, 119–128.

Vidal, L., Ares, G., Machín, L., & Jaeger, S. R. (2015). Using Twitter data for food-related consumer research: A case study on “what people say when tweeting about different eating situations.” *Food Quality and Preference*, *45*, 58–69.

Wen, B., Horlings, E., van der Zouwen, M., & van den Besselaar, P. (2017). Mapping Science Through Bibliometric Triangulation: An Experimental Approach Applied to Water Research. *Journal of The Association for Information Science and Technology*, *68*(3), 724–738.

Zhao, B., Zhang, Z., Qian, W., & Zhou, A. (2013). Identification of collective viewpoints on microblogs. *Data and Knowledge Engineering*, *87*, 374–393.

Chapter 2

Oral processing and dynamics of texture perception in commercial gluten-free breads

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ABSTRACT

There is an increasing demand for gluten-free products, with the texture being a critical aspect. The aim of this work was to study the food bolus properties of gluten-free breads in relation to the dynamics of sensations perceived during its consumption. In this study, five-commercial gluten-free breads and two regular breads were analysed for their texture, crumb structure, and moisture content. Bread bolus particle size after three chews, bolus characteristics at the swallowing point, and oral activity were determined. The dynamics of textural sensations during bread consumption was evaluated using the temporal dominance of sensations (TDS) technique. Texture and structure properties vary among gluten-free breads being some of them close to regular breads (crumb with more and smaller cells that shows low hardness and high springiness) that lead to different in-mouth breakdown and TDS patterns. At the beginning, harder breads with low springiness values resulted in hard dominant sensations, in contrast, breads with low hardness and high springiness values were perceived soft and spongy. Breads that fragmented into a greater number of small size particles created crumbly and sandy sensations, characteristic of gluten-free breads with large air cell sizes. Compact sensation appeared in breads with low saliva uptake during bolus formation, while pasty and sticky sensations were related to a cohesive and adhesive bolus, respectively. Not only structure and mechanical properties, but also its oral behaviour in terms of fragmentation and bolus formation can fully explain the dynamics of texture perception of gluten-free breads.

Keywords: Gluten-free bread, Texture, Bolus properties, Dynamic sensations.

1. INTRODUCTION

Over the last decade, there has been a growing demand for commercial gluten-free products, resulting from the increase in the detection of different gluten-related disorders including coeliac disease, wheat allergy, non-coeliac gluten sensitivity (Henggeler, Veríssimo, & Ramos, 2017; Sapone et al., 2012), and the wrongful conviction that a gluten-free diet is healthy (Christoph, Larson, Hootman, Miller, & Neumark-Sztainer, 2018; Gaesser & Angadi, 2012). Gluten present in wheat, rye, spelt, triticale, kamut, and some oat varieties, is the main structure-forming protein complex of dough and bread, providing characteristic viscoelastic properties of bread and bakery goods. The absence of gluten has a key impact on bread organoleptic characteristics, leading to poor mouthfeel and flavour (Lazaridou, Duta, Papageorgiou, Belc, & Biliaderis, 2007; Matos & Rosell, 2014; Naqash, Gani, Gani, & Masoodi, 2017; Tsatsaragkou, Protonotariou, & Mandala, 2016; Molina-Rosell, 2013). Therefore, studies have achieved products that resemble their gluten-containing counterparts by incorporating functional ingredients such as starches, hydrocolloids, proteins, and fibres, while also applying different technological processes (Capriles & Arêas, 2014; Diowksz, Sucharzewska, & Ambroziak, 2009; Houben, Höchstötter, & Becker, 2012; Korus, Witczak, Ziobro, & Juszczak, 2009; Martínez, Díaz, & Gómez, 2014).

Strategies to modify or improve texture attributes has focused on the product characteristics (structural or instrumental texture); however, a recent approach, based on the knowledge of product behaviour in the mouth (oral processing) to better understand the mechanisms of texture perception, is gaining interest from new food products developers and researchers. During oral processing, food structures are broken down to form a bolus suitable for swallowing. Fragmentation, agglomeration, hydration, and lubrication take place (De Wijk, Engelen, Prinz, & Weenen, 2003; Hoebler et al., 1998; Lucas, Prinz, Agrawal, & Bruce, 2002; Witt & Stokes, 2015) and contribute to the sensory sensations perceived in the mouth; like texture perception, a complex and dynamic process

(Devezeaux de Lavergne, van de Velde, & Stieger, 2017; Hutchings & Lillford, 1988).

Authors have developed methods for evaluating the various aspects involved in food oral processing (fragmentation, oral activity, bolus composition, and bolus mechanical properties). These approaches are different depending on the food properties (Tournier et al., 2017) and some have been developed or adapted for bread. To measure oral bread fragmentation, bolus particle size distribution has been analysed using image analysis or laser di ffraction techniques (Gao, Wong, Lim, Henry, & Zhou, 2015; Hoebler et al., 1998; Jourdren, Panouillé, et al., 2016; Jourdren, Saint-Eve, et al., 2016; Le Bleis, Chaunier, Della Valle, Panouillé, & Réguerre, 2013). To evaluate the bolus mechanical properties, different rheological techniques (capillary rheology, and viscoelasticity) and empirical methods like double compression or penetration tests, have been proposed (Assad-Bustillos, Tournier, Septier, Della Valle, & Feron, 2019; Gao, Wong, Lim, Henry, & Zhou, 2015; Jourdren et al., 2016; Le Bleis, Chaunier, Della Valle, Panouillé, & Réguerre, 2013; Panouillé, Saint-Eve, Déléris, Le Bleis, & Souchon, 2014; Peyron et al., 2011; Young, Cheong, Hedderley, Morgenstern, & James, 2013). This wide variety of small and large deformation measurements shows how difficult it is to characterise the breads' bolus. Furthermore, previous authors have measured the moisture and saliva incorporation during consumption of breads from expectorated bolus (Gao, Tay, Koh, & Zhou, 2018; Gao, Wong, Lim, Henry, & Zhou, 2015; Le Bleis, Chaunier, Montigaud, & Della Valle, 2016; Motoi, Morgenstern, Hedderley, Wilson, & Balita, 2013; Panouillé, Saint-Eve, Déléris, Le Bleis, & Souchon, 2014; Tournier, Grass, Septier, Bertrand, & Salles, 2014).

Sensations perceived during food consumption vary continuously because of the breakdown of food structure and the progressive changes in bolus characteristics, releasing stimuli of different sensations. To capture the sensations along the mastication process, different dynamic sensory methodologies have been used, such as Time Intensity (TI), Progressive Pro filing (PP), and TDS. The latter is the only method that registers the sensations that dominate during eating (Di Monaco, Su, Masi, & Cavella, 2014; Pineau et al., 2009; Wang & Chen, 2017).

TDS has been widely used to assess the temporality of sensations perceived in bread consumption (Gao, Ong, Henry, & Zhou, 2017; Gao, Tay, Koh, & Zhou, 2018; Jourdren, Panouillé, et al., 2016; Jourdren, Saint-Eve, et al., 2016; Panouillé, Saint-Eve, Déléris, Le Bleis, & Souchon, 2014). Authors have evaluated how bread properties affect bolus formation in mouth and the sensations perceived during mastication. Panouillé et al. (2014), found that with the same salt content, different crumb density (obtained by lowering the time of kneading and baking) resulted in a different sensory perception sequence (lighter crumb: chewy and aerated; denser crumb: dense and soft), different mastication time (denser crumbs: less time), and saltiness perception (denser crumbs: less saltiness perceived). Gao et al. (2017) studied how, in breads with different crust hardness and crumb structure (western baked bread, oriental steamed bread, and French baguette), oral processing performance (muscle activity and chewing rhythm), and texture perception were affected. The authors found that in breads with a hard crust, chewing effort increased and had a different sensations sequence than those with soft crusts. At the beginning of oral processing, the dominant attributes of breads with hard crusts were crunchy and chewy while steamed breads' initial dominant attribute was stickier. It should be noticed that these conclusions are valid when serving volume is kept constant across samples but not for experiments where mass is kept constant and volume varies (Tournier et al., 2014).

To the best of the authors' knowledge here, this approach has not been applied to gluten-free breads. Therefore, the present study aims to describe the oral trajectory (fragmentation and bolus properties) of gluten-free commercial breads in relation to the dynamics of sensations perceived during its consumption, to better understand the factors involved in the perception of different texture sensations.

2. MATERIALS AND METHODS

2.1. Bread samples

Seven commercial sliced bread samples were selected. Five of them were gluten-free breads (A, B, C, D, and E) and the other two were regular breads, containing gluten (G1 and G2). Breads were purchased at the same time in a local supermarket and stored at −20 °C. The day before analysis, the breads were thawed to 4 °C and tempered to ~25 °C prior to the tests. Table 1 shows the ingredients and nutrition facts of each bread.

Table 1. Ingredients and nutritional facts of the commercial bread samples in the study according to the information on the label / package.

Bread	Ingredients	Energy (kcal)	Total fat (g)	Saturated fat (g)	Total carbo-hydrate (g)	Fibre (g)	Protein (g)
A	Water, sourdough (rice flour, water), corn starch, rice syrup, high oleic sunflower oil, rice starch, tapioca starch, vegetable fibres (psyllium, bamboo), potato protein, thickener (hydroxypropylmethyl cellulose), sugar, yeast, salt, preservatives (sorbic acid, calcium propionate).	267	5.3	0.6	60.0	N/A	3.1
B	Water, potato starch, corn starch, refined sunflower oil, tapioca starch, egg white powder, rice bran, sugar, stabilizers (E-466, E-464, E-422, E-415), yeast, thickener (cellulose), salt, wine vinegar, preservatives (E-200, E-202, E-282), aroma	272	11.0	1.1	28.0	11.5	5.0

Table 1. Ingredients and nutritional facts of the commercial bread samples in the study according to the information on the label / package (Continued).

Bread	Ingredients	Energy (kcal)	Total fat (g)	Saturated fat (g)	Total carbo-hydrate (g)	Fibre (g)	Protein (g)
C	Corn starch, water, sugar, pasteurised liquid egg, margarine, yeast, thickener (xanthan gum), emulsifier (monoacetyl and diacetyl tartaric esters of monoglycerides and diglycerides of fatty acids), salt, preservative (sodium propionate), antioxidant (ascorbic acid), gasifiers (diphosphate disodium, sodium bicarbonate)	283	5.9	3.2	53.0	5.4	1.7
D	Water, corn starch, margarine , sugar, tapioca starch, rice flour, yeast, thickener (xanthan gum), emulsifier (monoacetyl and diacetyl tartaric esters of monoglycerides and fatty acid diglycerides), rice fibre, salt, preservative (sodium propionate), gasifiers (disodium diphosphate, sodium bicarbonate), antioxidant (ascorbic acid)	295	9.9	4.9	47.0	5.5	1.6
E	Corn starch, water, sourdough (rice flour, water), rice starch, rice syrup, vegetable fibre (psyllium), sunflower oil, millet flour, soy protein, flour quinoa, thickener, yeast, salt, honey	239	3.4	0.5	45.0	7.3	3.5
G1	Wheat flour, water, yeast, sugar, sunflower oil, salt, vinegar, bean flour, emulsifiers (E-472e, E-471), acidity corrector (E-341iii), antioxidant (E-300), preservatives (E-282, E-202).	255	2.2	0.5	48.0	3.5	9.0
G2	Wheat flour, water, yeast, vegetable oil (sunflower), conservative salts (E-282, E-200), emulsifiers(E-481, E-471), wine, vinegar, corn treatment agent for the flour (E-300, E-341)	252	1.9	0.5	49.0	2.9	9.4

N/A: data not available.

2.2. Bread characterisation

2.2.1. Internal structure of bread crumb

The internal crumb structure of commercial breads was studied by digital image analysis. Bread slices were digitised in TIF format at 600 ppi on a scanner (Canon MP270 model K.10339, NY., USA) using a black background. Images of the bread slices were analysed using NisElements® BR 3.2 software (Nikon, Tokyo, Japan). The image was first binarised from a 5 × 5 cm2 square at the centre of slice, defined as the region of interest; three parameters were measured: cell density, cell size, and crumb air area fraction. Cell density corresponded to the number of air cells per cm2 of crumb. Cell size corresponded to the mean of air cells areas (mm^2). Air area fraction (%) corresponded to the percentage of crumb area occupied by air cells. For each bread, six replicates were performed.

Crumb density was calculated from the volume and weight of the serving sample.

2.2.2. Instrumental texture of bread crumb

Bread crumb hardness and springiness were determined using a TAXT plus Texture Analyser equipped with Exponent software v.6 (Stable Micro Systems Ltd, Godalming, UK), using an aluminium cylindrical probe with a 35 mm diameter.

Two slices of bread were subjected to a double compress test with a 2 s waiting time between the two cycles, performing a 40% compression at 1 mm/s with a trigger force of 0.196 N. Hardness of the bread samples was determined at 5 mm of distance during the first compression. Springiness was obtained by calculating the ratio between the distance to the maximum peak force of the second compression and the distance to the maximum peak force of the first compression. The analyses were performed in triplicate for each bread.

2.2.3. Moisture of bread crumb

Moisture content of the breads was determined by a gravimetric method. Approximately 4 g of crumb were weighed, thoroughly mixed with 8 g of sand, which facilitated the even evaporation of moisture, and dried to a constant weight in an oven at 105 °C. Moisture content was expressed as g of water/100 g of bread crumb (wet basis). The analyses were performed in triplicate for each bread.

2.3. Bolus collection

2.3.1. Served samples

Cylinders from the central part of the bread slices were obtained with a metallic puncher (d = 3.2 cm). Samples served to participants comprised two stacked cylinders, resembling the consumption of a sandwich, with a total height of 2.4 ± 0.1 cm. Sample sizes had been previously established to allow consumption in one bite. Because of differences among bread densities, the weights varied from 2.9 ± 0.1 to 5.1 ± 0.4 g.

2.3.2. Procedure

Six subjects (four females and two males) from the 19, participating in the sensory evaluation, were recruited for this part of the study. Bread boluses were collected, after three chewing cycles, for particle size analysis and at swallowing point, for moisture and mechanical properties measurement.

Each participant was asked to eat the bread sample as usual and then spit the bolus out into a plastic cup, either after three chewing cycles or after full mastication, when they felt the need to swallow. Bread samples were presented monadically following William’s design in a different order across participants, on plastic plates labelled with three-digit codes.

For each subject, one bolus per sample was collected in each session. Boluses for the three tests (particle size analysis, moisture, and mechanical properties) were obtained considering three replicates over nine separate sessions.

2.4. Particle size analysis of bolus after three chewing cycles

Each bolus collected after three chewing cycles was spread out on a transparent glass surface (30 × 21 cm). Particles were carefully and manually separated from each another with thin wooden sticks and digitised in TIF format at 600 pixels per inch (42.33 µm) on a scanner (Canon MP270 model K.10339, NY., USA), using a black background. Images obtained from bolus particles were analysed using NisElements® BR 3.2 software (Nikon, Tokyo, Japan) and binarised using a histogram-based segmentation process, according to the pre-defined intensity threshold values. Particle size distribution and the number of particles were obtained for each bread and subject. The median particle area (a50), which is the particle area corresponding to 50% of total area occupied by particles, was calculated. For each subject, three boluses of each sample were collected over three different sessions.

2.5. Bolus characterisation at swallowing point

2.5.1. Moisture

Moisture content of each bolus at the swallowing point was gravimetrically determined. Approximately 5 g of bolus was weighed, thoroughly mixed with 10 g of sand, which facilitated the even evaporation of moisture, and dried to a constant weight in an oven at 105 °C. The moisture content was expressed as g of water/100 g bolus.

The saliva uptake was calculated as the difference between the water content of the bread samples (%) and the water content from the expectorated bolus (%). For each participant, three boluses of each sample were collected over three different sessions.

2.5.2. Mechanical properties

Consistency and adhesiveness of boluses obtained at swallowing point were determined using a TA.XT plus Texture Analyser (Stable Micro System, UK), fitted with a TTC Spreadability Rig containing a male cone (90° and 40 mm diameter) that matches a glass containing the female cone fixed in an HDP/90 platform. The bolus was placed into the female cone and carefully levelled. The force when penetrating the sample with the male cone at a constant rate of 2 mm/s until a depth of 28 mm was recorded.

From the force–displacement curves, consistency values corresponded to the maximum peak force during the downstroke (N.s). Adhesiveness value (N.s) corresponded to the area under the curve during rising the probe (negative area). For each subject, three boluses of each sample were collected over three different sessions. Measurements were performed at room temperature.

2.6. Sensory evaluation

Nineteen participants performed the sensory evaluation of the bread samples. Sensations perceived during consumption were assessed using the TDS method, focusing only on texture sensations.

Three preliminary sessions were conducted. In the first session, assessors generated, individually, a list of texture attributes based on the comparisons among the bread samples. In the second session, terms and descriptions of the sensations were discussed among assessors. A final list of nine attributes and definitions obtained by consensus is shown in Table 2. Furthermore, assessors were introduced to the notion of the TDS technique and the concept of the dominant sensation as the most salient or the attribute that captures their attention. In the third session, assessors evaluated samples of bread (not included in the study) to familiarise themselves with the TDS test.

Table 2. List of sensory attributes and definitions used for the TDS assessment of breads.

Attribute	Definition
Hard	Sensation that describes the resistance to being deformed by teeth during chewing.
Compact	The bread has a tight or little porous structure.
Soft	The bread has a tender texture, easy to crush when chewing.
Crumbly	The bread is easy to disaggregate in crumbs and breaks down rapidly.
Pasty	Sensation that describes the formation of a dough of the bolus.
Dry	Sensation that describes the absence of moisture in mouth when chewing and the difficulty to moisturise the bread.
Spongy	The bread has a light and porous structure.
Sticky	Sensation that describes the adhesion of the bolus to teeth and oral cavity during chewing.
Sandy	Sensation that describes the presence of particles in oral cavity which tend to scratch the tongue and throat.

For the evaluation sessions, samples were served as described in Section 2.3. Each participant was asked to introduce the whole sample into the mouth and click the “start” button on the screen at the same time they started chewing. During sample consumption, participants had to select the dominant sensation at each moment from a list of nine attributes. They were instructed to stop the test when they did not perceive any further sensation in the mouth. The order of attributes on the list varied (randomly) among assessors, but for each assessor the same order was kept across the different samples. Bread samples were presented monadically following the William’s design but in a different order across participants, on plastic plates labelled with three-digit codes. A dummy sample was always served first, to eliminate first-position bias. In all the experiments, participants could rest between samples and were provided with still mineral water for rinsing. For each sample, participants performed three replicates of the TDS test in three separate sessions. The assessments took place in a temperature-controlled room under white light and in standard sensory booths, designed according to ISO 8589 (ISO, 2007). Data were collected by using Compusense Cloud (Compusense Inc., Guelph, Canada).

2.7. Chewing and swallowing events

The same 19 participants took part in the chewing and swallowing events assessment. Sample presentation was performed as described in Section 2.3.1.

Participants were instructed to eat the bread sample, while at the same time indicate when each swallow occurred and the end of chewing happened using a temporal question with Compusense Cloud software (Compusense Inc., Guelph, Canada). From the data the number of swallows, first swallow, and chewing times were obtained.

For accuracy of the chewing and swallowing time, participants were instructed to place the entire sample in the mouth and click the software “start” button at the same time they started chewing. Three replicate assessments were performed over three separate sessions.

2.8. Statistical analysis

For moisture content, the internal structure, and instrumental texture parameters of breads one-way analysis of variance (ANOVA) was applied. Fisher’s least significant difference (LSD) was calculated to assess significant differences among samples ($\alpha < 0.05$).

For parameters of bolus characterisation, chewing and swallowing activity mixed ANOVAs with the bread as a fixed factor and the participant as a random factor were applied. Fisher’s LSD was calculated to assess significant differences among breads ($\alpha < 0.05$).

For the TDS data, the percentage of participants who selected one attribute as dominant at a specific time, was calculated per attribute for each product and time. The TDS curves representing the dominance rate for each of the sensations at different points of the chewing time, for a sample across participants, were obtained. According to Pineau et al. (2009), two limits can be included on graphs, representing the variations of the dominance rate with time. The chance limit represented the dominance rate that an attribute can be obtained by chance. The significance limit expressed the smallest value of the proportion being significantly higher ($p < 0.05$) than the chance level, based on a binomial test. The data from TDS evaluation was normalised according to individual evaluation time on a scale from 0 (beginning of consumption) to 100% (end of perception), according to the method described by Lenfant et al. (2009). For each sample, the dominance area was calculated as the area under the curve of dominance rate versus time.

Multi-factor analysis was applied to the matrix containing each sample (rows) and the dominance area value for the different attributes (columns); three supplementary tables containing bread characteristics, bolus properties, and chewing activity were also included.

Statistical analyses were performed with XLSTAT statistical software (version 2017.6, Microsoft Excel®, Addinsoft, Paris, France).

3. RESULTS AND DISCUSSION

3.1. Structure, moisture, and instrumental texture of breads

Cell density, cell size, and air area fraction were obtained from 2D scanned images to compare the internal structure of the bread crumb and are presented in Table 3. ANOVA results show that the three parameters significantly vary among bread samples ($p < 0.001$). Although both cell density and size vary among gluten-free breads, in general all of them show a lower number of air cells but larger than in regular breads (Table 3).

Table 3. Mean values of internal structure parameters, density, moisture content, mechanical texture parameters and weight and volume of serving samples of gluten-free breads (A - E) and regular breads (G1, G2).

Bread	Cell density (cells /cm^2)	Cell size (mm^2)	Air area fraction* (%)	Bread density (g/cm^3)	Hardness (N)	Springiness	Moisture content (gH_2O/ 100g bread)
A	10.0 d	4.7 a	45.3 a	0.21 ab	6.9 b	0.89 cd	35.1 d
B	13.5 c	3.1 d	41.0 b	0.27 c	5.6 b	0.96 ab	39.5 b
C	11.2 d	3.8 bc	41.7 b	0.27 c	20.9 c	0.86 d	36.5 c
D	10.7 d	3.9 b	40.9 b	0.33 d	23.4 c	0.90 c	32.2 e
E	12.9 c	3.2 cd	41.1 b	0.24 bc	5.9 b	0.96 ab	39.9 b
G1	22.0 a	1.7 e	36.5 c	0.16 a	1.8 a	0.97 a	34.9 d
G2	19.4 b	2.1 e	40.4 b	0.24 bc	1.3 a	0.93 bc	44.7 a

Letters indicate significant differences according to Fisher´s LSD test ($\alpha = 0.05$). For each column, values not sharing a letter are different.
*It should be noticed that air area fraction calculated from 2D images can underestimate the air fraction as described by Zghal et al. 1999, Pa 2013.

Air area fraction varies less among samples, with two exceptions; gluten-free bread A, with a higher proportion of air in the crumb than the rest of samples, and the regular bread G1, with a lower proportion of air than the rest of samples. However, the air area fraction calculated here is probably lower than the real air area fraction. As described by previous authors (Zghal, Scanlon, & Sapirstein, 1999; Pa, Chin, Yusof, & Aziz, 2013), cell size observed at the surface (2D technique) is always smaller than the diameter of the real cell, and in addition, the intramural air of cells walls has not been considered.

Among all breads studied, G1 is the bread with the lowest density values and D, the highest. Regarding gluten-free breads, A is the least dense, and the density of the other breads (G2, B, C, and E) does not differ.

Both hardness and springiness values vary significantly among bread samples (Table 3). Regular breads (G1 and G2) are less hard than gluten-free samples. Within gluten-free samples, C and D are harder than A, B, and E. Regarding springiness, G1, B, and E are the springiest, while gluten-free samples A and C show the lowest levels. These results are comparable to previously reported values for homemade gluten-free breads with rice flour (springiness values ranging from 0.77 to 0.94) and commercial gluten breads (0.87–0.95) (Marco & Rosell, 2008). In bread, springiness was associated with freshness (Matos & Rosell, 2012). In contrast, breads with low springiness were related with crumb brittleness (McCarthy, Gallagher, Gormley, Schober, & Arendt, 2005).

Moisture content significantly varies among samples ($p < 0.001$) regardless of the bread type. The highest value of moisture content is for gluten-free bread D, and the least is for the regular bread sample G1.

In this study, bread characteristics (structure, texture, and moisture) varied between regular and gluten-free breads and among samples in each group. Establishing solid relationships between texture and structure characteristics is difficult here, because of using commercial samples (different formulations and processing conditions). According to Zghal et al. (1999) mechanical properties of these solid foams depends on density, cellular structure, and the intrinsic properties of the cell wall. As bread has a porous structure; the compression during instrumental texture, is dependent on the resistance exerted by the three dimensional structure of the solid foam created (Jekle et al., 2018). In experimental breads, when only one ingredient is changed, greater crumb density is translated to more solid material, requiring more force to compress (Collar et al., 2005). In this study, harder breads (C and D) are the denser, however breads with lower hardness do not have low density. For instance, G2 is the softest bread but had medium density value. However, those breads with low hardness (regular breads: G1 and G2) have a greater number of smaller cells showing different cell wall properties than gluten-free breads. Previous studies have shown the relevant contribution of cell wall thickness to the mechanical response of breads (Zghal et al., 1999). In this study, cell wall thickness was not determined, which could have provided a better understanding of texture from structure.

3.2. Bolus characterisation

3.2.1. Particle size distribution after three chewing cycles

To study fragmentation of breads during mastication, the particle size distribution of the bread after being chewed (three strokes) were analysed from the scanned image of boluses (examples of each bread can be found in Figure 1).

Figure 2 shows, for each bread sample, the percentage of area occupied by small (0.3–10 mm^2), medium-sized (10–100 mm^2), and large particles (> 100 mm^2). For regular bread samples (G1 and G2), almost the totality of the area (> 97.5%) is occupied by large particles > 100 mm^2. The same is seen for two gluten-free breads (B and E) where large particles account for the 93.5 and 97.6% of the total area, respectively. In these four breads, the small and medium particles are sparse. For breads A, C, and D, small and medium-sized particles occupy a greater area percentage, indicating a higher degree of fragmentation. For sample A, small and medium-sized particles represent 8.5 and 26.9% of the area. For samples C and D, fragmentation is higher, with small particles representing 23.4 and 16. 9% of the area and medium particles representing 40.1 and 35.3% of the area.

The mean area and number of the particles in boluses are obtained from the images (Figure 1), both parameters show significant differences among breads (Table 4). Boluses of regular breads G1 and G2 and gluten-free samples B and E have few particles (2.1–7.1) while for samples A, C, and D, the number of particles was much higher. Among these, the sample with the lowest number of particles was sample A (112.8), while sample D has the highest particle number (769.9). Mean area values also varied among samples, being significantly higher for bread samples G1, G2, and gluten-free E than for the rest of samples; while significantly lower for samples A, C, and D.

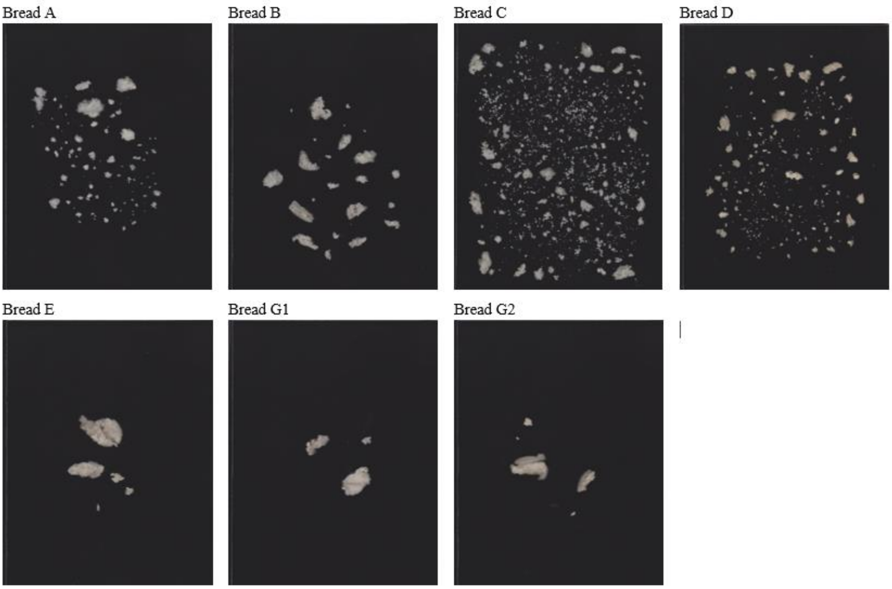

Figure 1. Example of particles obtained at three chewing cycles for each type of bread.

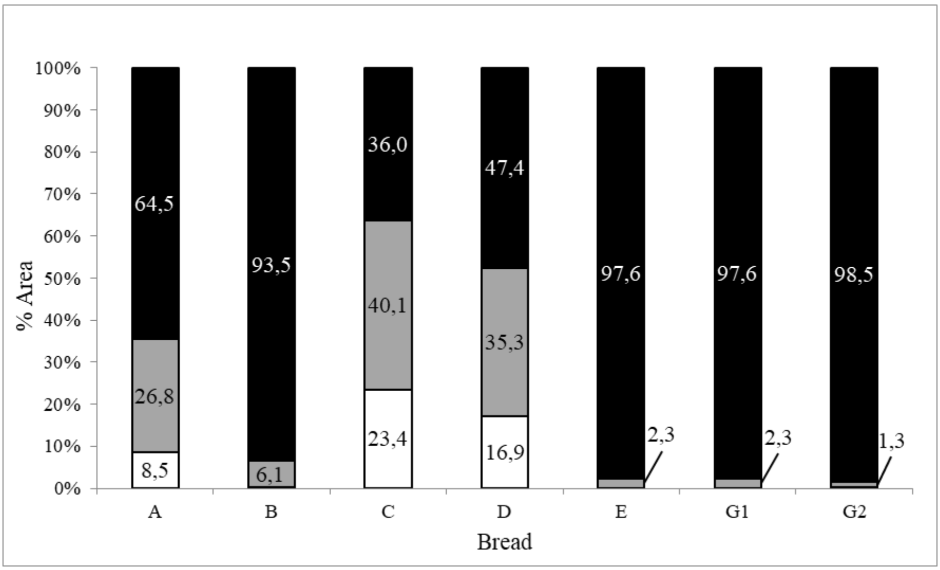

Figure 2. Particle size distribution of bolus after three chewing cycles. Percentage of area occupied by particles of size 0.3 - 10 (white), 10 - 100 (grey), and > 100 mm^2 (black).

This study shows different bread boluses after three chewing strokes. Gluten-free bread samples show high fragmentation, while sample group G1, G2, and E present boluses with two or three large particles. Previous authors, indicated that once fragile or soft solid foods are wetted for the saliva action and along mastication, the particle size distribution of boluses can reflect fragmentation and/or aggregation phenomena (Assad-Bustillos, Tournier, Septier, Della Valle, & Feron, 2019; Tournier, Grass, Septier, Bertrand, & Salles, 2014; Yven, Guessasma, Chaunier, Della Valle, & Salles, 2010). Using two alveolar structures (sponge cake and brioche), Assad-Bustillos et al. (2019) showed that the breakdown pattern was different for sponge cake, showing fragmentation, while brioche showed fragmentation and agglomeration. Therefore, boluses formed by few and large particles result from either a low fragmentation or a quick agglomeration of bread particles, that is the case of bread A, C and D. However, for the breads E, G1, G2, and to a lesser extent bread B, the bread material is maintained in mouth as a cohesive bolus and does not undergo a fragmentation status. It is possible, that in the gluten-free breads, A, C and D, the lack of gluten, that provides structure-building properties, made the structure of these breads crumblier (Gallagher et al., 2004), as observed in the Table 4.

Table 4. Mean values of the number and mean area of the particles in bolus obtained after three chewing cycles of gluten-free breads (A - E) and regular breads (G1, G2).

Bread	**Particles area (mm^2)**	**Particles number**
A	28.9 c	112.8 c
B	324.6 b	7.1 d
C	7.7 c	769.9 a
D	12.8 c	248.5 b
E	538.9 a	3.2 d
G1	562.6 a	2.1 d
G2	557.5 a	2.8 d

Letters indicate significant differences according to Fisher´s LSD test (α = 0.05). For each column, values not sharing a letter are different.

3.2.2. Bolus at the swallowing point

Bolus properties at the swallowing point were studied by evaluating moisture content, hardness, and adhesiveness of the boluses of six subjects.

Bolus moisture content values significantly vary among the bread samples ($p < 0.001$, (Table 5)). The moisture content ranges from 52.9% for boluses of bread G2 to 58.7% for boluses of bread B. The range of variation in moisture content among bread boluses at the swallowing point is lower (4.8%) than the variation in moisture content among breads (12.5%), indicating that during oral processing, the amount of saliva incorporated compensates, in part, the initial differences in moisture among breads. This confirms that, to trigger the swallowing action, a bolus must have similar moisture content, independently from the initial product characteristics (Panouillé et al., 2014).

Table 5. Mean values of moisture content and mechanical properties of the bolus obtained at swallowing point when eating gluten-free breads (A - E) and regular breads (G1, G2).

Bread	Bolus moisture content (g/100g)	Saliva uptake (%)	Bolus consistency (N)	Bolus adhesiveness (N.s)
A	54.6 c	19.5 b	65.5 abcd	1.98 bc
B	58.7 a	19.2 b	52.4 cd	2.28 b
C	54.7 bc	18.1 b	85.3 a	1.68 c
D	53.7 cd	21.5 a	57.3 bcd	1.83 c
E	54.6 c	14.7 c	76.5 ab	2.81 a
G1	56.2 b	21.3 a	47.0 d	2.03 bc
G2	52.9 d	8.2 d	69.3 abc	3.19 a

Letters indicate significant differences according to Fisher´s LSD test ($\alpha = 0.05$). For each column, values not sharing a letter are different.

The amount of saliva incorporated was calculated as the difference between the water content (%) of boluses at swallowing point and the water content (%) of the bread sample (Table 5). The amount of saliva incorporated varies according to the initial moisture content of the product. Bread sample G2, with higher moisture content, incorporated less saliva in the bolus during mastication than the rest. Samples G1, D, and A, with low initial moisture, incorporate a higher amount of saliva during mastication. Previous research has shown comparable results of bolus moisture at swallowing point (Le Bleis, Chaunier, Montigaud, & Della Valle, 2016; Panouillé, Saint-Eve, Déléris, Le Bleis, & Souchon, 2014). This confirms, during mastication, saliva is incorporated to the bolus, reaching a critical moisture level, needed for a suitable swallowable bolus, not only for bread, but for most food products (Loret et al., 2011).

Consistency and adhesiveness values of bolus also significantly varies among bread samples ($p = 0.006$ and $p < 0.001$, respectively). Bolus of the regular bread G1 is less consistent, while bolus of glutenfree bread C is the most consistent. Consistency of bread bolus (Table 5) is not related to initial bread hardness (Table 3). Previous authors explained that bread bolus' mechanical properties are governed by their initial water content and initial water absorbing capacity (Jourdren et al., 2016). Evidently, the boluses with higher moisture content requires less force to be compressed. However, this pattern is not observed for all the samples of this study: the bolus of sample D presented low moisture content and has a lower hardness value than other samples, probably due to the presence of different hydrocolloids in each recipe. The variation in adhesiveness of bolus also relates to the initial water content. The regular bread G2 and gluten-free bread E, with higher moisture content than the rest, results in the most adhesive bolus, while gluten-free breads C and D, with lower moisture content, results in the least adhesive bolus.

3.2.3. Oral activity

The number of swallows, the time of the first swallow, and the total chewing time of subjects when eating the bread sample (Table 6) vary significantly among samples ($p = 0.009$, $p < 0.001$, and $p < 0.001$, respectively). These parameters vary depending on the bread. Overall, the number of swallowing events is smaller for regular bread A than gluten-free breads A, C, and D. For gluten-free breads, the first swallowing event occurs later and chewing time is longer than for the regular breads. Gluten-free breads require more time to be processed because, as previously reported, harder products usually require more chewing time to be broken and form, with the help of the saliva, a cohesive bolus (Engelen, Fontijn-Tekamp, & Van Der Bilt, 2005; Tournier, Grass, Septier, Bertrand, & Salles, 2014).

Besides the initial hardness of product there are other reported factors that influence the oral activity. Swallowing triggers when the bolus is safe and comfortable and this is usually related to its moisture level and hardness. In this study, bolus moisture content and consistency seem to explain the differences in chewing time among samples in each group of breads. For example, bread D has a high hardness value among gluten-free breads but the time of chewing is lower than the breads because it has a high saliva uptake, leading to a bolus of low consistency attained sooner in mouth that is perceived soft enough and needs no further chewing. Likewise, in sample G1, that had similar hardness values to sample G2, but the time of chewing was shorter. The amount of saliva incorporated in the bread was higher in G1, making the bolus softer and ready to swallow sooner than for G2.

Table 6. Mean values of oral activity of participants when eating the gluten-free breads (A - E) and the regular breads (G1, G2).

Bread	**Number of swallows**	**First swallow time (s)**	**Total chewing time (s)**
A	3.1 a	22.7 ab	30.1 ab
B	2.8 ab	20.8 abc	28.9 ab
C	2.9 ab	23.1 ab	32.2 a
D	3.0 a	22.5 ab	29.9 a
E	2.9 ab	24.9 a	35.3 a
G1	2.5 b	17.3 c	23.6 b
G2	2.8 ab	20.2 bc	27.5 ab

Letters indicate significant differences according to Fisher´s LSD test (α = 0.05). For each column, values not sharing a letter are different.

3.3. Sensory sensations perceived during bread consumption

3.3.1. Temporal dominance of sensations

TDS curves showing the dominance rate (agreement among assessors) of each sensation during eating time were obtained for gluten-free and regular breads (Figure 3). Standardised time was divided into three periods: initial (0–33%), intermediate (33–66%), and final (66–100%). Regular breads G1 and G2 display a similar sequence of dominant texture sensations along the consumption of breads in the following order: soft and spongy at the initial period, with an intermediate compact, then the final pasty and sticky sensations. Some differences are seen among the two breads, especially in the first period. The dominance rates for soft and spongy are higher with the sensation lasting longer in bread G1 than in G2, thus, a higher dominance rate for the compact sensation becomes dominant sooner and endures for longer.

Gluten-free breads show different TDS curves that can be summarised in three different patterns. The first, for gluten-free breads C and D at the beginning, hard and dry are the dominant sensations, then crumbly during the intermediate period, and finally sandy; pasty; and sticky. The second, for bread A, dry and crumbly are the dominant sensations up to the intermediate period. Then, the sandy sensation is significantly dominant from the beginning of the intermediate period and reaches its maximum value during the final period, together with sticky sensation. The third pattern, in gluten-free breads B and E, soft and spongy are dominant during the first and intermediate periods, the pasty during intermediate and final periods, and sticky sensation emerges at the end. The main differences among these breads (B and E) is the compact sensation was dominant in bread E (initial and intermediate periods) but not in bread B, thus, a higher dominance rate of spongy and soft sensations endured over time.

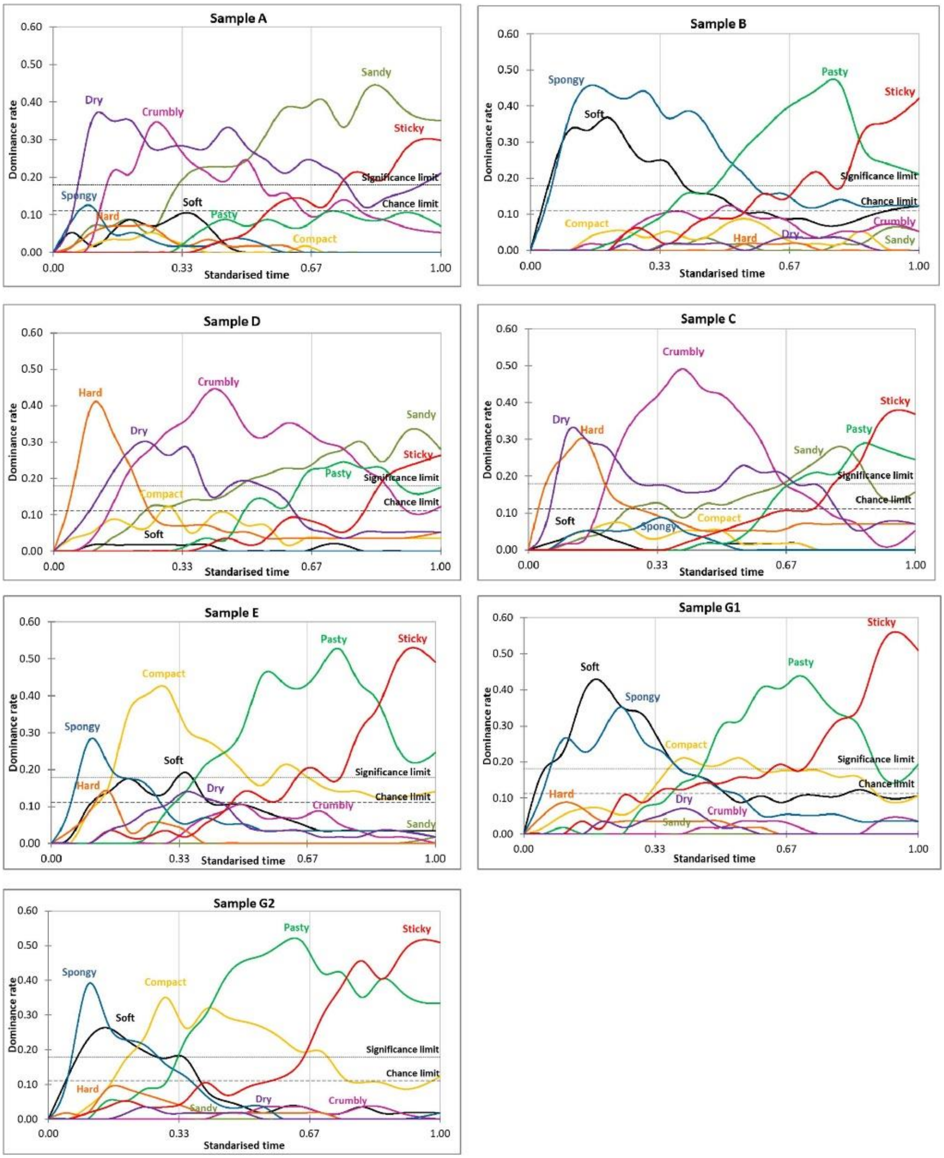

Figure 3. Normalised dominance curves of attributes (soft, spongy, sticky, pasty, compact, sandy, hard, dry, crumbly) obtained by TDS during consumption of the breads.

According to TDS plots, commercial gluten-free breads differ in the sensations that are elicited at different periods of consumption. Hard and soft sensations are mainly relevant for the initial period; while spongy, crumbly, dry, and compact are relevant during both the initial and intermediate periods. Sandy and pasty are sensations relevant during the intermediate and final periods, and the sticky sensation is relevant only during the final period. Two gluten-free breads (B and E) present a profile that was like regular breads (G1 and G2), with a higher dominance of soft and spongy sensations at the beginning, with pasty and adhesive sensations at the intermediate and final periods. However, the other gluten-free breads present very different profiles from regular breads (A, C, and D) with a higher dominance rate of hard or dry sensations at the beginning, crumbly at the intermediate period, and sandy at the end.

To understand the dynamic sensory perception of breads, TDS have been previously used with different breads types (Gao, Ong, Henry, & Zhou, 2017; Panouillé, Saint-Eve, Déléris, Le Bleis, & Souchon, 2014). Differences in bread properties provided different perceived sensations and different generated attributes for performing TDS. In breads with hard crust (baguette and baked bread), first sensations were associated with an initial perception of crunchy, while those without crust, initial sensations were associated with aerated, soft, and chewy (Gao et al., 2017). The intermediate sensations were related to crumb properties and moisture content, while the dominant attributes were dry, chewy, and dense, with sticky and hydrated appearing in all samples (Gao et al., 2017). In bread crumb with different fat content and processing time (kneading, fermentation, and baking), elicited sensations also differed, with more fat and aerated breads perceived with a similar pattern of the attributes dry, aerated, crumbly, and hydrated (Panouillé et al., 2014). In the present study, TDS technique has revealed differences among commercial gluten-free breads and compared to regular breads. Critical texture sensations on gluten-free breads have been identified such as hardness, dryness, crumbliness and sandiness sensations but also the lack of sponginess and pastiness.

3.3.2. Relationship between texture sensations, bolus properties, and oral activity during bread consumption

Differences in the dominance of texture sensations perceived among breads during the consumption and their relationship with the initial texture and structure of breads, the breakage pattern, and bolus characteristics were found via a multi-factorial analysis (MFA). Figure 4 shows the MFA plot where bread samples are distributed according to texture sensations (dominance area in TDS plot), bread characteristics, and oral trajectory parameters.

The first MFA dimension separated gluten-free samples A, C, and D (on the right) with a higher dominance of crumbly sensation, related to the number of particles generated during the first three chewing cycles. Among these samples, C and D are separated on the top with higher dominance of the hard sensation that was positively correlated with bread hardness, while sample A (at the bottom) was differentiated for the higher dominance of dry and sandy sensations, positively related to bread air cell size, yet negatively related to the size of particles in bolus. In contrast, in the other extreme of the first dimension, regular breads (G1 and G2) are found and the gluten-free samples B and E are close to them. These samples show higher dominance for sticky and pasty sensations than the rest of samples and sensations related to the size of bolus particles and adhesiveness. As it was observed in Section 3.3.1, the breakdown pattern (particle area and particle number) of these breads is similar, inducing similar sensations. Among these four samples, the second dimension separated samples G2 and E on the top, because of the higher dominance of compact sensation, that is inversely related to saliva uptake. While samples G1 and B (on the bottom) show a higher dominance for spongy and soft sensations, they are positively related with bread springiness and negatively related to bread hardness. Bread hardness and oral activity (total chewing time, first swallow time, and number of swallows) are related with samples C and D.

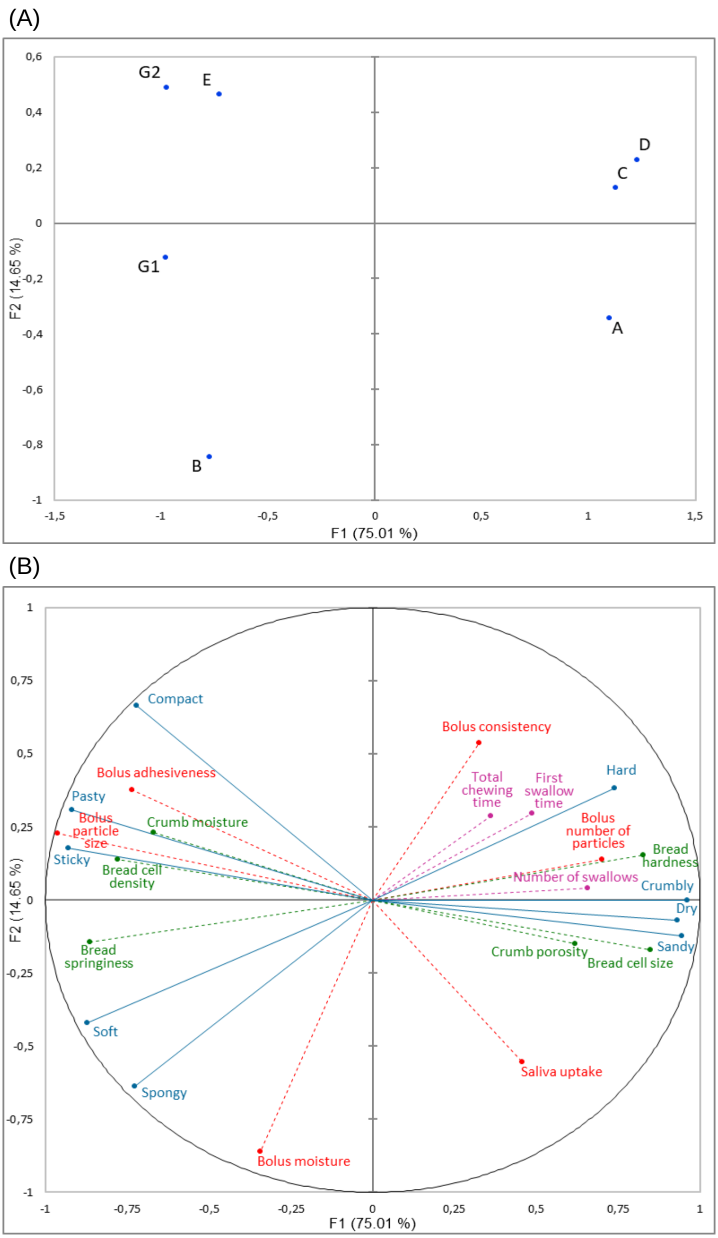

Figure 4. Multiple factor Analysis of the dominance area value for the different attributes. Bread characteristics, bolus properties, and chewing activity were included as supplementary variables. (A) Map of attributes (in blue) with supplementary variables (represented by dotted lines): bread characteristics (in green), bolus properties (in red) and chewing activity (in pink). (B) Map of samples.

Previous authors have proven that bread, perceived sensory characteristics are related to the structure fragmentation of bread and its brakeage pattern and bolus formation (Jourdren et al., 2016).

A limitation of this study, samples were commercial, and although they provide a realistic picture of breads (gluten-free and regular), factors such as formulation and processing conditions could impact results, as they are not controlled. Therefore, further studies including experimentally designed samples with controlled variability are needed. From a mechanical point of view, future studies including bread characterisation in 3D, cell wall thickness measurement, and microscopic disposition might also contribute to the structural understanding. For instance, X-ray computed tomography has been proposed as a non-destructive technique to studied the bread dough and baked bread (Schoeman, Williams, du Plessis, & Manley, 2016). This will allow validation of the proposed mechanisms of bread texture perception and determination of which formulation and bread-making factors are key for producing gluten-free breads with tailored texture characteristics.

Bread is a solid foam structure with two phases, air and cell wall material. The present study shows that in commercial breads, with and without gluten, there is a wide variation in bread structure. As it was briefly explained in the introduction, gluten is capable of retaining the air created during fermentation and baking, that also confers elastic and extensible properties to the bread (Khatkar et al., 1995). Our results show that bread structure and texture in regular breads (G1 and G2) is different, with lots of smaller cells and softer crumb, to gluten-free breads which contains fewer cells of bigger size, providing a harder structure. However, at mouth, these differences change, and regular breads G1 and G2, have similar bolus properties and provoke the same sensations than gluten-free breads B and E. This means that gluten-free breads B and E, despite having a different structure, have managed to mimic the oral behaviour of regular breads.

4. CONCLUSIONS

Commercial gluten-free breads with different structures and mechanical properties presented different oral trajectories (fragmentation, bolus formation, and oral activity) during its consumption. The sequence of texture sensations experienced during bread consumption also varied among commercial gluten-free breads. Sensations perceived at the beginning of bread consumption (hard, soft, spongy, and dry) were related to its structure and mechanical properties; however, the remaining sensations were mostly explained by oral trajectory features. Crumbly and sandy sensations were related to bread fragmentation in mouth, the compact sensation to the amount of saliva uptake, pasty sensation to a cohesive bolus (non fragmented), and sticky sensation to a bolus with high dominance of adhesiveness at the end of consumption.

In summary, this paper shows that when reformulating or improving gluten-free breads, strategies should take into account in-mouth behaviour of product, as its breakage pattern in presence of saliva and oral movements is crucial to modulate texture sensations. In the present work some of gluten-free breads showed similar behaviour to regular breads that seems to be achieved through including many different emulsifiers, thickeners and fat as the long list of ingredients for these breads. The challenge for the future is then to find alternatives (for example changing baking conditions) that allow obtaining breads with an in-mouth behaviour and texture sensations similar to gluten-containing breads.

REFERENCES

Aprodu, I., & Banu, I. (2015). Influence of dietary fiber, water, and glucose oxidase on rheological and baking properties of maize based gluten-free bread. *Food Science and Biotechnology*, *24*(4), 1301–1307.

Ashwini, A., Jyotsna, R., & Indrani, D. (2009). Effect of hydrocolloids and emulsifiers on the rheological, microstructural and quality characteristics of eggless cake. *Food Hydrocolloids*, *23*(3), 700–707.

Assad-Bustillos, M., Tournier, C., Septier, C., Della Valle, G., & Feron, G. (2019). Relationships of oral comfort perception and bolus properties in the elderly with salivary flow rate and oral health status for two soft cereal foods. *Food Research International*, *118*(September 2017), 13–21.

Capriles, V. D., & Arêas, J. A. G. (2014). Novel approaches in gluten-free breadmaking: Interface between food science, nutrition, and health. *Comprehensive Reviews in Food Science and Food Safety*, *13*(5), 871–890.

Cauvain, S. P., Whitworth, M. B., & Alava, J. M. (1999). The evolution of bubble structure in bread doughs and its effect on bread structure. In G. M. Campbell (Ed.), *Bubbles in food* (pp. 85–88). St. Paul, MN: American Association of Cereal Chemists.

Chin, N. L., Rahman, R. A., Hashim, D. M., & Kowng, S. Y. (2010). Palm oil shortening effects on baking performance of white bread. *Journal of Food Process Engineering*, *33*(3), 413–433.

Christoph, M. J., Larson, N., Hootman, K. C., Miller, J. M., & Neumark-Sztainer, D. (2018). Who values gluten-free? Dietary intake, behaviors, and sociodemographic characteristics of young adults who value gluten-free food. *Journal of the Academy of Nutrition and Dietetics*, *118*(8), 1389–1398.

Collar, C., Bollaín, C., & Angioloni, A. (2005). Significance of microbial transglutaminase on the sensory, mechanical and crumb grain pattern of enzyme supplemented fresh pan breads. *Journal of Food Engineering*, *70*(4), 479–488.

De Wijk, R. A., Engelen, L., Prinz, J. F., & Weenen, H. (2003). The influence of bite size and multiple bites on oral texture sensations. *Journal of Sensory Studies*, *18*(5), 423–435.

Devezeaux de Lavergne, M., van de Velde, F., & Stieger, M. (2017). Bolus matters: the influence of food oral breakdown on dynamic texture perception. *Food & Function*, *8*(2), 464–480.

Di Monaco, R., Su, C., Masi, P., & Cavella, S. (2014). Temporal dominance of sensations: A review. *Trends in Food Science and Technology*, *38*(2), 104–112.

Diowksz, A., Sucharzewska, D., & Ambroziak, W. (2009). Function of dietary fibre in forming functional properties of gluten free dough and bread. *Zywnosc. Nauka. Technologia. Jakosc/Food. Science Technology. Quality*, *16*, 83–93.

Engelen, L., Fontijn-Tekamp, A., & Van Der Bilt, A. (2005). The influence of product and oral characteristics on swallowing. *Archives of Oral Biology*, *50*(8), 739–746.

Gaesser, G. A., & Angadi, S. S. (2012). Gluten-free diet: Imprudent dietary advice for the general population? *Journal of the Academy of Nutrition and Dietetics*, *112*(9), 1330–1333.

Gallagher, E., Gormley, T. R., & Arendt, E. K. (2004). Recent advances in the formulation of gluten-free cereal-based products. *Trends in Food Science and Technology*, *15*(3–4), 143–152.

Gao, J., Ong, J. J. X., Henry, J., & Zhou, W. (2017). Physical breakdown of bread and its impact on texture perception: A dynamic perspective. *Food Quality and Preference*, *60*, 96–104.

Gao, J., Tay, S. L., Koh, A. H. S., & Zhou, W. (2018). Dough and bread making from high- and low-protein flours by vacuum mixing: Part 3. Oral processing of bread. *Journal of Cereal Science*, *79*, 408–417.

Gao, J., Wong, J. X., Lim, J. C. S., Henry, J., & Zhou, W. (2015). Influence of bread structure on human oral processing. *Journal of Food Engineering*, *167*, 147–155.

Hager, A. S., & Arendt, E. K. (2013). Influence of hydroxypropylmethylcellulose (HPMC), xanthan gum and their combination on loaf specific volume, crumb hardness and crumb grain characteristics of gluten-free breads based on rice, maize, teff and buckwheat. *Food Hydrocolloids*, *32*(1), 195–203.

Henggeler, J. C., Veríssimo, M., & Ramos, F. (2017). Non-coeliac gluten sensitivity: A review of the literature. *Trends in Food Science and Technology*, *66*, 84–92.

Hoebler, C., Karinthi, A., Devaux, M.-F. F., Guillon, F., Gallant, D. J., Bouchet, B., … Barry, J.-L. (1998). Physical and chemical transformations of cereal food during oral digestion in human subjects. *British Journal of Nutrition*, *80*(5), 429–436.

Houben, A., Höchstötter, A., & Becker, T. (2012). Possibilities to increase the quality in gluten-free bread production: An overview. *European Food Research and Technology*, *235*(2), 195–208.

Hutchings, J. B., & Lillford, P. J. (1988). The perception of food texture - The philosophy of the breakdown path. *Journal of Texture Studies*, *19*(2), 103–115.

Jekle, M., Fuchs, A., & Becker, T. (2018). A normalized texture profile analysis approach to evaluate firming kinetics of bread crumbs independent from its initial texture. *Journal of Cereal Science*, *81*, 147–152.

Jourdren, S., Panouillé, M., Saint-Eve, A., Déléris, I., Forest, D., Lejeune, P., & Souchon, I. (2016). Breakdown pathways during oral processing of different breads: impact of crumb and crust structures. *Food & Function*, *7*(3), 1446–1457.

Jourdren, S., Saint-Eve, A., Panouillé, M., Lejeune, P., Déléris, I., & Souchon, I. (2016). Respective impact of bread structure and oral processing on dynamic texture perceptions through statistical multiblock analysis. *Food Research International*, *87*, 142–151.

Khatkar, B. S., Bell, A. E., & Schofield, J. D. (1995). The dynamic rheological properties of glutens and gluten sub-fractions from wheats of good and poor bread making quality. Journal of Cereal Science, 22(1), 29-44.

Korus, J., Witczak, M., Ziobro, R., & Juszczak, L. (2009). The impact of resistant starch on characteristics of gluten-free dough and bread. *Food Hydrocolloids*, *23*(3), 988–995.

Lazaridou, A., Duta, D., Papageorgiou, M., Belc, N., & Biliaderis, C. G. (2007). Effects of hydrocolloids on dough rheology and bread quality parameters in gluten-free formulations. *Journal of Food Engineering*, *79*(3), 1033–1047.

Le Bleis, F., Chaunier, L., Della Valle, G., Panouillé, M., & Réguerre, A. L. (2013). Physical assessment of bread destructuration during chewing. *Food Research International*, *50*(1), 308–317.

Le Bleis, F., Chaunier, L., Montigaud, P., & Della Valle, G. (2016). Destructuration mechanisms of bread enriched with fibers during mastication. *Food Research International*, *80*, 1–11.

Lenfant, F., Loret, C., Pineau, N., Hartmann, C., & Martin, N. (2009). Perception of oral food breakdown. The concept of sensory trajectory. *Appetite*, *52*(3), 659–667.

Loret, C., Walter, M., Pineau, N., Peyron, M. A., Hartmann, C., & Martin, N. (2011). Physical and related sensory properties of a swallowable bolus. *Physiology and Behavior*, *104*(5), 855–864.

Lucas, P. W., Prinz, J. F., Agrawal, K. R., & Bruce, I. C. (2002). Food physics and oral physiology, *13*, 203–213.

Mancebo, C. M., San Miguel, M. Á., Martínez, M. M., & Gómez, M. (2015). Optimisation of rheological properties of gluten-free doughs with HPMC, psyllium and different levels of water. *Journal of Cereal Science*, *61*, 8–15.

Marco, C., & Rosell, C. M. (2008). Functional and rheological properties of protein enriched gluten free composite flours. *Journal of Food Engineering*, *88*(1), 94–103.

Martínez, M. M., Díaz, Á., & Gómez, M. (2014). Effect of different microstructural features of soluble and insoluble fibres on gluten-free dough rheology and bread-making. *Journal of Food Engineering*, *142*, 49–56.

Matos, M. E., & Rosell, C. M. (2012). Relationship between instrumental parameters and sensory characteristics in gluten-free breads. *European Food Research and Technology*, *235*(1), 107–117.

Matos, M. E., & Rosell, C. M. (2014). Understanding gluten-free dough for reaching breads with physical quality and nutritional balance. *Journal of the Science of Food and Agriculture*, *95*(4), 653–661.

McCarthy, D. F., Gallagher, E., Gormley, T. R., Schober, T. J., & Arendt, E. K. (2005). Application of response surface methodology in the development of gluten-free bread. *Cereal Chemistry*, *82*(5), 609–615.

Molina-Rosell, C. (2013). Alimentos sin gluten derivados de cereales. In L. Rodrigo & A. Peña (Eds.), *Enfermedad celíaca y sensibilidad al gluten no celíaca* (pp. 447–461). Barcelona, España: OmniaScience.

Morreale, F., Garzón, R., & Rosell, C. M. (2018). Understanding the role of hydrocolloids viscosity and hydration in developing gluten-free bread. A study with hydroxypropylmethylcellulose. *Food Hydrocolloids*, *77*.

Motoi, L., Morgenstern, M. P., Hedderley, D. I., Wilson, A. J., & Balita, S. (2013). Bolus moisture content of solid foods during mastication. *Journal of Texture Studies*, *44*(6), 468–479.

Naqash, F., Gani, A., Gani, A., & Masoodi, F. A. (2017). Gluten-free baking: Combating the challenges - A review. *Trends in Food Science and Technology*, *66*, 98–107.

Noorlaila, A., Hasanah, H. N., Asmeda, R., & Yusoff, A. (2018). The effects of xanthan gum and hydroxypropylmethylcellulose on physical properties of sponge cakes. *Journal of the Saudi Society of Agricultural Sciences*.

Pa, N. C., Chin, N. L., Yusof, Y. A., & Aziz, N. A. (2013). Measurement of bread crumb texture via imaging of its characteristics. Journal of Food, Agriculture and Environment (JFAE), 11(2), 48-55.

Panouillé, M., Saint-Eve, A., Déléris, I., Le Bleis, F., & Souchon, I. (2014). Oral processing and bolus properties drive the dynamics of salty and texture perceptions of bread. *Food Research International*, *62*, 238–246.

Peyron, M. A., Gierczynski, I., Hartmann, C., Loret, C., Dardevet, D., Martin, N., & Woda, A. (2011). Role of physical bolus properties as sensory inputs in the trigger of swallowing. PloS one, 6(6).

Phimolsiripol, Y., Mukprasirt, A., & Schoenlechner, R. (2012). Quality improvement of rice-based gluten-free bread using different dietary fibre fractions of rice bran. *Journal of Cereal Science*, *56*(2), 389–395.

Pineau, N., Schlich, P., Cordelle, S., Mathonnière, C., Issanchou, S., Imbert, A., … Köster, E. (2009). Temporal Dominance of Sensations: Construction of the TDS curves and comparison with time-intensity. *Food Quality and Preference*, *20*(6), 450–455.

Renzetti, S., & Arendt, E. K. (2009). Effect of protease treatment on the baking quality of brown rice bread: From textural and rheological properties to biochemistry and microstructure. *Journal of Cereal Science*, *50*(1), 22–28.

Sapone, A., Bai, J. C., Ciacci, C., Dolinsek, J., Green, P. H. R., Hadjivassiliou, M., … Fasano, A. (2012). Spectrum of gluten-related disorders: Consensus on new nomenclature and classification. *BMC Medicine*, *10*.

Schoeman, L., Williams, P., du Plessis, A., & Manley, M. (2016). X-ray micro-computed tomography (μCT) for non-destructive characterisation of food microstructure. Trends in Food Science & Technology, 47, 10-24.

Tournier, C., Devezeaux de Lavergne, M., van de Velde, F., Stieger, M., Salles, C., & Bertrand, D. (2017). Investigation of oral gels breakdown using image analysis. *Food Hydrocolloids*, *63*, 67–76.

Tournier, C., Grass, M., Septier, C., Bertrand, D., & Salles, C. (2014). The impact of mastication, salivation and food bolus formation on salt release during bread consumption. *Food & Function*, *5*(11), 2969–2980.

Tsatsaragkou, K., Protonotariou, S., & Mandala, I. (2016). Structural role of fibre addition to increase knowledge of non-gluten bread. *Journal of Cereal Science*, *67*, 58–67.

Wang, X., & Chen, J. (2017). Food oral processing: Recent developments and challenges. *Current Opinion in Colloid and Interface Science*, *28*, 22–30.

Witt, T., & Stokes, J. R. (2015). Physics of food structure breakdown and bolus formation during oral processing of hard and soft solids. *Current Opinion in Food Science*, *3*, 110–117.

Young, A. K., Cheong, J. N., Hedderley, D. I., Morgenstern, M. P., & James, B. J. (2013). Understanding the link between bolus properties and perceived texture. Journal of texture studies, 44(5), 376-386.

Yven, C., Guessasma, S., Chaunier, L., Della Valle, G., & Salles, C. (2010). The role of mechanical properties of brittle airy foods on the masticatory performance. *Journal of Food Engineering*, *101*(1), 85–91.

Zghal, M. C., Scanlon, M. G., & Sapirstein, H. D. (1999). Prediction of bread crumb density by digital image analysis. Cereal Chemistry, 76(5), 734-742.

Impact of gluten-free bread's structure on oral processing and sensory perception

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ABSTRACT

This work assessed oral processing and textural sensations perceived during consumption of gluten-free breads presenting different structure and mechanical properties, obtained by varying two baking conditions: the level of water hydration in dough and the fermentation time. Properties of bolus obtained from breads (after three chewing cycles and at swallowing point), subject's chewing and swallowing activities, and dynamics of texture sensations perceived were measured. Bolus from long fermented breads, which were less dense and presented a more open structure than short fermented breads, broke down in smaller particles during mastication. Before swallowing, bolus from long fermented breads were moister and softer than bolus obtained from short fermented breads, which presented higher values of consistency and adhesiveness. Breads with lower initial hydration, incorporated more amount of saliva during mastication to be swallowed. Short fermented breads required more chews, time and swallows for full oral processing. At the beginning of the mastication, short fermentation breads were perceived compact, whereas long fermentation, aerated. Independently of the formulation, all were perceived sticky. Thus, modifying bread structure using just changes in breadmaking conditions impacts not only on the initial mechanical properties of bread but also on its in-mouth behaviour, which represents an opportunity to modulate texture sensations in gluten-free breads.

Keywords: Gluten-free bread, Texture, Bolus characteristics, Oral Processing, Sensory properties

1. INTRODUCTION

The rise in coeliac disease diagnosis and its social awareness has expanded the gluten-free products available. For the food industry this represents a technical challenge, as gluten is the main structure-forming protein in baked goods (Espinosa-Ramírez, Garzón, Serna-Saldivar, & Rosell, 2018). Particularly in breads, the gluten matrix helps to retain the CO_2 produced in fermentation, forming a network that is responsible for the springiness, elasticity and cohesiveness of dough, as well as an open structure of crumb (Deora, Deswal, & Mishra, 2014). Gluten absence drastically affects bread characteristics, commonly resulting in low volume, a crumbly texture, pale colour, and poor flavour; thus, less quality than their gluten containing counterparts (Espinosa-Ramírez et al., 2018; Houben, Höchstötter, & Becker, 2012; Matos Segura & Rosell, 2011).

Commercial gluten-free-breads are characterised by an extensive list of ingredients, including acidifiers, emulsifiers, leavening agents, preservatives, and aromas or flavourings (Matos Segura & Rosell, 2011; Puerta et al., 2020). Additionally, because of consumer demand for a clean label breadmaking (Asioli et al., 2017), breadmaking conditions have been investigated as a novel approach to improve gluten-free bread characteristics, (Vallons, Ryan, & Arendt, 2011). For example, fermentation time has shown to increase volume and produce softer texture (Cao et al., 2020), a strategy, that although not tested in gluten-free breads could change and improve the gluten-free bread structure and texture. Another approach could be to change one of the main ingredients such as water. In a previous study, this altered the bread volume and the texture of gluten-free breads (Sahin, Wiertz, & Arendt, 2020).

However, for both approaches (changing conditions or reformulation), studies are mainly based on bread's mechanical properties (Cao et al., 2020; Morreale, Garzón, & Rosell, 2018; Sahin et al., 2020; Schober, Bean, Boyle, & Park, 2008; Ziobro, Witczak, Juszczak, & Korus, 2013) and/or final sensory properties (Armstrong, Luecke, & Bell, 2009; Morais, Cruz, Faria, & Bolini, 2014). But it is still pendent to know how this alter the in-mouth process and the sensations along the different stages of the mastication.

Food oral processing studies have shown how products behave in-mouth and can help us better understand and modulate sensations perceived during consumption of products (Chen, 2014; Jourdren, Saint-Eve, et al., 2016). Through food oral processing, the structure of foods is broken down by teeth and tongue comminution, dissolving components in saliva (Devezeaux de Lavergne, Van de Velde, & Stieger, 2017) until a swallowable bolus is formed. This transition of food to a swallowable bolus, through oral processing, can be characterised at several stages with rheology (hardness, cohesiveness, viscosity, tribology) (Jourdren, Panouillé, et al., 2016; Peyron et al., 2011) or particle size characterisation (Aleixandre, Benavent-Gil, & Rosell, 2019). Particle size characterisation also provides insight about the fragmentation pattern during mastication, by using sieving (Devezeaux de Lavergne, van de Velde, van Boekel, & Stieger, 2015; Van Der Bilt & Fontijn-Tekamp, 2004), or image analysis (Aleixandre et al., 2019; Rizo, Peña, Alarcon-Rojo, Fiszman, & Tárrega, 2018; Tournier, Grass, Zope, Salles, & Bertrand, 2012).

Additionally, to study the dynamics of perception during the full duration of the mastication process, different sensory dynamic techniques can be used, such as Time Intensity, Progressive Profiling, Temporal Check-All-That-Apply (TCATA) or Temporal Dominance of Sensations (TDS).

The TDS method allows a subject to select a dominant parameter from a list of attributes, providing the dynamics of sensations that dominate along eating time (Pineau et al., 2009). While in TCATA, each panellist can select and deselect the attributes that apply to the tested sample moment-to-moment (Castura, Antúnez, Giménez, & Ares, 2016). Both dynamic techniques have been used to further understand bolus formation and sensation in ham (Rizo et al., 2019), gels (Devezeaux de Lavergne, van de Velde, et al., 2015), and sausages (Devezeaux de Lavergne, Derks, Ketel, de Wijk, & Stieger, 2015). Furthermore, in breads, the TDS method has been used to link bolus formation and sensations along the mastication (Jourdren, Saint-Eve, et al., 2016; Panouillé, Saint-Eve, Déléris, Le Bleis, & Souchon, 2014).

Previous bread studies have investigated structural breakdown linked to perceived sensations, showing that, by only varying bread structure, the perception of salt changes, as a denser bread crumb is related to a less salty perception (Panouillé et al., 2014; Tournier, Grass, Septier, Bertrand, & Salles, 2014). Moreover, the initial bread structure is critical for gluten-free products, conditioning the textural sensations, the breakdown pattern in oral activity, and the perceived sensations (Puerta et al., 2020). Gluten-free breads with a greater number of smaller air cells in the crumb were less hard and springier than breads with few and bigger air cells. Gluten-free breads (with smaller air cells) were perceived as softer and spongier than breads with few air cells, perceived as hard breads (Puerta et al., 2020). Further, bread is usually consumed combined with other foods such as sauces (for example, gravy), or spreads (such as butter, cheese spread), which can also alter the breakdown pattern and thus, the oral behaviour, bolus properties, and sensory perception (van Eck, Fogliano, Galindo-Cuspinera, Scholten, & Stieger, 2019). Recent studies have shown how the addition of a sauce like mayonnaise facilitates the bolus formation (decreases the number of chewing cycles before swallowing), changing the perceived sensations, in special at the beginning of the oral processing (van Eck et al., 2020, 2019).

The objective of this work was to study how gluten-free breads with different crumb structure and mechanical properties, obtained by varying conditions in breadmaking (level of water hydration in dough and time of fermentation) impact on oral processing of breads during eating (breakdown pattern and bolus formation) as well as on sensory perception of texture.

2. MATERIALS AND METHODS

2.1. Bread samples

Four types of gluten-free breads prepared by specialised staff from the Institute of Agrochemistry and Food Technology (IATA-CSIC) were used for the study. These breads were based on rice flour and corn starch in a 70:30 blend ratio and formulations varied in water amount (85 and 100% of flour and starch blend) and fermentation time (30 and 75 minutes). The crumb of the breads obtained by combining both levels of water and fermentation time, H85F30, H85F75, H100F30, and H100F75, presented differences in their mechanical properties, density and structure and moisture. Crumb of breads fermented during longer time H85F75 and H100F75 were harder, less dense and contained a smaller number of air cells, which were higher in size than short fermented breads. Crumb moisture of breads with lower initial hydration level H85F30 and H85F75 was lower than in breads with higher hydration level.

2.2. Bread bolus characterisation

2.2.1. Samples and participants

Bread samples for bolus characterisation and sensory evaluation comprised a cylinder of the central part of the crumb (diameter = 3.3 cm; height = 2 cm) of the different formulated gluten-free breads (H100F30, H100F75, H85F30, and H85F75), discarding the end of loaves and crust. In all studies, samples were presented monadically following a William's design in a different order across subjects, in sealable plastic cups labelled with three-digit codes.

Eleven subjects (six women and five men, aged 22-39 years old, average 30.5) with healthy complete dentition participated in the study. They gave informed consent and received compensation for their participation. Participants could rest between samples and were provided with still mineral water for rinsing their palates in all the experiments.

2.2.2. Bolus collection procedure

Subjects were asked to place the entire sample in the mouth, chew it as usual, and spit the bolus out into the plastic cup; either after three chewing cycles for determining particle size characterisation or after full mastication, for determining bolus moisture and mechanical properties.

2.2.2.1. Particle characterisation after three chewing cycles

Each bolus collected was spread out manually on a transparent glass surface (30 × 21 cm). Particles were manually separated and digitised in TIF format at 600 ppi on a scanner (Canon MP270 model K.10339, Canon U.S.A. Inc. Lake Success, NY., USA) using a black background. Images were analysed using Nis-Elements® BR 3.2 software (Nikon, Tokyo, Japan). Sample images were binarised using a histogram-based segmentation process, according to the predefined intensity threshold value. Particle size distribution of the bolus collected from each subject after chewing each type of bread was obtained. The number of particles was obtained, and the median particle area (a50) that correspond to the size of particle when the 50% of total area is reached in the cumulative distribution was calculated. The median particle area (a50), which is the particle area corresponding to 50% of total area occupied, and the interquartile ratio (a75/a25) between 75 and 25% of the cumulative area occupied by particles were calculated. A cumulative curve of total area occupied by particles of assorted sizes was obtained. Two boli per sample and subject were collected over two separate sessions.

2.2.2.2. Bolus characterisation at swallowing point

Bolus moisture

Bolus moisture was determined in triplicate. Four grams of bolus were weighed, mixed with 8 g of sand, and dried to a constant weight in an oven at 105 °C for > 16 h. The difference in water content (g water / 100 g bolus) between the initial bread and bolus at swallowing point was calculated as an indicator of saliva uptake. Three boli were collected over three separate sessions from each participant.

Bolus mechanical properties

Mechanical properties of bolus at swallowing point were determined. Consistency and adhesiveness of the bolus were obtained with a TA.XT plus Texture Analyser (Stable Micro System, Godalming, UK) using a TTC Spreadability Rig. For the measurement, the bolus was placed into a female cone fixed in an HDP/90 platform and penetrated with a male cone (90º, 40 mm diameter) of the Spreadability Rig at a constant rate of 2 mm/s until reaching a 28 mm depth. The force required for penetrating the bolus was registered.

From the force-displacement curves, consistency values corresponded to the maximum peak force during the downstroke (N.s). Adhesiveness value (N.s) corresponded to the area under the curve while rising the probe (negative area). For each subject, three boli of each sample were collected over three different sessions. Six boli were collected over separate sessions from each participant.

2.3. Chewing and swallowing activity

Each subject was instructed to eat the bread cylinder in their usual manner while indicating the start of the test, and each of their swallows. This information was recorded using Compusense Cloud software (Compusense Inc., Guelph, Canada). From the data, the number of swallows, first swallow time, and chewing time were obtained. Participants were also recorded on video to visualise the chewing cycles count.

Three replicates per sample were performed in three separate sessions.

2.4. Sensory evaluation

Texture sensations perceived during consumption of the four bread samples were assessed by 11 subjects using the TDS method. Two previous sessions were held to establish the list of texture attributes. In the first session, each subject generated a list of attributes by comparing the different bread samples. A second session comprised a discussion and sample tasting to achieve, by consensus, a final list of attributes and their definitions. Table 1 shows the list of nine attributes and definitions. In addition, each panellist attended one session for familiarisation with the TDS.

Table 1. List of texture attributes (and definitions) used in the sensory evaluation of the gluten-free breads by TDS technique.

Attributes	**Definition**
Compact	The bread is hard to compress when chewing because it is dense.
Aerated	The bread is easy to compress, light.
Roughness	The bread scratches the internal surfaces of the mouth (palate, tongue, throat).
Crumbly	The bread disaggregates and breaks down in particles easily.
Bolus hard to form	Difficulty to aggregate or agglutinate the bread particles in a swallowable bolus, it is not cohesive.
Hard to swallow	Bread particles remain retained through the throat.
Gritty	Presence of particles in the mouth.
Sticky particles	Presence of bread particles adhered to oral mucosa that need to be removed with the tongue.
Dry	Bread that resulted difficult to moisturize/hydrated.

In the evaluation sessions, participants introduced the whole sample into the mouth and initiated the test while they pressed the "start" button and started chewing. They were asked to select the dominant sensation at each moment among the list of nine attributes while eating. They could select each attribute as often as they considered and until they stopped perceiving any sensation in the mouth.

The order of the attributes in the list was varied among participants according to a balanced design. Each panellist evaluated the four samples in each session. Six replicates were performed over six separate sessions. The serving size and sample presentation were as described in Section 2.2. The assessments took place in a temperature-controlled room under white light and in standard sensory booths, designed in accordance with ISO 8589 (ISO, 2007). Data collection from TDS tests and analysis were conducted using Compusense Cloud (Compusense Inc., Guelph, Canada).

Experimental procedure of this work was approved by the Ethical Committee of CSIC (ethics references 018/2019).

2.5. Statistical analysis

For each instrumental parameter of breads, a one-way analysis of variance (ANOVA) was applied. Tukey's test was used to assess significant differences ($\alpha = 0.05$) among samples.

Values of bolus characterisation after three chewing cycles and at swallowing point, as well as chewing and swallowing activity parameters showed a non-normal distribution according to the Shapiro-Wilks test, and showed heteroscedasticity according to Levene's test. Therefore, they were analysed by the non-parametric Friedman's test. Nemenyi's test was used to assess significant differences ($\alpha = 0.05$) among samples.

TDS curves representing the dominance rate for each sensation at various times of the chewing period were obtained for each bread. TDS data were normalised according to individual evaluation time on a scale from 0 to 100% of consumption. Both chance and significance limits were included in the graphs. The chance level represented the dominance rate of an attribute that can be obtained by chance (chance level, $P_0 = 1/9$, as there were 9 attributes), and significance level representing the minimum value significantly higher than the chance level (significant level = $P_s = P_0 + 1.645 \sqrt{[P_0(1 - P_0) / \text{number of replicates}]}$).

XLSTAT statistical software (Version 2010.5.01, Microsoft Excel®, Addinsoft, Paris, France) was used for the statistical analysis.

3. RESULTS

3.1. Bolus characterisation

3.1.1. Particle size distribution

The median particle area (a50) and interquartile ratio (a75/a25) after three chews are presented in Table 2. Significant differences ($P < 0.001$) were found among samples for both a50 and a75/a25 ratio parameters. Long fermentation breads (H85F75 and H100F75) generated more particles smaller than those obtained from short fermentation breads (H85F30 and H100F30), indicated by a50 values. Particles obtained from long fermentation breads presented lower a75/a25 ratio values, indicating that these breads fragmented into particles more homogeneous in size than short-fermented breads.

The cumulative curve of the total area occupied by particles (Figure 1) showed that for long fermentation breads, the area is occupied mostly by smaller particles, while for short-fermented breads, particles with bigger size indicating a heterogeneous pattern of fragmentation were present.

Table 2. Mean and standard deviation of the median particle area (a50) and interquartile ratio (a75/a25) between 75 and 25% of the cumulative area occupied by particles of bolus obtained after three chews of gluten-free breads (n=2).

Bread	**a50 (mm^2)**	**a75/a25**
H85F30	53.1 ± 4.7 b	7.4 ± 26.7 b
H85F75	24.8 ± 0.6 a	3.4 ± 8.4 a
H100F30	45.8 ± 4.1 b	6.6 ± 19.1 b
H100F75	27.9 ± 0.9 a	3.4 ± 7.3 a
Friedmans's Q	43.8	39.66
p-Value	<0.001	<0.001

Different letters within columns indicate significant differences among breads according to Nemenyi's test ($\alpha = 0.05$).

H85 and H100: addition of 85 or 100 g of water / 100 g of the flour and starch blend, respectively. F30 and F75: fermentation time of 30 or 75 minutes, respectively.

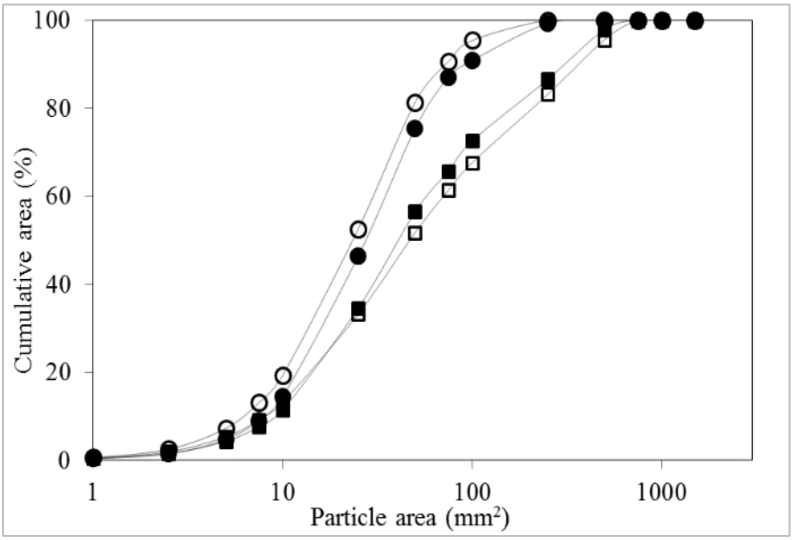

Figure 1. Cumulative curve representing the total area occupied by particles of bolus obtained after three chews of gluten-free breads H85F30 (-□-), H85F75 (-○-), H100F30 (-■-) and H100F75 (-●-).

H85 and H100: addition of 85 or 100 g of water/ 100 g of the flour and starch blend, respectively. F30 and F75: fermentation time of 30 or 75 minutes, respectively.

3.1.2. Moisture content of bolus at swallowing point

Table 3 shows the moisture of bolus, at swallowing and saliva uptake, for the four gluten-free breads. Bolus moisture at the swallowing point slightly varied (64.3-66.4 g water/100g bolus) among breads (P < 0.001); and significant differences were found between short-fermented bread (H85F30) and long-fermented breads (H85F75 and H100F75).

Saliva uptake significantly varied among bread samples (P < 0.001), being higher in low hydration breads (H85F30 and H85F75) than high hydration breads (H100F30 and H100F75). Particularly, the highest significant difference was found between H85F30 and H100F75 (15.5 and 13.2 g water/100 g bolus, respectively).

Table 3. Mean and standard deviation of the mechanical properties and moisture content of bolus obtained from gluten-free breads at swallowing point and saliva uptake values deviation (n=6 for mechanical properties and n=3 for bolus moisture and saliva uptake values).

Bread	**Bolus consistency (N)**	**Bolus adhesiveness (N.s)**	**Bolus moisture (g water / 100g bolus)**	**Saliva uptake (g water / 100g bolus)**
H85F30	10 ± 6 c	1.6 ± 0.9 c	64.30 ± 0.04 a	15.50 ± 0.04 bc
H85F75	7 ± 5 a	1.0 ± 1.4 a	65.80 ± 0.04 b	16.50 ± 0.04 c
H100F30	9 ± 5 bc	1.3 ± 0.7 b	65.50 ± 0.05 ab	13.20 ± 0.04 a
H100F75	8 ± 5 ab	1.1 ± 0.6 ab	66.40 ± 0.03 b	13.70 ± 0.03 ab
Friedmans's Q	41.16	45.49	19.07	29.62
p-Value	<0.001	<0.001	<0.001	<0.001

Different letters within columns indicate significant differences among breads according to Nemenyi's test (α = 0.05).

H85 and H100: addition of 85 or 100 g of water / 100 g of the flour and starch blend, respectively. F30 and F75: fermentation time of 30 or 75 minutes, respectively.

3.1.3. Mechanical properties of bolus at swallowing point

Consistency and adhesiveness values of bolus obtained at swallowing point were significantly different among bread samples ($P < 0.05$, Table 3). At the swallowing point, bolus from longer fermentation breads (H85F75 and H100F75) were less consistent bolus than shorter fermentation breads (H100F30 and H85F30). This effect was higher and only significant in low hydration breads (H85). Likewise, bolus adhesiveness varied with fermentation, long-fermented breads resulted in less adhesive boli than short-fermented breads, but this effect was only significant for low hydration breads.

3.2. Chewing and swallowing activity

Among breads, significant differences were found for the number of chewing cycles, swallows, time to the first swallow and total chewing time ($P < 0.005$, Table 4), because of the fermentation time.

Longer fermentation breads (H85F75 and H100F75) required a lower number of chews, swallows, time to first swallow, and chewing time than short-fermented breads (H85F30 and H100F30). The effects of fermentation time were more noticeable for low hydration breads.

Table 4. Mean and standard deviation values of the oral activity parameters (number of chewing cycles, number of swallows, time for first swallow and total chewing time) when consuming gluten-free breads, (n=3).

Bread	**Chewing cycles**	**Swallows**	**Time first swallow (s)**	**Total chewing time (s)**
H85F30	53 ± 18 b	5 ± 2 c	32 ± 7 b	59 ± 13 b
H85F75	38 ± 14 a	4 ± 2 a	24± 8 a	44 ± 12 a
H100F30	52± 16 b	5 ± 2 bc	32± 9 b	58 ± 14 b
H100F75	42± 14 a	4 ± 2 ab	27± 8 a	47 ± 12 a
Friedmans's Q	68.03	29.41	29.41	53.44
p-Value	<0.001	<0.001	<0.001	<0.001

Different letters within columns indicate significant differences among breads according to Nemenyi's test (α = 0.05).

H85 and H100: addition of 85 or 100 g of water / 100 g of the flour and starch blend, respectively. F30 and F75: fermentation time of 30 or 75 minutes, respectively.

3.3. Sensory evaluation

The TDS curves in Figure 2 show the fundamental differences among breads occurred at the beginning of the oral processing.

Initial sensations described by consumers when eating short-fermented breads were compact and dry, whereas aerated was the first sensation described in long-fermented breads. Immediately after, crumbly sensation appeared as dominant for all breads, but frequency of selection was higher in long than in short fermentation breads. Bolus hard to form and grittiness were the sensations with maximum frequency in the middle of consumption for all breads. Grittiness seemed more frequent in long fermentation breads. At the end of mastication, having a sticky particles sensation was dominant in all samples, lasting longer in short fermentation breads.

Among breads with different hydration level, no differences in the TDS were found.

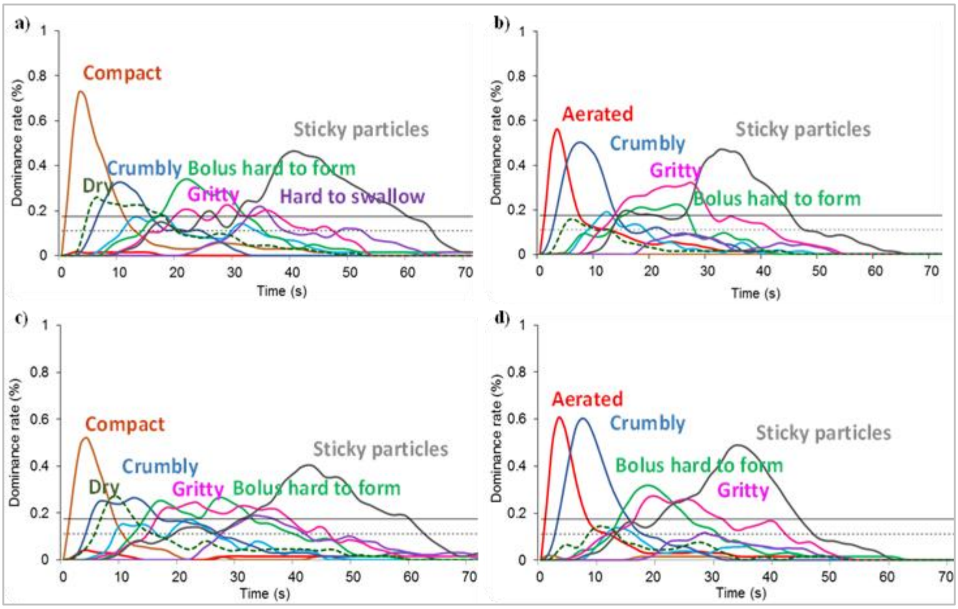

Figure 2. Dominance curves of attributes compact (—), aerated (—), roughness (—), crumbly (—), bolus hard to form (—), hard to swallow (—), gritty (—), sticky particles (—) and dry (—) obtained by TDS when consuming gluten-free breads: a) H85F30, b) H85F75, c) H100F30 and d) H100F75. Dotted black line indicates the chance level and solid black line, significance level.

H85 and H100: addition of 85 or 100 g of water/ 100 g of the flour and starch blend, respectively. F30 and F75: fermentation time of 30 or 75 minutes, respectively.

4. DISCUSSION

The gluten-free breads used in this study presenting different structure and mechanical properties, showed to affect in-mouth behaviour. During eating, chewing movements first aim to break down food. This breakage pattern was different among the gluten-free breads of this study. After three chews, breads with long fermentation broke easily into more homogeneous and smaller particles; as a lack of gluten in bread results in crumblier structures, because there is no gluten to provide a structural network (Espinosa-Ramírez et al., 2018). In our study, we showed that gluten absence and the processing can change the breakdown pattern, as longer fermentation time produced crumblier gluten-free breads. Furthermore, during eating, saliva is incorporated to foods until a safe and comfortable-to-swallow bolus is formed (Panouillé et al., 2014). At the end of the mastication, samples with lower initial hydration required more saliva incorporation, during mastication, to achieve the critical moisture level to swallow. Bolus consistency and adhesiveness were lower for long fermentation gluten-free bread bolus and higher for short fermentation and low hydration gluten-free bread bolus. Previous authors hypothesised that bolus' mechanical properties depend on the initial water content and absorbing capacity (Jourdren, Panouillé, et al., 2016). In this study, the initial hydration level and fermentation time influenced the structure and formation of bolus, because bread boli with short fermentation were more consistent and adhesive. The plasticiser role of water contributed to this behaviour, as bread de-structuration has been related to hydration and crumb fragmentation (Le Bleis, Chaunier, Montigaud, & Della Valle, 2016).

Oral activity also varied among the gluten-free breads studied. Short fermentation breads required more time and chews to form a swallowable bolus, because they were denser, harder and less breakable. This agrees with previous studies that showed dry and hard products required more chewing cycles and time to form a swallowable bolus (Tournier et al., 2012; Engelen, Fontijn-Tekamp, & Van Der Bilt, 2005).

At different times of the mastication process, the dynamics of sensations also varied among breads. These differences stand out at the beginning of the mastication, where longer fermented breads were perceived as more aerated and less dry, improving the sensory characteristics of gluten-free breads. As the mastication of the gluten-free breads progressed, all provided similar sensations. Previous studies have shown that at the beginning of the mastication the initial structure is still somewhat intact (Gao, Tay, Koh, & Zhou, 2018), having a higher impact on the sensory perception. In this study, these differences seem to be diluted as the mastication progressed, in contrast from previous studies with different commercial gluten-free breads, where sensations differed along mastication (Puerta et al., 2020). When comparing sensations of commercial gluten-free breads with structures similar to those of regular bread, authors observed perceptual changes at the beginning (soft and spongy vs. dry and crumbly), at the middle (compact vs. sandy), and at the end (pasty, sticky vs. sticky) of mastication (Puerta et al., 2020). The difference in perception between the commercial gluten-free breads and the breads of this study can be attributed to the diverse ingredients added in commercial gluten-free breads; for example, the flour; or starches blends; hydrocolloids, and fats. In this study, the recipe was kept constant and only breadmaking conditions were altered, but further investigation might be needed to improve the perceived texture sensations along the entire mastication process, not only at the beginning.

5. CONCLUSIONS

Four types of gluten-free breads with different structure and mechanical properties were obtained by varying the water hydration in dough and the time of fermentation. Both breadmaking conditions impacted on mechanical properties of the bolus formed during mastication, but only the time of fermentation impacted on in-mouth behaviour and dynamics of sensations perceived while eating the breads.

The study of oral processing of gluten-free breads has helped to understand the initial bolus formation, related with different sensations as compact or aerated. Furthermore, the dominant sensations were not discriminant, although the bolus had a different consistency before swallowing.

The implication of this study for the gluten-free bread industry is that baking conditions, such as fermentation time, can improve gluten-free bread's sensory characteristics regarding texture, creating more aerated sensations that are usually missed in gluten-free breads. However, further investigation, such as reformulation, might be needed to improve textural sensations along the entire mastication process.

REFERENCES

Aleixandre, A., Benavent-Gil, Y., & Rosell, C. M. (2019). Effect of bread structure and in vitro oral processing methods in bolus disintegration and glycemic index. *Nutrients*, *11*(9).

Ares, G., Jaeger, S. R., Antúnez, L., Vidal, L., Giménez, A., Coste, B., … Castura, J. C. (2015). Comparison of TCATA and TDS for dynamic sensory characterization of food products. *Food Research International*, *78*, 148–158.

Armstrong, L. M., Luecke, K. J., & Bell, L. N. (2009). Consumer evaluation of bakery product flavour as affected by incorporating the prebiotic tagatose. *International Journal of Food Science and Technology*, *44*(4), 815–819.

Asioli, D., Aschemann-Witzel, J., Caputo, V., Vecchio, R., Annunziata, A., Næs, T., & Varela, P. (2017). Making sense of the "clean label" trends: A review of consumer food choice behavior and discussion of industry implications. *Food Research International*, *99*(April), 58–71.

Cao, Y., Zhang, H., Yang, Z., Zhang, M., Guo, P., & Li, H. (2020). Influence of the fermentation time and potato pulp addition on the technological properties and volatile compounds of wheat dough and steamed bread. *LWT - Food Science and Technology, 128*, 109377.

Castura, J. C., Antúnez, L., Giménez, A., & Ares, G. (2016). Temporal Check-All-That-Apply (TCATA): A novel dynamic method for characterizing products. *Food Quality and Preference*, *47*, 79–90.

Chen, J. (2014). Food oral processing: Some important underpinning principles of eating and sensory perception. *Food Structure*, *1*(2), 91–105.

Deora, N. S., Deswal, A., & Mishra, H. N. (2014). Alternative Approaches Towards Gluten-Free Dough Development: Recent Trends. *Food Engineering Reviews*, *6*(3), 89–104.

Devezeaux de Lavergne, M., van de Velde, F., van Boekel, M. A. J. S., & Stieger, M. (2015). Dynamic texture perception and oral processing of semi-solid food gels: Part 2: Impact of breakdown behaviour on bolus properties and dynamic texture perception. *Food Hydrocolloids*, *49*, 61–72.

Devezeaux de Lavergne, M., Derks, J. A. M., Ketel, E. C., de Wijk, R. A., & Stieger, M. (2015). Eating behaviour explains differences between individuals in dynamic texture perception of sausages. *Food Quality and Preference, 41,* 189–200.

Devezeaux de Lavergne, M., Van de Velde, F., & Stieger, M. (2017). Bolus matters: the influence of food oral breakdown on dynamic texture perception. *Food & Function*, *8*(2), 464–480.

Espinosa-Ramírez, J., Garzon, R., Serna-Saldivar, S. O., & Rosell, C. M. (2018). Functional and nutritional replacement of gluten in gluten-free yeast-leavened breads by using β-conglycinin concentrate extracted from soybean flour. *Food Hydrocolloids*, *84*(May), 353–360.

Gao, J., Tay, S. L., Koh, A. H. S., & Zhou, W. (2018). Dough and bread making from high- and low-protein flours by vacuum mixing: Part 3. Oral processing of bread. *Journal of Cereal Science*, *79*, 408–417.

Hong, Y. E., & Kweon, M. (2020). Optimization of the formula and processing factors for gluten-free rice bread with tamarind gum. *Foods, 9*(2), 1–11.

Jourdren, S., Panouillé, M., Saint-Eve, A., Déléris, I., Forest, D., Lejeune, P., & Souchon, I. (2016). Breakdown pathways during oral processing of different breads: impact of crumb and crust structures. *Food Funct.*, *7*(3), 1446–1457.

Jourdren, S., Saint-Eve, A., Panouillé, M., Lejeune, P., Déléris, I., & Souchon, I. (2016). Respective impact of bread structure and oral processing on dynamic texture perceptions through statistical multiblock analysis. *Food Research International*, *87*, 142–151.

Le Bleis, F., Chaunier, L., Montigaud, P., & Della Valle, G. (2016). Destructuration mechanisms of bread enriched with fibers during mastication. *Food Research International*, *80*, 1–11.

Matos Segura, M. E., & Rosell, C. M. (2011). Chemical Composition and Starch Digestibility of Different Gluten-free Breads. *Plant Foods for Human Nutrition*, *66*(3), 224–230.

Morais, E. C., Cruz, A. G., Faria, J. A. F., & Bolini, H. M. A. (2014). Prebiotic gluten-free bread: Sensory profiling and drivers of liking. *LWT - Food Science and Technology*, *55*(1), 248–254.

Moreno Sandoval, L. G., Sánchez-Barriga, C., Buitrago, E. K., Pomares Quimbaya, A., & Garcia, J. (2018). Spanish Twitter Data Used as a Source of Information About Consumer Food Choice. In W. E. Holzinger A., Kieseberg P., Tjoa A. (Ed.), *Machine Learning and Knowledge Extraction. CD-MAKE 2018* (Vol. 11015, pp. 134–146). Cham: Springer.

Morreale, F., Garzón, R., & Rosell, C. M. (2018). Understanding the role of hydrocolloids viscosity and hydration in developing gluten-free bread. A study with hydroxypropylmethylcellulose. *Food Hydrocolloids*, *77*.

Panouillé, M., Saint-Eve, A., Déléris, I., Le Bleis, F., & Souchon, I. (2014). Oral processing and bolus properties drive the dynamics of salty and texture perceptions of bread. *Food Research International*, *62*, 238–246.

Peyron, M.-A., Gierczynski, I., Hartmann, C., Loret, C., Dardevet, D., Martin, N., & Woda, A. (2011). Role of physical bolus properties as sensory inputs in the trigger of swallowing. *PLoS ONE*, *6*(6).

Pineau, N., Schlich, P., Cordelle, S., Mathonnière, C., Issanchou, S., Imbert, A., … Köster, E. (2009). Temporal Dominance of Sensations: Construction of the TDS curves and comparison with time-intensity. *Food Quality and Preference*, *20*(6), 450–455.

Puerta, P., Laguna, L., Villegas, B., Rizo, A., Fiszman, S., & Tarrega, A. (2020). Oral processing and dynamics of texture perception in commercial gluten-free breads. *Food Research International*, *134*(December 2019), 109233.

Rizo, A., Peña, E., Alarcon-Rojo, A. D., Fiszman, S., & Tárrega, A. (2018). Relating texture perception of cooked ham to the bolus evolution in the mouth. *Food Research International*, (October 2017), 0–1.

Schober, T. J., Bean, S. R., Boyle, D. L., & Park, S. H. (2008). Improved viscoelastic zein-starch doughs for leavened gluten-free breads: Their rheology and microstructure. *Journal of Cereal Science*, *48*(3), 755–767.

Tournier, C., Grass, M., Septier, C., Bertrand, D., & Salles, C. (2014). The impact of mastication, salivation and food bolus formation on salt release during bread consumption. *Food & Function*, *5*(11), 2969–2980.

Tournier, C., Grass, M., Zope, D., Salles, C., & Bertrand, D. (2012). Characterization of bread breakdown during mastication by image texture analysis. *Journal of Food Engineering*, *113*(4), 615–622.

van Eck, A., Fogliano, V., Galindo-Cuspinera, V., Scholten, E., & Stieger, M. (2019). Adding condiments to foods: How does static and dynamic sensory perception change when bread and carrots are consumed with mayonnaise? *Food Quality and Preference*, *73*(November 2018), 154–170.

van Eck, A., Franks, E., Vinyard, C. J., Galindo-Cuspinera, V., Fogliano, V., Stieger, M., & Scholten, E. (2020). Sauce it up: influence of condiment properties on oral processing behavior, bolus formation and sensory perception of solid foods. *Food & Function, 11*(7), 6186–6201.

van Eck, A., Hardeman, N., Karatza, N., Fogliano, V., Scholten, E., & Stieger, M. (2019). Oral processing behavior and dynamic sensory perception of composite foods: Toppings assist saliva in bolus formation. *Food Quality and Preference, 71*(March 2018), 497–509.

Van Der Bilt, A., & Fontijn-Tekamp, F. A. (2004). Comparison of single and multiple sieve methods for the determination of masticatory performance. *Archives of Oral Biology*, *49*(3), 193–198.

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

Ziobro, R., Witczak, T., Juszczak, L., & Korus, J. (2013). Supplementation of gluten-free bread with non-gluten proteins. Effect on dough rheological properties and bread characteristic. *Food Hydrocolloids*, *32*(2), 213–220.

Chapter 3

Visual attention and response of coeliac consumers towards packages of gluten-free breads. Impact of certification logo and brand

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ABSTRACT

In this study, the visual attention and response of coeliac consumers towards packages of gluten-free breads, the impact of the brand, and a gluten-free certification logo were investigated. Ten commercial gluten-free breads were included in the study (either only producing gluten-free products or a regular brand) and including or not the gluten-free certification logo on the package. The packages of gluten-free breads were presented on a computer screen to eighty-six adults that suffered coeliac disease or were related to someone who did. Visual attention was registered using eye-tracking while participants evaluated purchase intention, expected acceptability, and trust. Characterization and description of breads was performed using projective mapping. Most participants fixated on the image displayed on the package when evaluating the breads. The list of ingredients received the highest number of fixations, probably because of safety or hedonic aspects. The trust conferred to consumers was high for all the breads, especially with gluten-free specific brands. The certification logo did not affect this trust, but conditioned their visual attention, as consumers paid more attention to the list of ingredients or nutritional facts, especially when the brand was not specific. The type of brand affected the expected acceptability, which was also explained by other characteristics of the breads. Consumers' expected acceptability was higher when breads were described as soft, spongy, white, had seeds, sourdough, different cereals, or good taste, while those described as dry, brittle, hard, or not having a transparent package showed lower values of expected acceptability. The combination of both techniques —eye-tracking and projective mapping— provided complementary information about aspects of product packages affecting coeliac consumers' response to food, such as the expected acceptability or trust.

Keywords: Coeliac consumers; Eye-tracking; Projective mapping; Visual attention; Gluten-free breads; Consumers' response

1. INTRODUCTION

A gluten-free diet is the only current available treatment for individuals with coeliac disease. Therefore, they are forced to avoid gluten and consume products free from this protein (Xhakollari, Canavari, & Osman, 2019). In recent years has been a rise in the diagnosis of coeliac disease that has led to a growing demand of gluten-free products in the market, especially bakery products (do Nascimento, Fiates, & Teixeira, 2017; Espinosa-Ramírez, Garzon, Serna-Saldivar, & Rosell, 2018).

Most studies regarding gluten-free have focused on optimizing gluten-free products trying to improve the sensory properties, especially for breads (Campo, del Arco, Urtasun, Oria, & Ferrer-Mairal, 2016; Carini et al., 2015; Feizollahi et al., 2018; Machado-Alencar, de Morais, Steel, & Bolini, 2017; Matos & Rosell, 2012) and other bakery goods like cookies, muffins, or sponge cakes (Jan, Panesar, & Singh, 2018; Jeong & Chung, 2019; Krupa-Kozak et al., 2019). Additionally, do Nascimento et al. (2017) reported sensory attributes, price, and nutritional value were the main concerns for coeliac consumers of gluten-free breads. However, no further studies have explored the overall perception of coeliac consumers on gluten-free products, also including the breads extrinsic properties that could also help consumers' choice.

Extrinsic factors such as the packaging information, price, or other context factors, with consumers' previous experiences, their attitudes, beliefs or food habitudes contribute to create expectations toward the product and influence consumer's response (Costell et al., 2010; Deliza & MacFie, 1996; Torres-Moreno, Tarrega, Torrescasana, & Blanch, 2012).

Because of diet restrictions, coeliac people constitute a special group of consumers with specific attitudes and needs. According to do Nascimento, Fiates, dos Anjos, & Teixeira (2014) the reduced availability and variety of gluten-free products and the social restrictions imposed by their limited diet are the main causes of dissatisfaction for coeliac consumers. These factors, with the high prices seems to negatively affect the long-term adherence of coeliac people to a gluten-free diet (Villafuerte-Galvez et al., 2015). Furthermore, for coeliac consumers, knowing if the product is free from gluten or even the exact ingredients is key for their choices (do Nascimento, Fiates, Dos Anjos, & Teixeira, 2013). Thus, coeliac consumers are expected to inspect the product label and have different response than regular consumers to the information provided in the food product, driven by both liking and trust.

Brand and a gluten-free certification logo are two extrinsic factors expected to give information, influencing acceptability and trust of coeliac consumers. Decades ago, gluten-free products were manufactured by brands producing only gluten-free products that coeliac consumers knew well and recognized. However, due to the increased demand for gluten-free products over the last years, brands producing regular products now also offer gluten-free products, readily available on the market.

Labels of gluten-free products can include different messages—indicating they are gluten free—like symbols, words, or claims. The statement ‘gluten-free’ on a product label can be made only when food contains ≤20 ppm of gluten (Regulation (EU) No. 828/2014), this expression can be given with a logo or symbol, whose design depends on the manufacturer. In addition, the crossed grain trademark safety certification is a logo accredited by the Association of European Coeliac Societies (AOECS), which ensures not only a gluten content ≤20 ppm, but also that the product manufactured conforms to high and safe standards of production (AOECS, 2015).

To determine important factors for consumer information processing and decision making when observing a product, eye-tracking has been useful, as it registers the consumers’ attention (Ares, Mawad, Giménez, & Maiche, 2014; Bialkova, Grunert, Juhl, Wasowicz-Kirylo, Stysko-Kunkowska, & van Trijp, 2014). Eye-tracking is an observational technique that characterizes gazing behavior, identifying where someone is looking (Duerrschmid & Danner, 2018). It provides a way to record an eye’s gaze, show exact eye movements, and fixations; thus, a consumers’ focus of interest (Bialkova & Van Trijp, 2011; Graham, Orquin, &

Visschers, 2012). The eye-tracking technique has been widely used in food research and consumers' perception studies (Gere, Danner, de Antoni, Kovács, Dürrschmid, & Sipos 2016; Stasi et al., 2018), particularly when performing specific tasks like evaluating their willingness to purchase a product, product healthiness, or hedonic aspects and motivations (Ares, Giménez, Bruzzone, Vidal, Antúnez, & Maiche, 2013; Graham & Jeffery, 2012; Piqueras-Fiszman, Velasco, Salgado-Montejo, & Spence, 2013; Tórtora, Machín, & Ares, 2019; van Herpen & van Trijp, 2011; Visschers, Hess, & Siegrist, 2010).

Furthermore, knowing how consumers differentiate and describe products within a category, can provide the relevant attributes for consumers, helping in understanding their response. Projective mapping is a descriptive technique to study consumer's perception of food products in a holistic manner, based on the evaluation of global characteristics of the product (Dehlholm, Brockhoff, Meinert, Aaslyng, & Bredie, 2012; Varela et al., 2017). Projective mapping has been applied to describe sensory characteristics and identify similarities and differences among products in a wide range of food categories (Varela et al., 2017). However, it has also been applied to study non-sensory aspects of a product, like the influence of packaging and label information on consumers' behavior; which can be comparable to what happens in front of the supermarket shelf in a purchasing situation (Carrillo, Varela, & Fiszman, 2012a, 2012b). As consumers can use their own words to characterize a sample, this technique is useful for gaining insight into how consumers describe and differentiate a set of products; suitable for use with gluten-free breads.

The objectives of this work were first to investigate the visual attention, perception, and response of coeliac consumers to packaging of commercial gluten-free breads; second, investigate the impact of having a gluten-free certification logo or being a gluten-free product specific brand.

2. MATERIALS AND METHODS

2.1. Samples

Ten commercial gluten-free breads purchased in local supermarkets were used for the study. For sample selection, two factors related to the breads were considered: i) type of brand (either a specific brand only producing gluten-free products or a regular brand, non-specific of gluten-free products), and ii) presence of the gluten-free certification logo (with or without certification logo). Breads were designated to one of the two levels of both factors (Table 1).

2.2. Participants

Eighty-six adult volunteers (71 females and 15 males) aged between 16 and 73 participated in the study. Individuals under 18 were included with parental consent. They were recruited through the Spanish Coeliac Association of the Valencian Community, for being coeliac (60.5%) or a relative of a coeliac person and doing regular shopping for him/her (39.5%). All participants were informed before starting the study about the protocols and they signed a consent form. This study was approved by CSIC Research Ethics Committee (Ref: 050/19).

Table 1. Commercial gluten-free bread samples used in the study according to the factors type of brand (Specific and Non-specific of gluten-free products), presence of gluten-free certification logo (Cert. logo and No Cert. logo), and ingredients of each bread.

Type of brand	Gluten-free certification logo	Bread	Ingredients
Specific of gluten-free products	Cert. logo	S1	Corn starch, water, sourdough (rice flour, water), rice starch, cereals (millet flour, quinoa flour), vegetable fiber (psyllium), beet sugar syrup, rice syrup, sunflower oil, soy flakes, sunflower seeds, soy bran, flax seeds, thickener (hydroxypropylmethylcellulose), millet flakes, soy protein, yeast, sea salt, honey.
		S2	Water, corn starch, rice starch, calcium caseinate, corn flour, rice flour, extra virgin olive oil, yeast, apple fiber, salt, stabilizers (hydroxypropylmethylcellulose, sodium carboxymethylcellulose, xanthan gum), soy protein isolate, whole cane brown sugar, preservatives (sorbic acid, calcium propionate), aroma.
	No Cert. logo	S3	Corn starch, water, sourdough (rice flour, water), rice starch, rice syrup, vegetable fiber (psyllium), sunflower oil, millet flour, soy protein, quinoa flour, thickener (hydroxypropylmethylcellulose), yeast, salt, honey.
		S4	Corn starch, water, sourdough (rice flour, water), rice starch, cereals, vegetable fiber (psyllium), beet sugar syrup, rice syrup, sunflower oil, soy flakes, sunflower seeds, soy bran, flax seeds, thickener (hydroxypropylmethylcellulose), millet flakes, soy protein, yeast, sea salt, honey.
		S5	Water, sourdough (rice flour, water), corn starch, rice syrup, high oleic sunflower oil, rice starch, tapioca starch, vegetable fiber (psyllium), potato protein, thickener (hydroxypropylmethylcellulose), sugar, yeast, salt, preservatives (sorbic acid, calcium propionate).
Non-specific of gluten-free products	Cert. logo	S6	Corn starch, water, sugar, pasteurized liquid egg, margarine, yeast, thickener (xanthan gum), flax seeds, emulsifier (monoacetyl and diacetyl tartaric esters of monoglycerides and diglycerides of fatty acids), salt, preservative (sodium propionate), gasifiers (disodium diphosphate, sodium bicarbonate), antioxidant.
		S7	Corn starch, water, sugar, pasteurized liquid egg, margarine, yeast, thickener (xanthan gum), emulsifier (monoacetyl and diacetyl tartaric esters of monoglycerides and diglycerides of fatty acids), salt, preservative (sodium propionate), antioxidant (ascorbic acid), gasifiers (disodium diphosphate, sodium bicarbonate).
	No Cert. logo	S8	Water, potato starch, corn starch, high oleic refined sunflower oil, tapioca starch, egg white powder, rice bran, sugar, stabilizers (E-466, E-464, E-422, E-415), yeast, thickener (cellulose), salt, wine vinegar, preservatives (E-200, E-202, E-282), aroma.
		S9	Corn starch, water, thickeners (E-415, E-464, E-466), dextrose, humectant (glycerol), salt, millet flour, yeast, emulsifier (E-322), bamboo fiber, potato fiber, gasifying agents (E-541, E-450a, E-341, E-500i), preservative (E-200), antioxidant (E-300).
		S10	Water, sourdough (rice flour, water), corn starch, rice flour, rice syrup, sunflower oil, decorticated buckwheat flour, sunflower seeds, sesame seeds, emulsifier (hydroxypropylmethylcellulose), buckwheat flour, decorticated millet flour, sugar syrup, pea protein isolate, vegetable fiber (psyllium), citric fiber, brown flax seeds, sea salt, yeast, acidulant (tartaric acid), emulsifier (monoglycerides and diglycerides of fatty acids), lactose-free skimmed milk powder.

2.3. Procedures

2.3.1. Evaluation of purchase intention, expected acceptability, and trust perception of breads

Each participant was asked to imagine being at the supermarket to purchase gluten-free bread and to observe the images of the product, that were monadically presented on a screen (51 × 27.8 cm). Then, he/she was asked to indicate if he/she would purchase each bread using a 5-point scale (ranging from "1 = definitely would not buy" to "5 = definitely would buy") and rate how much he/she would like each bread using a 9-point hedonic scale (ranging from "1 = dislike extremely" to "9 = like extremely"). To evaluate the degree of trust and safety conferred by the breads, each participant was asked to indicate the level of agreement with five statements (Table 2) using a 7-point Likert scale. The order of presentation of the bread images varied among participants, following a balanced design (Williams' Latin square). Participants took a five-minute break after evaluating five products. Data collection was carried out using Compusense Cloud (Compusense Inc., Guelph, Canada).

Table 2. Statements related to trust and safety aspects.

Aspect	Statement
Trust	I would not buy/eat this product because I distrust it (R)
	I feel confident about this product
Safety	I believe that this product will make me feel good
	I believe that this product is safe
	The information displayed on the product makes me feel safe

(R) Reversed statement.

2.3.2. Eye-tracker recording

During the evaluation of the images of bread packages, the eye movements of participants were recorded using a Pupil mobile eye-tracking headset (Pupil Labs GmbH, Berlin, Germany). They were asked to sit at a distance of 60– 70 cm from the screen, and could move their head freely and naturally in front of the screen.

Gaze fixations between 100 and 400 ms of duration and 1º of dispersion of visual angle were registered for studying visual attention (Bialkova & van Trijp, 2011; Salvucci & Goldberg, 2000). Sixty-six out of the eighty-six participants involved in the study performed the eye-tracker task, as those wearing glasses were excluded.

2.4. Consumer's description of gluten-free breads

Characterization and description of breads were performed using projective mapping. Each participant was provided with a white paper sheet (119 × 84 cm) and the 10 bread products. He/she was asked to examine the bread packages and distribute them on the sheet according to the differences and similarities they found among the breads, so breads placed close to each other were considered similar, and breads placed distant from each other were considered different. He/she was encouraged to use the entire area of the sheet. After positioning the breads, he/she was asked to write down next to each product, all the characteristics for describing them.

2.5. Data analysis

Eye-tracker recordings were analyzed using Pupil Player software (Pupil Labs GmbH, Berlin, Germany). For each product, fixations of participants on the different elements (brand name, list of ingredients, nutritional facts, bread type description and gluten-free symbol) of the bread packages were obtained. For each package and element, the percentage of participants that fixated on it at least once, and the number of fixations received from each consumer were counted.

Mixed analysis of variance (ANOVA) was performed on the number of fixations received by each element, with type of brand and gluten-free certification as fixed factors with their interactions, and the participant as the random effect. Post-hoc

Tukey tests were carried out to determine significant differences among categories (α = 0.05).

Trust/safety evaluation obtained from the scores on Likert scale for the five statements was checked, showing good internal reliability (Cronbach's α = 0.94). Average values on scores of the five statements were calculated for further analysis. Mixed ANOVA was performed on acceptability and trust and safety scores, with the participant as the random factor. Post-hoc Tukey tests were carried out to determine significant differences among samples (α = 0.05). From the purchase intention data, the percentage of participants that would purchase each bread was calculated.

Data obtained from the projective mapping technique about the description of breads were registered to construct a table with X and Y coordinates of each product on the paper sheets, and a table with the frequencies of mention of each descriptor. Multiple Factor Analysis (MFA) was applied on the X and Y coordinates considering an individual table for each participant. Tables including descriptors, acceptability, and trust/safety data were included as supplementary variables in the analysis.

Data analysis were performed using XLSTAT 2019.3.1 package (Addinsoft, France).

3. RESULTS

3.1. Gaze fixations on bread package labels and their elements

For each participant, the gaze fixations received by each element of bread packages (brand name, list of ingredients, nutritional facts, bread type description, and elements referring to gluten-free—the symbol, words, and certification logo) were registered. The number of participants looking at the element (at least once) varied among elements but also among products. The image, when present, was the element most visualized by participants (59–94%, 78% on average), followed by the nutritional facts (44–88%, 69% on average), the list of ingredients (55–79%, 68% on average), and the bread description (11–83%, 67% on average). The percentage of participants that fixated at least once on one of the three elements referring to gluten-free was also high on average (71%) but varied greatly among breads (39–89%). Brand name was visualized by fewer consumers (33–65%, 49% on average).

Table 3 shows ANOVA results of the effects of bread brand and certification logo on the number of fixations for each element. For brand name, the number of fixations did not significantly vary with the brand (p = 0.226) nor with gluten-free certification logo (p = 0.272).

Table 3. Summary of statistics for number of fixations to the different elements of the bread package labels received according to the factors type of brand, presence of a gluten-free certification logo, and their interaction.

	Type of brand		**Gluten-free certification logo**		**Type of brand* Gluten-free certification logo**	
	F-ratio	*p* Value	F-ratio	*p* Value	F-ratio	*p* Value
Brand name	1.47	0.226	1.21	0.272	0.16	0.686
List of ingredients	0.04	0.852	10.65	0.001	8.14	0.004
Nutritional facts	0.21	0.650	15.45	<0.001	4.37	0.037
Bread type description	3.90	0.049	34.81	<0.001	0.34	0.561
Gluten-free symbol	16.23	<0.001	2.50	0.115	0.91	0.341

Ingredients and nutritional facts fixations significantly varied depending on the presence of a certification logo (p = 0.001 and p < 0.001, respectively), and correlated with the brand (p = 0.004 and p = 0.037, respectively), indicating the effect of the certification logo depended on the brand type. As Figure 1 shows for both the list of ingredients and nutritional facts, the number of fixations was higher when there was no certification logo, but the difference was much higher and only significant with breads of a non-specific brand. The number of fixations received by the bread type description differed significantly with the presence of the certification logo (p < 0.001), but also with the brand (p = 0.049) (Table 3). Furthermore, when there was no gluten-free certification logo, the average number of fixations on the bread type description was lower (Figure 1). For gluten-free symbol, the number of fixations significantly depended on the brand ($p < 0.001$), being higher with non-specific brands.

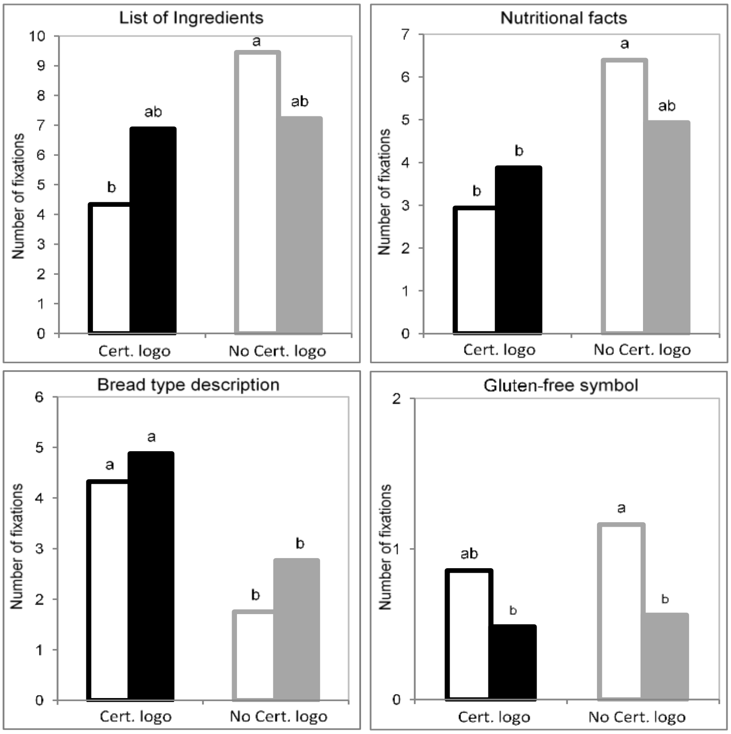

Figure 1. Average number of fixations received by elements on the label for breads of each type, varying on the presence of gluten-free certification logo and on the type of brand (specific or non-specific of gluten-free products): non-specific with certification logo ( ); specific with certification logo ( ); non-specific without certification logo ( ); and specific without certification logo ( ). Different letters in columns indicate significant differences among values (Tukey test, α = 0.05).

3.2. Expected acceptability, trust and purchase intention of commercial gluten-free breads

Average values of expected acceptability and trust/safety of consumers when observing bread packages are shown in Table 4. ANOVA results (Table 5) showed that acceptability scores varied depending mainly on the packages brand. Breads from specific brands showed expected acceptability higher than those from non-specific brands (Table 5). A certification logo also affected expected acceptability. However, this effect seems related to individual differences of breads, as some breads without a certification logo showed high expected acceptability; this is not applicable to all breads.

Table 4. Average values of expected acceptability, trust/safety, and purchase intention for the different gluten-free breads.

Type of brand	Gluten-free certification logo	Bread sample	Expected acceptability	Trust/ safety	Purchase intention (%)*
Specific of gluten-free products	Cert. logo	S1	7.2 a	6.2 abc	81
		S2	6.0 bc	5.9 bcd	56
	No Cert. logo	S3	7.2 a	6.3 ab	85
		S4	7.6 a	6.4 a	90
		S5	6.1 bc	5.7 de	57
Non-specific of gluten-free products	Cert. logo	S6	5.3 d	5.4 ef	34
		S7	5.5 cd	5.6 def	41
	No Cert. logo	S8	5.8 bcd	5.3 f	51
		S9	5.7 cd	5.4 ef	49
		S10	6.5 b	5.8 cd	62

For expected acceptability and trust/safety columns, values not sharing letters are significantly different according to the Tukey test ($\alpha = 0.05$).
*Purchase intention is expressed as the % of participants that would buy each bread.

Regarding trust, average values varied among samples between 5.3 and 6.4, indicating that all breads conferred trust to consumers; ANOVA showed that it was mainly affected by the brand. Participants trusted the breads from specific brands more. A certification logo did not significantly affect the trust that the breads conferred to participants.

In agreement with expected acceptability and trust, the percentage of consumers that would buy the bread after observing the package mainly varied with the brand, being higher for the breads of specific brands (56–90%) than those from non-specific brands (34–62%).

Table 5. Analysis of variance for the expected acceptability and trust/safety considering two factors (type of brand and gluten-free certification logo), and their interaction.

	Type of brand		**Gluten-free certification logo**		**Type of brand* Gluten-free certification logo**	
	F-ratio	*p* Value	F-ratio	*p* Value	F-ratio	*p* Value
Expected acceptability	112.26	<0.001	22.31	<0.001	0.913	0.340
Trust/safety	105.03	<0.001	0.29	0.591	0.120	0.729

3.2. Characterization and description of commercial gluten-free breads by coeliac consumers

Differences and similarities perceived by consumers on observing the breads on their packages were assessed using a projective mapping technique. Multi Factor Analysis data showed the two first dimensions accounts for the 53.2% of the total variability. The MFA plot (Figure 2) shows the samples distribution according to the similarities and differences evaluated by consumers with the descriptors, the acceptability and trust projected are shown in Supplementary Table 1. There was no clear distribution of the bread samples on the map according to the factors type of brand and presence of gluten-free certification logo.

Consumers separated a group of breads (at the left extreme of the map; S1, S4, and S10) described as having seeds, cereals, fiber, or being multigrain. The rest of the breads (on the right side of the map) were separated along the second dimension based on a wide range of descriptions. At the top, appeared those described as brittle, dry, hard, or having the certification logo (breads S6, S7, and S2) and among them, S6 and S7 were differentiated for having palm oil, a lot of sugar, or small size, from bread S2, for having bad appearance. Having a not transparent package differentiated bread S9, however being white like breads S3, S5, and S8 (on the bottom of the map), and also described as soft. In addition, descriptors like good appearance, healthy, spongy, having sourdough, good texture, or good taste were used to describe S3, S1, and S4.

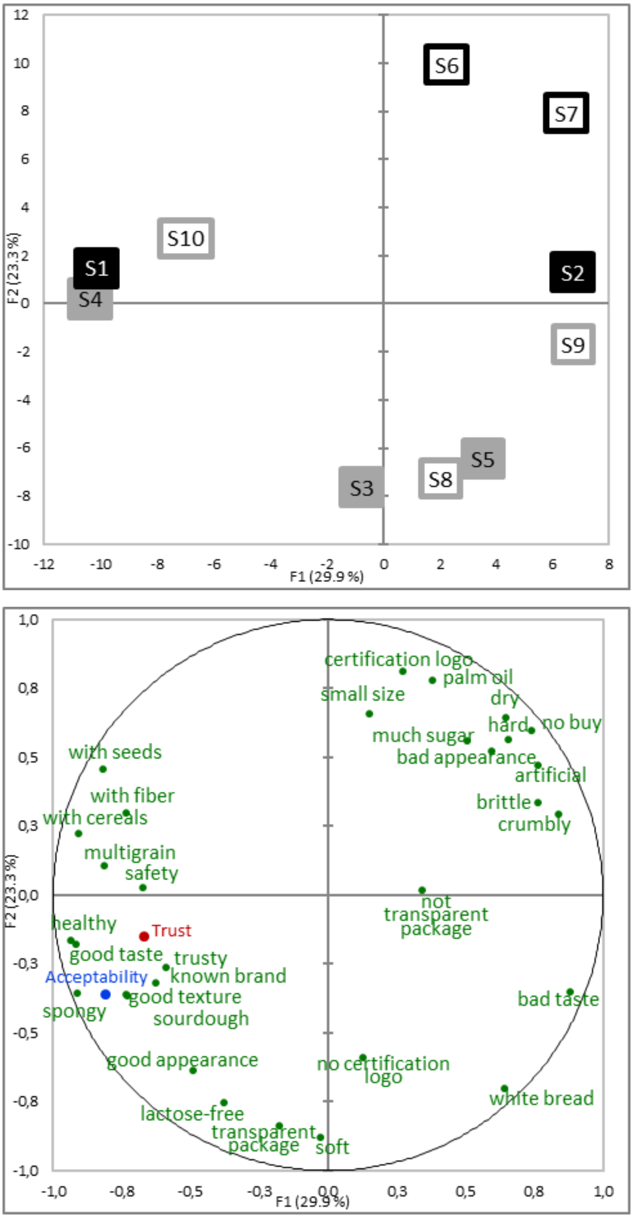

Figure 2. Multiple Factor Analysis of consumers' evaluation of gluten-free breads using projective mapping. Bread samples (S1-S10) varying on the type of brand (specific or non-specific of gluten-free products) and on the presence of gluten-free certification logo: specific with logo (■); specific without logo (■); non-specific with logo (□); and non-specific without logo (□). Descriptors expected acceptability and trust/safety perception were projected as supplementary variables.

Expected acceptability and trust/safety were also projected on the map. High values of expected acceptability were associated to breads S1, S4, and S3, which shared the descriptors good texture, good taste, soft, spongy, good appearance, or having sourdough. The breads with lower values of acceptability were those separated on the upper right side of the map, which shared descriptors as dry, hard, brittle and having a lot of sugar and palm oil. Trust/safety was also projected on the map but varied to a lesser extent. Breads S1, S3, and S4 presented higher values for trust/safety, and were associated to descriptors healthy, trusty, safety, or known brand.

4. DISCUSSION

4.1. Attention of coeliac consumers on gluten-free bread labels

In this study, coeliac consumer's fixations when evaluating gluten-free bread labels have been analyzed. Most consumers looked at the image displayed on the label (78%). The relevance of the image can be due to it receiving both goal-driven attention and saliency driven-attention. Images can transmit information to consumers about the product sensory attributes and can also create liking expectations (Ares, et al., 2013; Deliza, Macfie, & Hedderley, 2003). Piqueras-Fiszman et al. (2013) reported that an image of the product on labels also influences consumers' willingness to try the product. However, images usually have salient characteristics (different color, big size, shape, and central position) that can catch the consumer's attention, simply because it stands out in the visual field (Ares et al., 2013; Bialkova et al., 2014; Bialkova & van Trijp, 2011; Mawad, Trías, Giménez, Maiche, & Ares 2015; Torrico, Fuentes, Viejo, Ashman, Gurr, & Dunshea, 2018). Independent from the reasons behind, image received an important part of the attention of coeliac consumers similarly to what has been described for non-coeliac consumers. A recent study showed that the image was the most fixated element when coeliac children and their parents choose a biscuit in a simulated supermarket context, but the number of fixations was lower for both factors than for non-coeliac products (Puerta, Laguna, Tárrega, & Carrillo, 2022).

Attention paid to gluten-free elements, nutritional facts, brand, and list of ingredients is expected to be mainly goal-driven as they give information about product properties. Coeliac consumers are expected to check if a product contains gluten, and in general they fixated on one of the gluten-free elements of the packages (gluten-free symbol, gluten-free words, or certification logo). The average percentage of coeliac consumers that fixated on the gluten-free words was 61% (39–82%); on the certification logo, 41% (23–58%); and on the gluten-free symbol, 32% (9–55%). In most cases, more consumers looked at the words mentioning gluten-free rather than the gluten-free symbol or certification logo, probably because these words occupied a bigger area than the symbols and logos. However, when observing the percentage of coeliac consumers that looked at the gluten-free elements (39–89%), on some bread packages most consumers did not fixate on any elements. It is believed these consumers identify other elements to determine if the product is suitable for them (known brand, known product, or the ingredients list).

Many participants also directed their attention to the list of ingredients, which was the element that on average received the highest number of fixations. The attention paid to the list of ingredients is expected to provide information for consumers' assessment of both the safety and liking of the product. Reading the list of ingredients can help these consumers to double check the absence of gluten and minimize the risk perception associated with a food product (Bogue & Sorenson, 2011). Our results suggest that they fixated on the ingredients like other consumers suffering food intolerances, who frequently review the ingredients on food labels to avoid allergens (Cochrane, Gowland, Sheffield, & Crevel, 2013; Soon, 2019). However, coeliac consumers used to cook and baking, can recognize and appreciate the different flours used in gluten-free products (Puerta, Laguna, Vidal, Ares, Fiszman, & Tárrega, 2020), thus fixations on the list of ingredients might be directed to the flour type to decide how much they would like the bread

3.2. Relevance of the brand type and certification logo on coeliac consumers' responses.

The brand (specific or non-specific of gluten-free products) and certification logo affected consumer's attention on gluten-free bread packages. When a gluten-free certification logo was present, the number of fixations dedicated to the list of ingredients and the nutritional facts of the breads was reduced. Participants inspected both the list of ingredients and nutritional facts with more attention on packages without a certification logo, to be sure about the absence of gluten in the bread and to check if it is a safe product for consumption. However, when breads were from a gluten-free products brand, participants fixated less on the gluten-free symbol and the list of ingredients of the packages, which seems to indicate that brand is also an element providing information about safety. These factors indicate coeliac consumers use three main sources of information on bread packages—gluten-free logos, the brand, and the list of ingredients—to check the safety of the product.

Trust values reported for all breads were high, indicating that the risk perception that coeliac consumers have towards commercial gluten-free breads is low. They trusted gluten-free bread brands slightly more, confirming that the brand also provides information about how safe the product is for them. However, having a certification logo did not significantly vary the trust of coeliac consumers. Moreover, visual attention information indicates that certification logo participates in the trust decision, given that when present, consumers needed to pay less attention to other elements, like the list of ingredients. This logo can facilitate the consumer's decision but is not determinant for trust, as when not present, consumers looked to other elements for deciding if the product is trustworthy.

Expected liking of coeliac consumers from packages highly varied among commercial gluten-free breads. Coeliac consumers gave higher acceptability scores to gluten-free bread brands, because either they expected (or even already knew) those breads would have better sensory properties and would like more, or because of a loyalty to these brands that were providing them safe products. The importance of brand for consumers' response and decision making has been also related to the sensory and hedonic expectations of other products like biscuits (Carrillo, Varela, & Fiszman, 2012), chocolate (Torres-Moreno, Tárrega, Torrescasana, & Blanch, 2012), orange juices (Varela, Ares, Giménez, & Gámbaro, 2010), and beers (Guinard, Uotani, & Schlich, 2001). As expected, in this study, the brand did not fully explain the differences in expected acceptability, and other features perceived by consumers on packages could have an influence. Therefore, projective mapping analysis showed that coeliac consumers perceived many differences among gluten-free packages associated to different aspects like the bread type (white *versus* multigrain or with cereals or seeds), texture attributes (dry, brittle), flavor attributes, package attributes (transparent), nutritional facts, ingredients (palm-oil, fiber, a lot of sugar), or other aspects like artificial; trustworthy; or healthy. Breads described by coeliac consumers as white bread, soft, spongy, having seeds, sourdough, good texture, or good taste were the most accepted, also being likely to purchase by participants. In contrast, the least accepted were those described as hard, brittle, crumbly, with bad appearance or not having a transparent package. Higher values of trust were related to breads described as trustworthy, healthy, or from a known brand. As all breads were perceived as safe for consumption, consumers decided if purchasing depended on if they would like each bread.

This study has limitations. First, participants evaluated both front and back package labels on a computer screen, which could have increased the attention directed to the back of the packages. In a real-life situation, the consumer's attention to information contained on the back is expected to be lower (e.g., purchasing at supermarket, where the front of packages is usually shown). Second, images of bread labels were presented on the screen one by one, which does not represent the real-life setting of a supermarket shelf, where all the products are seen by the consumer simultaneously. Future research could address and explore the behavior of coeliac consumers in more ecological and realistic environments, such as in a real-life situation of purchasing in a supermarket.

5. CONCLUSIONS

Coeliac consumers' trust was high for all observed commercial gluten-free bread packages. The gluten-free certification logo does not directly affect the trust of coeliac consumers, but it facilitates the decision as it reduces their attention given other information like the list of ingredients or nutritional facts. The trust of coeliac consumers is higher when bread packages show a gluten-free product brand, and in these cases paid less attention to the gluten-free symbol and list of ingredients.

Expected acceptability of coeliac consumers is higher for gluten-free bread brands. It has been explained by other individual characteristics perceived by consumers from packages: the most accepted related to being soft, spongy, white bread, having a good taste, seeds, or different cereals, while those described as dry, brittle, hard, with bad appearance or not having a transparent package, were related to less accepted breads.

Using an eye-tracker combined with projective mapping has provided complementary information on consumer's response to food packages. The aspects that attract consumer's attention and the distinctive features they describe help to explain their expectations about product such as liking or trust.

REFERENCES

Ares, G., Giménez, A., Bruzzone, F., Vidal, L., Antúnez, L., & Maiche, A. (2013). Consumer Visual Processing of Food Labels: Results from an Eye-Tracking Study. *Journal of Sensory Studies*, *28*(2), 138–153.

Ares, G., Mawad, F., Giménez, A., & Maiche, A. (2014). Influence of rational and intuitive thinking styles on food choice: Preliminary evidence from an eye-tracking study with yogurt labels. *Food Quality and Preference*, *31*(1), 28–37.

Association of European Coeliac Societies (AOECS), 2015. Retrieved 05/2019, from https://www.aoecs.org/licensing-crossed-grain-symbol

Bialkova, S., Grunert, K. G., Juhl, H. J., Wasowicz-Kirylo, G., Stysko-Kunkowska, M., & van Trijp, H. C. M. (2014). Attention mediates the effect of nutrition label information on consumers' choice: Evidence from a choice

Bialkova, S., & Van Trijp, H. C. M. (2011). An efficient methodology for assessing attention to and effect of nutrition information displayed front-of-pack. *Food Quality and Preference*, *22*(6), 592–601.

Bogue, J., & Sorenson, D. (2011). The marketing of gluten-free cereal products. In B. F. Dal & E. Arendt (Eds.), *Gluten-free cereal products and beverages* (pp. 393–411). Elsevier Science & Technology Books.

Campo, E., del Arco, L., Urtasun, L., Oria, R., & Ferrer-Mairal, A. (2016). Impact of sourdough on sensory properties and consumers' preference of gluten-free breads enriched with teff flour. *Journal of Cereal Science*, *67*, 75–82.

Carini, E., Scazzina, F., Curti, E., Fattori, F., Mazzeo, T., & Vittadini, E. (2015). Physicochemical, sensory properties and starch in vitro digestion of gluten-free breads. *International Journal of Food Sciences and Nutrition*, *66*(8), 867–872.

Carrillo, E., Varela, P., & Fiszman, S. (2012a). Effects of food package information and sensory characteristics on the perception of healthiness and the acceptability of enriched biscuits. *Food Research International*, *48*(1), 209–216.

Carrillo, E., Varela, P., & Fiszman, S. (2012b). Packaging information as a modulator of consumers' perception of enriched and reduced-calorie biscuits in tasting and non-tasting tests. *Food Quality and Preference*, *25*(2), 105–115.

Cochrane, S. A., Gowland, M. H., Sheffield, D., & Crevel, R. W. R. (2013). Characteristics and purchasing behaviours of food-allergic consumers and those who buy food for them in Great Britain. *Clinical and Translational Allergy*, *3*(1), 1–8.

Costell, E., Tárrega, A., & Bayarri, S. (2010). Food acceptance: The role of consumer perception and attitudes. *Chemosensory Perception*, *3*(1), 42–50.

Dehlholm, C., Brockhoff, P. B., Meinert, L., Aaslyng, M. D., & Bredie, W. L. P. (2012). Rapid descriptive sensory methods - Comparison of Free Multiple Sorting, Partial Napping, Napping, Flash Profiling and conventional profiling. *Food Quality and Preference*, *26*(2), 267–277.

Deliza, R., & MacFie, H. J. H. (1996). External Cues and Its Effect on Sensory Perception and Hedonic Ratings: a Review. *Journal of Sensory Studies*, *11*(1996), 103–128.

Deliza, R., Macfie, H., & Hedderley, D. (2003). Use of computer-generated images and conjoint analysis to investigate sensory expectations. *Journal of Sensory Studies*, *18*(6), 465–486.

do Nascimento, A. B., Fiates, G. M. R., Dos Anjos, A., & Teixeira, E. (2013). Analysis of ingredient lists of commercially available gluten-free and gluten-containing food products using the text mining technique. *International Journal of Food Sciences and Nutrition*, *64*(2), 217–222.

do Nascimento, A. B., Fiates, G. M. R., Dos Anjos, A., & Teixeira, E. (2014). Gluten-free is not enough-perception and suggestions of celiac consumers. *International Journal of Food Sciences and Nutrition*, *65*(4), 394–398.

do Nascimento, A. B., Fiates, G. M. R., & Teixeira, E. (2017). We want to be normal! Perceptions of a group of Brazilian consumers with coeliac disease on gluten-free bread buns. *International Journal of Gastronomy and Food Science*, *7*, 27–31.

Duerrschmid, K., & Danner, L. (2018). Eye tracking in consumer research. In *Methods in Consumer Research* (pp. 279–318). Woodhead Publishing.

Espinosa-Ramírez, J., Garzon, R., Serna-Saldivar, S. O., & Rosell, C. M. (2018). Mimicking gluten functionality with β-conglycinin concentrate: Evaluation in gluten free yeast-leavened breads. *Food Research International*, *106*, 64–70.

European Commission, 2014. Commission Implementing Regulation (EU) No. 828/2014 of 30 July 2014 on the requirements for the provision of information to consumers on the absence or reduced presence of gluten in food. Official Journal of the European Union L228: 5-8.

Feizollahi, E., Mirmoghtadaie, L., Mohammadifar, M. A., Jazaeri, S., Hadaegh, H., Nazari, B., & Lalegani, S. (2018). Sensory, digestion, and texture quality of commercial gluten-free bread: Impact of broken rice flour type. *Journal of Texture Studies*, *49*(4), 395–403.

Gere, A., Danner, L., de Antoni, N., Kovács, S., Dürrschmid, K., & Sipos, L. (2016). Visual attention accompanying food decision process: An alternative approach to choose the best models. *Food Quality and Preference, 51*, 1-7.

Graham, D. J., & Jeffery, R. W. (2012). Predictors of nutrition label viewing during food purchase decision making: An eye tracking investigation. *Public Health Nutrition*, *15*(2), 189–197.

Graham, D. J., Orquin, J. L., & Visschers, V. H. M. (2012). Eye tracking and nutrition label use: A review of the literature and recommendations for label enhancement. *Food Policy*, *37*(4), 378–382.

Guinard, J. X., Uotani, B., & Schlich, P. (2001). Internal and external mapping of preferences for commercial lager beers: Comparison of hedonic ratings by consumers blind versus with knowledge of brand and price. *Food Quality and Preference*, *12*(4), 243–255.

Jan, K. N., Panesar, P. S., & Singh, S. (2018). Optimization of antioxidant activity, textural and sensory characteristics of gluten-free cookies made from whole indian quinoa flour. *Lwt*, *93*, 573–582.

Jeong, D., & Chung, H.-J. J. (2019). Physical, textural and sensory characteristics of legume-based gluten-free muffin enriched with waxy rice flour. *Food Science and Biotechnology*, *28*(1), 87–97. article.

Krupa-Kozak, U., Drabińska, N., Rosell, C. M., Fadda, C., Anders, A., Jeliński, T., & Ostaszyk, A. (2019). Broccoli leaf powder as an attractive by-product ingredient: effect on batter behaviour, technological properties and sensory quality of gluten-free mini sponge cake. *International Journal of Food Science & Technology*, *54*(4), 1121–1129. article.

Machado-Alencar, N. M., de Morais, E. C., Steel, C. J., & Bolini, H. M. A. (2017). Sensory characterisation of gluten-free bread with addition of quinoa, amaranth flour and sweeteners as an alternative for coeliac patients. *International Journal of Food Science and Technology*, *52*(4), 872–879.

Matos, M. E., & Rosell, C. M. (2012). Relationship between instrumental parameters and sensory characteristics in gluten-free breads. *European Food Research and Technology*, *235*(1), 107–117.

Mawad, F., Trías, M., Giménez, A., Maiche, A., & Ares, G. (2015). Influence of cognitive style on information processing and selection of yogurt labels: Insights from an eye-tracking study. *Food Research International*, *74*, 1–9.

Piqueras-Fiszman, B., Velasco, C., Salgado-Montejo, A., & Spence, C. (2013). Using combined eye tracking and word association in order to assess novel packaging solutions: A case study involving jam jars. *Food Quality and Preference*, *28*(1), 328–338.

Puerta, P., Laguna, L., Tárrega, A., & Carrillo, E. (2022). Relevant elements on biscuits purchasing decision for coeliac children and their parents in a supermarket context. *Food Quality and Preference 98,* 104496.

Puerta, P., Laguna, L., Vidal, L., Ares, G., Fiszman, S., & Tárrega, A. (2020). Co-occurrence networks of Twitter content after manual or automatic processing. A case-study on “gluten-free”. *Food Quality and Preference, 86*, 103993.

Salvucci, D. D., & Goldberg, J. H. (2000). Identifying fixations and saccades in eye-tracking protocols. *Proceedings of the Symposium on Eye Tracking Research & Applications - ETRA ’00*, 71–78.

Soon, J. M. (2019). Food allergen knowledge, attitude and practices among UK consumers: A structural modelling approach. *Food Research International*, *120*(December 2018), 375–381.

Stasi, A., Songa, G., Mauri, M., Ciceri, A., Diotallevi, F., Nardone, G., & Russo, V. (2018). Neuromarketing empirical approaches and food choice: A systematic review. *Food Research International, 108*, 650-664.

Torres-Moreno, M., Tarrega, A., Torrescasana, E., & Blanch, C. (2012). Influence of label information on dark chocolate acceptability. *Appetite*, *58*(2), 665–671.

Torrico, D. D., Fuentes, S., Viejo, C. G., Ashman, H., Gurr, P. A., & Dunshea, F. R. (2018). Analysis of thermochromic label elements and colour transitions using sensory acceptability and eye tracking techniques. *LWT - Food Science and Technology*, *89*(July 2017), 475–481.

Tórtora, G., Machín, L., & Ares, G. (2019). Influence of nutritional warnings and other label features on consumers’ choice: Results from an eye-tracking study. *Food Research International*, *119*, 605–611.

van Herpen, E., & van Trijp, H. C. M. (2011). Front-of-pack nutrition labels. Their effect on attention and choices when consumers have varying goals and time constraints. *Appetite*, *57*(1), 148–160.

Varela, P., Antúnez, L., Berget, I., Oliveira, D., Christensen, K., Vidal, L., … Ares, G. (2017). Influence of consumers' cognitive style on results from projective mapping. *Food Research International*, *99*, 693–701.

Varela, P., Ares, G., Giménez, A., & Gámbaro, A. (2010). Influence of brand information on consumers' expectations and liking of powdered drinks in central location tests. *Food Quality and Preference*, *21*(7), 873–880.

Villafuerte-Galvez, J., Vanga, R. R., Dennis, M., Hansen, J., Leffler, D. A., Kelly, C. P., & Mukherjee, R. (2015). Factors governing long-term adherence to a gluten-free diet in adult patients with coeliac disease. *Alimentary Pharmacology and Therapeutics*, *42*(6), 753–760.

Visschers, V. H., Hess, R., & Siegrist, M. (2010). Health motivation and product design determine consumers visual attention to nutrition information on food products. *Public Health Nutrition*, *13*(7), 1099–1106.

Xhakollari, V., Canavari, M., & Osman, M. (2019). Factors affecting consumers' adherence to gluten-free diet, a systematic review. *Trends in Food Science and Technology*, *85*, 23–33.

Relevant elements on biscuits purchasing decision for coeliac children and their parents in a supermarket context

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ABSTRACT

The aim of this work was to study the behaviour and motivations of coeliac children and their parents when purchasing biscuits. Four groups (n=30) of participants differing in coeliac condition (coeliac and non-coeliac) and age (children and parents) were studied. Participants were asked to "purchase" biscuits, either for themselves (children) or for their children (parents), in a simulated supermarket aisle that included twelve commercial biscuits (six gluten-free and six regular ones). Eye-tracking technique was used to register visual attention during the purchasing exercise and laddering interviews were used to obtain the self-reported reasons for their choice. The number of fixations received by biscuits and label elements were analysed and most of them varied depending on the coeliac condition, the age or both. In comparison with the non-coeliac children, coeliac children fixated more on the ingredients, gluten-free words and symbols, and fixated less on the biscuit image. Parents of coeliac children put more attention on the ingredients and the certified gluten-free symbol, and less attention on the biscuit image, product name, cartoon, and nutritional information than non-coeliac parents. According to the chains of reasons (attribute-consequence-value), all children looked for pleasure as the final value, but only coeliac children showed interest in the brand and in unknown products they want to try. Parents differed on the attributes linked to health that were certification logo and a short ingredient list for coeliac group, and low sugar or fat contents for non-coeliac one. Trust and economy were relevant only for parents of coeliac children.

Keywords: Coeliac children; Eye-tracking; Purchasing decision; Laddering; Gluten-free; Simulated context

1. INTRODUCTION

Coeliac disease is a disorder characterized by the inflammation of the intestine because of gluten ingestion. Therefore, it is essential to exclude wheat, barley, spelt, and rye (Jnawali, Kumar, & Tanwar, 2016; Lebwohl, Sanders, & Green, 2018). According to a recent meta-analysis review (Singh et al., 2018), estimated global prevalence of coeliac disease is 1.4% (based on serologic diagnosis) and 0.7% (based on biopsy diagnosis), and it is greater in children than in adults (0.9% *vs*. 0.5%). Lifelong adherence to a gluten-free diet is the only effective therapy for coeliac disease. Therefore, those with coeliac disease must ensure that their food does not contain gluten or has not been cross contaminated with gluten-containing products. Those with coeliac disease show high adherence to the gluten-free diet, but they find obstacles that impact on everyday living and quality of life. In children starting a gluten-free diet, problems have been reported, such as difficulty in determining whether foods were gluten-free, finding allowed foods, and anger about having to follow a special diet (Rashid et al., 2005). Likewise, a more recent survey showed availability, poor quality, poor labelling, and cost of products are the major barriers for Canadian coeliac children and adolescents trying to follow a gluten-free diet (MacCulloch & Rashid, 2014).

The gluten-free products market size has grown in recent years, due to the increase in coeliac disease incidence (mostly due to a rise in recognition of coeliac disease and improvement on diagnosis tests) and the interest in gluten-free diet of tolerant consumers who consider it is a healthier option—even if this is not evidenced. This is common in bakery products, as the lack of gluten results in products with sensory properties that differ from those regular and are less appealing to consumers. Thus, most research has focused on improving the texture of gluten-free products to resemble regular products (Juhász, Colgrave, & Howitt, 2020; Di Cairano, Galgano, Tolve, Caruso, & Condelli, 2018) and to improve the sensory quality and acceptance (Ávila, Cardozo, Alves, Gularte, Monks, & Elias, 2019; Morais, Cruz, Faria, & Bolini, 2014). However, food choice is determined by sensory properties and liking, as well as other factors like the extrinsic properties of product (label information, brand, and price); furthermore, consumers' characteristics and attitudes (age, health concerns, expectations, or past experiences) must be considered to understand their decision (Costell, Tárrega, & Bayarri, 2010; Köster, 2009). In today's competitive market, food labels and packages display a wide range of visual features (colours, illustrations, logo, and shapes) to attract the consumer's attention to the product, but also provide information for consumers interested in some specific aspects of quality (sensory or nutritional). Coeliac condition and age can thus affect how all these characteristics are perceived, its relevance, and which of them drive purchase or consumption decision. However, there is little information on how the drivers of choice of non-gluten (coeliac) consumers, specifically children, differ from gluten (non-coeliac) ones. In a recent study, Pontual et al. (2017) showed that sensory expectations created by different gluten-free pizza concepts did not differ among coeliac and non-coeliac adult consumers, but health and novelty aspects were more relevant to the group of coeliac participants.

Food choices and consumption in childhood have been the object of research in studies focused on facing overweight issues and promoting healthy diets in children (Keller et al., 2012; Graham, Lucas-Thompson, Mueller, Jaeb, & Harnack, 2017). In pre-adolescent children, parents hold a primary role in food choices, purchases, and preparation (Gross, Pollock, & Braun, 2010; Pliner, & Saunders, 2008). Thus, it is interesting to examine how parents make food choices for their children, as this can influence what they will eat. Despite the different sociological perspectives for conducting research in children (Punch, 2002), adapting methods to participants' interest and ability is important to assure their engagement. Using a combination of techniques, not relying exclusively on verbal methods (interviews), and including other observational or participatory tasks, is especially recommended when children are participants (Grønhøj & Gram, 2020). Furthermore, when focusing on food consumption, many choices and decisions are part of routines, often unnoticed, and therefore, are difficult to be spontaneously verbalized. Participatory methods, such as situational tasks, can remind what would happen in a particular situation of choice, thus triggering participants' experiences.

Using retail or supermarket environments is frequently found in studies analysing consumer choice and purchasing intention of products. Real supermarket experiments that allow observing customer experience are usually used in studies aiming to determine the number and type of products selected, the money spent or consumer response to price, promotions, healthy products selection, or shelf display options in a real purchasing situation (Camargo, Farias, Mazzonetto, Dean, & Fiates, 2020; O'Brien et al., 2015; Pechey, & Monsivais, 2015; Terblanche, 2018). In a laboratory setting, using simulated supermarket environments (products arranged on a store shelf) allows participants to get immersed in the purchasing experience while researchers can control the variables or factors to be studied. Both physical or virtual simulated supermarkets are useful to study how consumer choice is affected by product characteristics (brand, price, nutritional information, label information, claims), environment aspects (position, lighting, scents), and individual consumer factors (attitudes toward health, vegan, etc.) (Ballco, de-Magistris, & Caputo, 2019; Hashim, McWatters, Rimal, & Fletcher, 2001; van Herpen, van den Broek, van Trijp, & Yu, 2016).

In simulated purchasing exercises in supermarkets, participants' behaviour is usually analysed by direct observation of how they spontaneously behave. Interviewing participants about their choice reasons, just after being made, can help to understand their behaviour. Eye-tracking is an observational technique that allows identifying where and how someone is looking (Duerrschmid & Danner, 2018). It is widely used in consumer and marketing studies to register the unconscious and spontaneous response of consumers toward products and marketing messages. In food products, eye-tracking has been applied for packaging or labels design, to know the elements and traits that capture consumer attention (Antúnez, Vidal, Sapolinski, Giménez, Maiche, & Ares, 2013; Ares, Giménez, Bruzzone, Vidal, Antúnez, & Maiche, 2013; Bialkova, Grunert, Juhl, Wasowicz-Kirylo, Stysko-Kunkowska, & van Trijp, 2014, Piqueras-Fiszman, Velasco, Salgado-Montejo, & Spence, 2013). Wearable eye-trackers (built as a kind of glasses) allow subjects to move around and interact with objects and are optimized to analyse consumer's fixations and choice behaviour in real or simulated purchasing contexts. Laddering is an interview technique for investigating motivations behind people's behaviour. It is based on the Means-End Chain Theory that considers decisions are based in a hierarchy of perceptions at three levels: "Attribute," "Consequence," and "Value" (Reynolds & Gutman, 1988). In consumer research, laddering has been used to explore the drivers of purchasing decisions (Arcia, Curutchet, Costell, & Tárrega, 2012; Nielsen, Bech-Larsen, & Grunert). It comprises consecutive why-questions that facilitate participant self-analysis of their behaviour and allows gathering the three-level chain of reasons, providing more detailed information than conventional open questions.

The goal of this study was to analyse the factors that drive biscuits choice in children with coeliac disease and their parents, as compared to their non-coeliac counterparts through an approach that combines direct measurement of visual attention (eye-tracking) and self-reported motivations (laddering) of consumers when purchasing biscuits in a simulated supermarket context.

2. MATERIALS AND METHODS

2.1. Participants

Two groups of children (those with and without-coeliac disease) with their parents participated in this study. The recruitment of coeliac participants was through an advertisement in a local coeliac association (ACECOVA), and non-coeliac children were recruited by posting announcements in local schools.

Thirty children with coeliac disease and thirty without participated in this study. The age range was 8–13. The coeliac children (23 girls, and 7 boys), and the non-coeliac children (14 girls, and 16 boys) came to the facilities accompanied by their mother or father, and one family per session participated at a time. The 30 parents of the coeliac children and the 30 parents of the non-coeliac children also participated in the study.

Parents gave informed consent and received a gift as compensation for participating. This study was approved by the Ethics Committee of CSIC (Ref. number 050/2019).

2.2. Samples

Twelve commercial biscuits were used in this study. Six gluten-free biscuits of four types (with chocolate chips, sandwich—"Oreo” like type, animal-shaped, and “María” type) were purchased in local supermarkets. Six regular (gluten-containing) biscuits representative of the same four types were also used (Table 1). All biscuits were selected from supermarkets, considering the type of biscuit as the most representative gluten-free and regular.

Table 1. Biscuit characteristics used in the study.

Group	Biscuit type	Biscuit code	Main ingredients	Images and symbols	Price (€)	Weight (g)
Gluten-free	Chocolate chips	GF-Cho1	Corn starch, palm oil, cornmeal, choco chips, cacao powder, cacao butter, emulsifiers, sugar, soybean flour, gasifiers	Biscuit image, gluten-free symbol	2.65	200
	Chocolate chips	GF-Cho2	Corn starch, palm, coconut and sunflower oil, cornmeal, choco chips, emulsifiers, acidifying, sugar, choco chips, cocoa paste, cacao butter, eggs, gasifiers	Biscuit image, cartoon character, certified gluten-free symbol	2.10	220
	Chocolate chips	GF-Cho3	Choco chips, sugar, cocoa paste, cocoa butter, emulsifiers, corn flour, sunflower and coconut oil, starch flour, eggs, gasifiers	Biscuit image, gluten-free symbol, lactose-free symbol	1.75	220

Table 1. Biscuit characteristics used in the study (Continued).

Group	Biscuit type	Biscuit code	Main ingredients	Images and symbols	Price (€)	Weight (g)
Gluten-free	Sandwich ("Oreo" like)	GF-San	Cream, sugar, palm oil, emulsifiers, corn flour, potato starch, cocoa powder, vanilla, gasifiers	Biscuit image, certified gluten-free symbol, lactose-free symbol	4.35	300
	Animal-shaped	GF-Ani	Corn starch, sugar, sunflower oil, cocoa powder, corn flour, potato starch, rice flour, emulsifiers, gasifiers	Biscuit image, cartoon character, gluten-free symbol, lactose-free symbol, oleic oil symbol	2.10	250
	"María" type	GF-Mar	Corn starch, sugar, rice flour, sunflower oil, emulsifier, corn flour, pea protein, gelling agents' oil, emulsifiers, gasifiers	Biscuit image, gluten-free symbol	1.30	200
Regular	Chocolate chips	Cho1	Wheat flour, choco chips, emulsifier, sugar, palm oil, glucose syrup, butter, gasifiers	Biscuit image	0.85	225
	Chocolate chips	Cho2	Sugar, wheat flour, vegetable oil, cocoa paste, cocoa butter, milk powder, emulsifiers, gasifiers	Biscuit image, GDA symbol	3.40	400
	Sandwich ("Oreo" like)	San	Wheat flour, sugar, palm oil, rapeseed oil, cocoa powder, wheat starch, glucose and fructose syrups, emulsifier, salt, gasifiers	Biscuit image, GDA symbol, promotional toy announcement	3.08	440
	Animal-shaped	Ani1	66% of cereals (wheat flour, rye flour, wheat starch, wheat bran), sugar, sunflower oil, milk, glucose syrup, gasifiers	Biscuit image, cartoon character, GDA symbol, sunflower oil symbol	1.40	330
	Animal-shaped	Ani2	Wheat flour, sugar, sunflower oil, whey, glucose syrup, emulsifier, vitamins (a, b), gasifiers	Biscuit image, cartoon character, sunflower oil symbol	1.39	600
	"María" type	Mar	Wheat flour, sugar, sunflower oil, whey, glucose and fructose syrup, emulsifier, gasifiers	Biscuit image, sunflower oil symbol	0.99	800

2.3. Experimental procedure

2.3.1. Eye-tracker recording when choosing biscuits in a supermarket context

The first part of the experiment took place in a room that contained a supermarket shelf (length: 270 cm, height: 180 cm) simulating a supermarket aisle. The biscuits in the study (eight products per sample) were placed on the two central shelves. One shelf was located at an appropriate eye-level for children and the other shelf at an appropriate eye-level for parents. Other products (different from biscuits) occupied the other shelves (the top and the bottom shelves). As often found in supermarkets, gluten-free and regular biscuits were grouped. The placement of the biscuits and the groups on the shelf was changed among participants to avoid the potential effect of product placement (Atalay, Bodur & Rasalofoaruson, 2012; Gidlöf, Anikin, Lingonblad, & Wallin, 2017).

Each parent and his/her children attended the session together but conducted the activities individually (parents before children). First, the parent was provided with a Pupil mobile eye-tracking headset (Pupil Labs GmbH, Berlin, Germany) equipped with a binocular camera system that recorded the participant's eye and another camera that recorded the participants' field of vision. Gaze fixations between 100 and 400 ms of duration and 1º of visual angle dispersion were registered for studying visual attention, as previously described (Bialkova & van Trijp, 2011; Salvucci & Goldberg, 2000). The information captured by the cameras was registered and recorded using the Pupil Capture Software Version 1.11 (Pupil Labs GmbH). The cameras' positions were adjusted for each participant to detect their pupils and accommodate distances for obtaining a wide field of view. Once the eye-tracker system was established, the participant was asked to imagine being in a supermarket to buy biscuits. He/she was provided with a basket, placed in front of the supermarket aisle and asked to choose the biscuit that would buy for his/her child. Once the biscuit was chosen, the participant was asked to select a second option.

Once the parent had finished, his/her child performed the same purchasing activity wearing the eye-tracker glasses. He/she was asked to imagine being in a supermarket with his/her parents buying biscuits and to put inside the basket the biscuits he/she would choose. Then he/she was asked to select his/her second option.

2.3.2. Laddering interview to register the reasons for choosing biscuits

After the participant finished the purchasing task, the eye-tracking glasses were removed and he/she was interviewed about the motives for choosing each biscuit (first and second option) using the laddering technique. It consists in asking a series of “why”-questions to obtain attributes, consequences and final values behind the decision. Thus, the participant was first asked, “Why did you choose this biscuit?” and then “why is that important to you?” and then “why is the latter important to you?”. This same procedure was followed to interview parents and children.

2.4. Data analysis

Two researchers independently analysed the eye-tracker video recordings using Pupil Player Software Version 1.11 (Pupil Labs GmbH). A first inspection of the videos was performed to determine the relevant elements of products (package characteristics and price) that received the attention of participants during the purchasing task. Accordingly, a list of elements was established by consensus. A second inspection of the videos registered the time to choose the first biscuit, the first element that received fixation on a package, the number of fixations toward each biscuit, and the number of fixations received by each element of the package. The elements considered were *biscuit image*, *product name* (e.g., “Oreo,” “María,” “Chips’ Ahoy”), *cartoon character*, *gluten-free words*, *brand name*, *list of ingredients*, *price*, *gluten-free symbol*, *lactose-free symbol*, *sunflower oil symbol*, *oleic oil symbol*, *GDA—Guideline Daily Amount—symbol, lactose-free words, nutritional information, weight, promotional toy announcement, sunflower oil symbol, best before date, fibre symbol, and nuts-free symbol.* The joint information registered by both researchers from each video was contrasted, and if differences or discrepancies were found between researchers, the video was watched again to reach consensus.

The effects of age group (children and their parents), coeliac condition (coeliac and non-coeliac), and its interaction on the number of fixations on the gluten-free biscuits, on the regular biscuits, and on each element of the package were analysed using General Linear Model (GLM) analysis with a Poisson distribution. Differences between mean values were analysed through Bonferroni test. The variation in the time to choose the first biscuit was analysed using ANOVA. These analyses were conducted in IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA).

Information collected during the interviews using the laddering technique of each participant was first categorized into the categories: attribute, consequence, and value (A-C-V) (Reynolds & Gutman (1988; Arcia et al., 2012) independently by two researchers. By consensus, the final A-C-V chains and their frequencies in each consumer group were established. The obtained chains were used to construct the Hierarchical Value Map (HVM). The cut-off or link between A-C-V used for chains was 10% of the size. Therefore, only chains with at least three mentions were considered for the graph.

3. RESULTS

3.1. Consumers' attention when choosing a biscuit in a supermarket context

The time to choose the first biscuit was registered and it vary greatly among participants. ANOVA showed it did not significantly depend on the coeliac condition or age ($p > 0.05$), and it was more related to the individual behaviour of subjects during the purchasing task, that followed three patterns. (1) Some participants located themselves in the middle of the room and quickly scanned the biscuits from both shelves' sides, without spending time on each one, then they went straight to choose their first option. These were the participants with the quickest choice. (2) Others also first scanned all biscuits, and went straight to one side of the aisle, where their interest type of biscuits was located (gluten-free or regular biscuits), and then they looked more in detail at that group of biscuits until they decided which one to choose. (3) Some participants looked at all the biscuits one by one—and compared them—until they chose one.

The total fixations on the gluten-free biscuits and on the regular biscuits was registered and according to GLM, significantly depended on the coeliac condition and age ($p < 0.05$). Figure 1 shows the mean values of the number of fixations received by the totality of biscuits of each type for each group of participants. The number of fixations on gluten-free biscuits did not significantly differ among coeliac children and their parents ($p < 0.05$), and as expected, they were higher than for non-coeliac groups. The number of fixations on regular (non-gluten-free) biscuits was higher for non-coeliac groups, but children showed lower number of fixations than parents. Coeliac children were those that less fixated on the regular biscuits.

Figure 1. Mean values of the number of fixations dedicated to the totality of biscuits of each type (gluten-free biscuits or regular biscuits) by each group of participants: coeliac children (), non-coeliac children (), parents of coeliac children (), and parents of non-coeliac children (). For each biscuit type, letters above the bars indicate significant differences among values according to Bonferroni test ($p<0.05$).

The element of the package that received the first fixation from the participant when they looked at each product was also registered. The distribution of the first fixation among the different elements (Figure 2) was similar for the four groups of participants. *Biscuit image* and *product name* were the elements that caught participants' first fixation more frequently (41–52%). *Cartoon character* received fixations with a frequency of 6–8%. The rest of the elements were first looked at in less than 5% of cases, except for the *gluten-free symbol* that in 7% of cases was the first element that parents of the coeliac-children group fixated on.

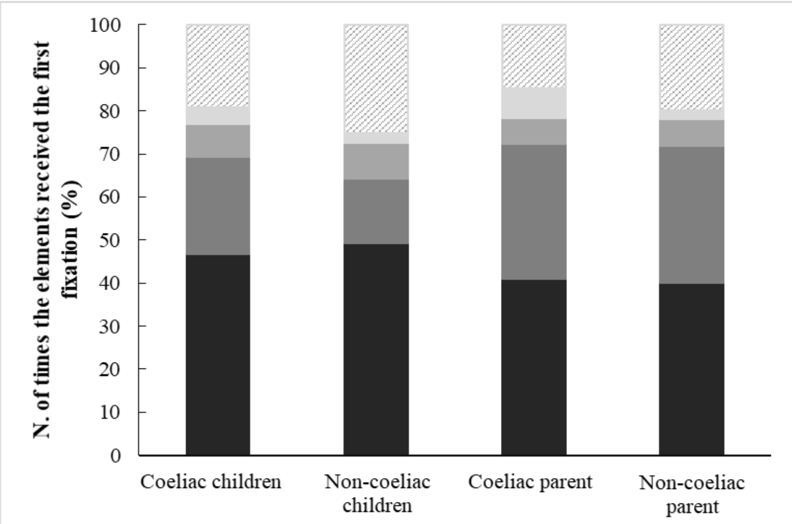

Figure 2. Number of times the element was the first item fixated on. Elements considered: Biscuit image (), Product name (), Cartoon character (), Gluten-free symbol (), and others ().

For the different elements of the biscuit packages on the supermarket shelves, the fixations of participants during the purchasing task were also studied. First, the percentage of participants that looked at the element at least once (fixations ≥1) was counted to evaluate how many participants paid attention to it (Figure 3).

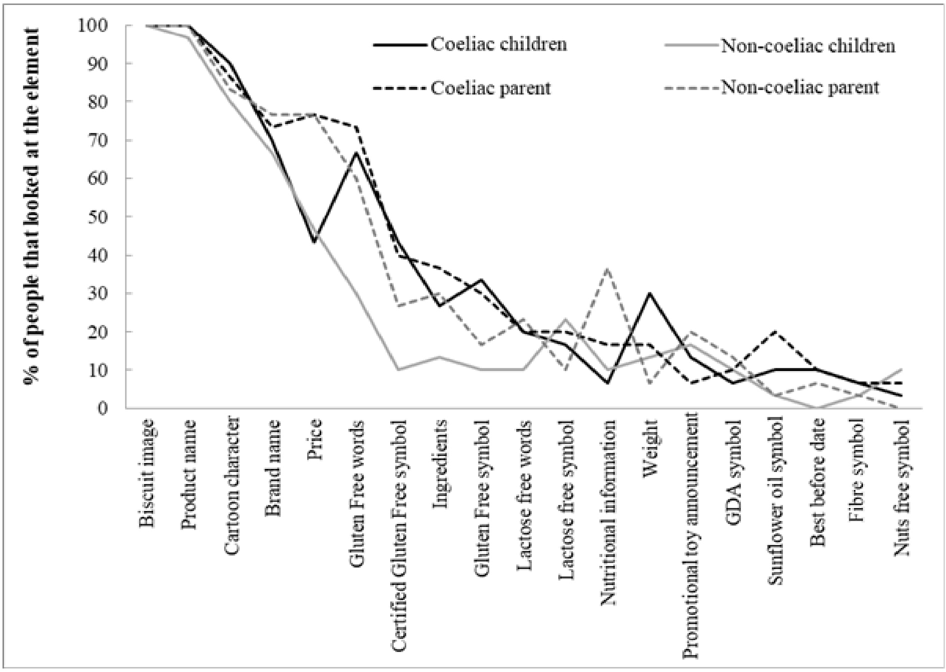

Figure 3. Elements looked during the purchasing task for each group of participants.

During the purchasing task, all the participants looked at the *biscuit image* and the *product name*. The *cartoon character* and *brand name* received fixations from at least 70% of the participants in all the four groups. *Price* and *gluten-free words* were observed by 40 to 75% of participants, depending on the group. *Certified gluten-free symbol*, *list of ingredients*, and *gluten-free symbol* captured the attention from 20 to 49% participants, with differences among groups. Finally, other elements of the biscuit packages such as *lactose-free words*, *lactose-free symbol*, *nutritional information*, *weight*, *promotional toy announcement*, *GDA symbol*, *sunflower oil symbol*, *best before date*, *fibre symbol*, and *nuts-free symbol* captured attention from less than 20% of participants.

The number of fixations on each element of the biscuit packages was also registered, and GLM analysis was used to determine the effects of age (children *vs*. parents) and coeliac condition (coeliac *vs.* non-coeliac) on each element (Table 2).

Table 2. Effects of participant age (children vs. parents), coeliac condition (coeliac vs. non-coeliac), and their interaction on the number of fixations received by each element during buying task.

Elements	Age		Coeliac condition		Interaction	
	Wald-*X2*	P-value	Wald-*X2*	P-value	Wald-*X2*	P-value
Biscuit image	2.78	0.095	10.45	0.001	0.58	0.447
Product name	83.55	<0.001	2.15	0.143	9.13	0.003
Cartoon character	3.32	0.069	0.59	0.444	8.83	0.003
Gluten-free words	17.52	<0.001	29.05	<0.001	14.87	<0.001
Brand name	4.46	0.035	0.22	0.637	9.49	0.002
List of ingredients	53.78	<0.001	45.50	<0.001	8.98	0.003
Price	20.28	<0.001	0.36	0.547	1.78	0.182
Gluten-free symbol	0.22	0.637	12.91	<0.001	11.36	0.001
Nutritional information	10.38	0.001	8.59	0.003	0.43	0.513
Certified gluten-free symbol	1.19	0.276	22.33	<0.001	0.96	0.326

For *price*, the number of fixations varied significantly only with the age group ($p < 0.001$); it was lower for children than for parents (Table 3). For the elements *biscuits image* and *certified gluten-free symbol*, the number of fixations varied significantly only with the coeliac condition ($p \leq 0.001$). Coeliac children and their parents dedicated more fixations to the *certified gluten-free symbol* and fewer fixations to the *biscuits image* than the corresponding non-coeliac groups.

Table 3. For each group of participants, mean values of the number of fixations on each of biscuits element.

Elements	Coeliac children	Non-coeliac children	Coeliac Parents	Non-coeliac parents
Biscuit image	18.60^{a}	20.57^{ab}	19.30^{a}	22.70^{b}
Product name	10.97^{a}	10.13^{a}	14.97^{b}	18.80^{c}
Cartoon character	3.30^{ab}	2.63^{a}	2.93^{a}	4.30^{b}
Gluten-free words	2.53^{b}	0.60^{a}	2.67^{b}	2.10^{b}
Brand name	2.27^{ab}	1.43^{a}	2.00^{ab}	2.80^{b}
List of ingredients	2.10^{b}	0.37^{a}	4.57^{c}	2.33^{b}
Price	1.37^{ab}	1.23^{a}	2.13^{bc}	2.80^{c}
Gluten-free symbol	1.23^{b}	0.10^{a}	0.43^{ab}	0.40^{a}
Nutritional information	1.10^{a}	1.53^{a}	1.60^{a}	2.70^{b}
Certified gluten-free symbol	0.90^{b}	0.13^{a}	0.93^{b}	0.27^{a}

For an element (row), frequency values not sharing letters are significantly different according to Bonferroni test ($p < 0.05$)

For *nutritional information*, the number of fixations showed to depend on both age group and coeliac condition (p = 0.001 and p = 0.003, respectively). The parents fixated more than their children, with the non-coeliac parent group putting more attention on this element.

For the rest of the elements, the interaction was significant ($p < 0.05$), indicating that the effect of the age group depended on the coeliac condition and vice versa. *Gluten-free symbol* and *gluten-free words* received more fixations by the coeliac than non-coeliac group but only with children. The *list of ingredients* received more fixations from the coeliac group and more fixations from parents than children. Parents of coeliac children put more attention on the *list of ingredients* than the other three groups. *Product name* received fewer fixations from children than parents, and for coeliac parents, the number of fixations was lower than for non-coeliac parents. *Brand name* and *cartoon character* received fewer fixations from children than from parents, but only in the non-coeliac group. For both coeliac children and their parents, the number of fixations on these two elements was between those obtained for non-coeliac children and their parents.

Summarizing, coeliac children fixated significantly more on the *list of ingredients*, *gluten-free words* and *gluten-free symbols* than the non-coeliac children and fixated significantly less on the *biscuit image*. Furthermore, it was observed that the profile of fixations of coeliac children changed little from their parents, whereas for non-coeliac children, it differed greatly from their parents.

Parents of coeliac children also showed differences from parents of non-coeliac children. They fixated less on the *biscuit image*, *product name*, *cartoon character*, and *nutritional information*, and put more attention on the *list of ingredients* and on the *certified gluten-free symbol* than the parents of non-coeliac children.

3.2. Motivations for biscuit choice

In the first choice, coeliac children selected mainly biscuits containing chocolate (GF-San, 33%; GF-Cho1, 27%; GF-Cho3, 20%) and the second choice was more diverse, including besides those containing chocolate, others like animal-shaped (GF-Ani) and “María” type (GF-Mar). Likewise, their parents first selected the biscuits containing chocolate chips (GF-Cho3, 27%; GF-Cho1, 23%), but also those animal-shaped (GF-Ani 23%). For the coeliac group, 30% of the parents selected the same biscuit as their children as the first choice.

Furthermore, non-coeliac children chose biscuits containing chocolate Cho2 (40%) and San (30%) as the first option, and the second option was more diverse, including besides biscuits containing chocolate chips (Cho1, Cho2), animal-shaped (Ani1, Ani2) and “María” type (Mar). Their parents bought the same biscuits Cho2 (27%) and San (23%) at first, but also those animal-shaped (Ani2, 17%). In the non-coeliac group, only 3% of parents selected the same biscuit as their children for the first option.

To understand the motives underlying the choice of biscuits, responses to laddering interviews were converted into the three-level chains (Attribute/Consequence/Value) and they were represented in a laddering map for each group of participants. As shown in Figure 4, all motivation chains elicited by children (coeliac and non-coeliac) led to the same ultimate value, pleasure. Different attributes and consequences led to this same ultimate value. For both coeliac and non-coeliac children, product characteristics such as having cream, chocolate, a good texture, good taste or being a known product were the attributes that made them think they would like the biscuit, and thus, would get the pleasure they expected. However, coeliac children elicited other attributes and consequences not found for non-coeliac children. Being unknown biscuits he/she would like to try or being a product from a known brand would give the feeling of a good product. In addition, a product that can be eaten in small bites, allowing to eat greater quantity of biscuits, or being a product like the regular one he/she would like, were the other reasons that coeliac children gave for choosing the biscuit.

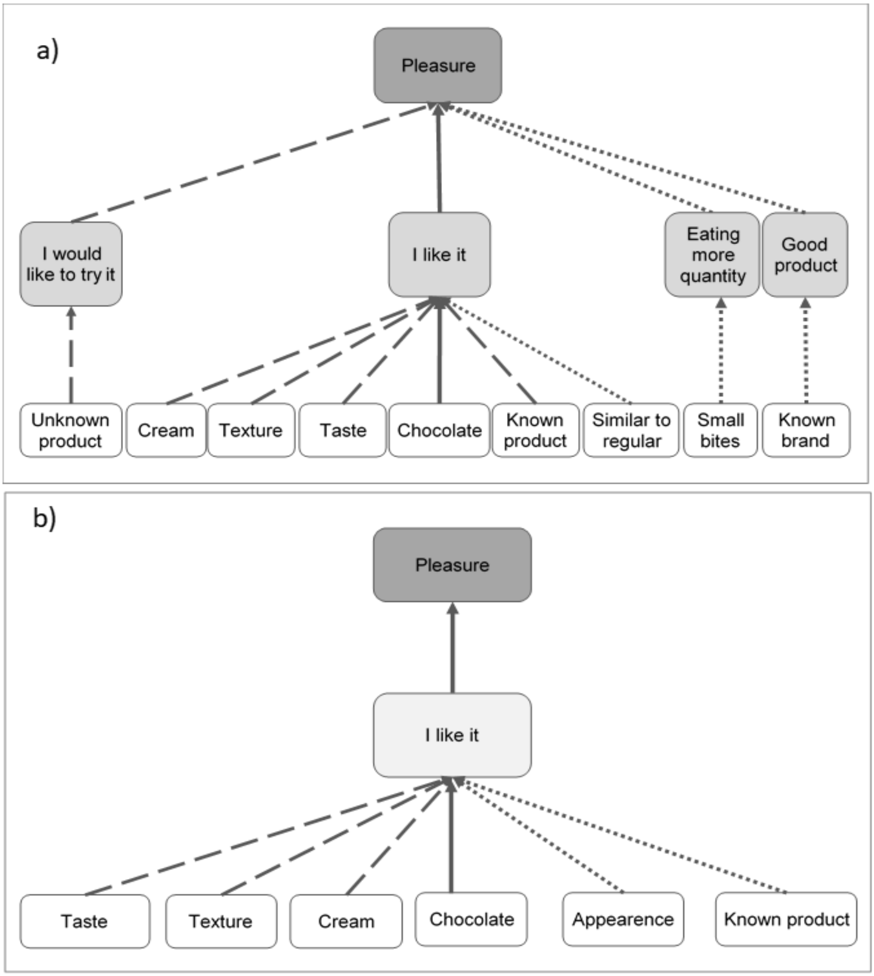

Figure 4. Motivations of coeliac children (a) and non-coeliac children (b) for choosing biscuits. Laddering plot showing the motivation chain: attribute (▭), consequence (▭), and value (▬). Frequency of mention of each relation is indicated by the arrow line style: ≤4 times (•••••), 5 to 14 times (▬ ▬), and >15 times (▬▬).

Figure 5 shows the chains of reasons given by parents when choosing the biscuits for their children. Like their children, the biscuit characteristics (good taste or texture, having cream or chocolate, appealing appearance, or being a known product) were the attributes the two groups of parents indicated for choosing the biscuit their children would like and enjoy. Parents of coeliac children also mentioned being a product like the regular one, and being an unknown product that their children would like to try.

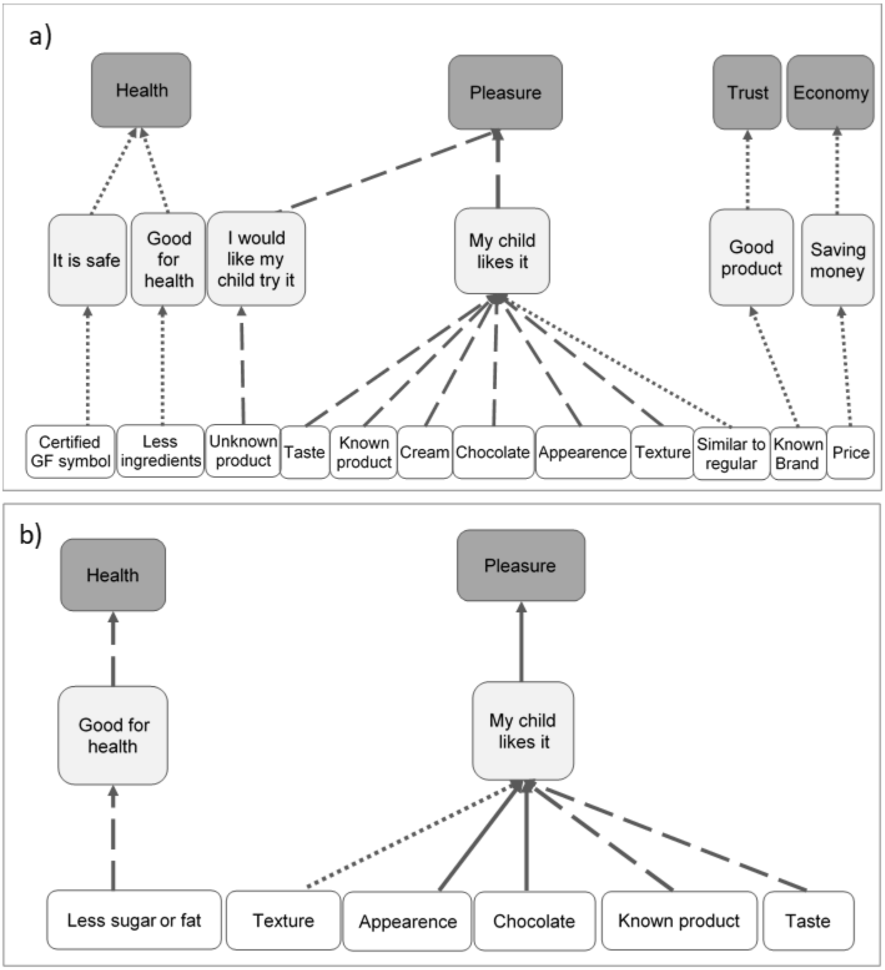

Figure 5. Motivations of parents of coeliac children (a) and parents of non-coeliac children (b) for choosing biscuits. Laddering plot showing the motivation chain: attribute (▭), consequence (▭), and value (▬). Frequency of mention of each relation is indicated by the arrow line style: ≤4 times (•••••), 5 to 14 times (▬ ▬), and >15 times (▬▬).

Besides pleasure, parents' choice showed to be driven by other final values. Healthiness was a reason for parents of both coeliac and non-coeliac children.

Parents of coeliac children that looked for providing healthiness to their children chose the biscuits having fewer ingredients or the certified gluten-free symbol, as they considered they were healthier and safer, respectively. However, for parents of non-coeliac children looking for healthiness, the attributes they considered important were having less sugar or fat content. For parents of coeliac children, a more complex response was observed, including trust and economy, as the values underlying their biscuit choice. Some parents of coeliac children chose the biscuit of a certain brand they already knew for having a product of good quality that conferred trust to them. Finally, the price was also a reason stated by parents of coeliac children looking to spend less money and better family economy.

4. DISCUSSION

4.1. Relevant elements and motivations of coeliac children and their parents compared to those non-coeliac

Product characteristics that caught participants' visual attention during the purchasing task were first studied. For the four groups of participants, *biscuit image*, *product name*, and *cartoon character* were the elements on the biscuits packages that caught participants' first fixation and that were looked at (at least once) by most participants during the purchasing task. It should be considered that in eye-tracking studies, part of the recorded eye movements is driven by the intention or interest of the subject (top-down attention) but there is also an important part of movements driven by the stimulus properties (bottom-up attention) as more salient elements receive visual attention even if the consumer is not searching for them.

For the biscuit packages in this study, these three elements (*biscuit image*, *product name*, and *cartoon character*) had those characteristics that can maximize visual attention, such as large surface size, centred or top position on the front of the package, and colour contrast (Bialkova, & van Trijp, 2010; Chen & Pu, 2010; Peschel & Orquin, 2013; Varela, Antúnez, Silva Cadena, Giménez,

& Ares, 2014; Wedel, & Pieters, 2007). The saliency of these elements capturing bottom-up attention would explain the high number of fixations received by these elements compared to the others. However, a goal-directed intention from consumers when fixating on these elements cannot be discarded. The number of fixations was especially high for *biscuits image* and *product name*, as these elements communicate its sensory traits, providing information that the consumer needs to make the choice decision. In previous studies, some have observed that, of all packaging elements, the image of a product provides quick and easy information to the consumer (García-Madariaga, López, Burgos, & Virto, 2019) and are the main element capturing consumers' attention (Pieters & Wedel, 2004). This is confirmed by the self-reported motivations of participants to choose the biscuit in the laddering interview. Common to all four groups, attributes such as having chocolate, cream, good appearance, taste, or texture are features that the consumer can obtain observing the biscuit image and product name, and were the reasons of many participants to choose the biscuit they would like and enjoy.

For the other less salient elements, such as *brand name*, *list of ingredients*, *nutritional information*, *claims*, *symbols*, and *price* the number of fixations received were lower and were mainly driven by the interest (goal-driven attention) of consumers as there were significant differences among the groups of consumers. Coeliac condition significantly affected the number of fixations on the elements related to gluten-free (*words* and *symbols*) and to the *list of ingredients*, which were in general higher for coeliac participants, especially when comparing the children groups. The need to avoid gluten in their diet explains the goal-driven attention paid by coeliac participants on these elements to check the product is suitable for them and minimize risk. Children with coeliac disease have reported to have difficulties in following a gluten-free diet (Fernández-Miaja, Martín, Treviño, González, & García, 2021) as they, and their parents, struggle to determine if food is gluten-free (Rashid et al., 2005; Gutowski et al., 2020). Therefore, when asking coeliac sufferers under 16 years old how to improve their life quality, they first mentioned to have better labelling of gluten-free food (Rashid et al., 2005).

The *list of ingredients* was also more relevant for coeliac participants. The type of flour can provide information to check the suitability of the product but also about its sensory quality, as coeliac consumers are concerned or interested about alternative flours for elaborating gluten-free products (Puerta, Laguna, Vidal, Ares, Fiszman, & Tárrega, 2020). However, healthiness seems to be the reason behind this attention to the *list of ingredients,* as consumers only refer to this element in the laddering task to declare choosing the biscuits with fewer ingredients because they are good for their children's health. Ares et al. (2013) have shown that ingredients were relevant for consumers for estimating the healthfulness and willingness to purchase products. Because fixations on the *list of ingredients* was higher for parents also supports that healthiness is the reason behind the attention paid to ingredients, as healthiness greatly concerns parents and their food choices (Ford, Eadie, Adams, Adamson, White, & Stead, 2020), but not children, that are more driven by the pleasure of eating a food product (Laureati, & Pagliarini, 2018).

Likewise, the number of fixations on *price* was higher for parents than children because they are more concerned about price. The parent of both groups of children looked at price similarly, but when they reported reasons for their choice, only parents of coeliac children mentioned the price. This is not strange as the price of gluten-free biscuits was two or three times the price of regular biscuits. The high price of gluten-free products (Capacci, Leucci, & Mazzocchi, 2018; Xhakollari, Canavari, & Osman, 2019) has been already reported as one of the main difficulties encountered by coeliac consumers to adhere to a gluten-free diet.

Coeliac children looked at the biscuits package differently to non-coeliac children, with a more goal-driven attention on ingredients and gluten-free words and symbols, and more like their parents than non-coeliac children. They showed to make a more informed or complex decision, which is corroborated when observing laddering plots of coeliac children that showed more attributes and reasons than non-coeliac children.

4.2. Comparing the information provided by eye-tracking and laddering in the purchasing context

As described in the previous section, the relevance of the different elements of packages based on the eye-tracking records were related to the attributes, consequences, or final motivations they elicited in the laddering technique. However, some aspects were only registered by one technique, providing additional information on how these factors influence the decision.

According to eye-tracking records, gluten-free words and symbols were relevant for coeliac children as they observed them more than non-coeliac children, probably to check that the biscuit was suitable for him/her (this is supported by none of the 30 coeliac children chose a regular biscuit). None of these aspects appeared when coeliac children stated the reasons behind their choice. Coeliac children looked at gluten-free indications to select the biscuit but during the interview they did not include this as a reason for the selection. Laddering did not reflect the relevance of being gluten-free as an attribute of choice of coeliac children, probably because they have assimilated that being gluten-free is a condition and it is not an option, so they verbalize the reasons to choose the biscuit among those that are gluten-free and suitable for them (which is reflected in the low attention coeliac children paid to regular biscuits).

The laddering technique reflects the relevance of unknown products for both coeliac children and their parents, and their willingness to try new products. This behaviour can be related to the range of gluten-free products in the market being limited (lower than for regular products) and usually with a poor sensory quality that according to Do Nascimento, Fiates, Dos Anjos, & Teixeira (2014), have two main consequences in coeliac individuals: food choice is restricted and their diets become monotonous. In this study, an additional consequence has been found as coeliac children are more open to try new or unknown products. Recently, Xhakollari, & Canavari (2019) have also described the interest of coeliac adults in trying new gluten-free products. Notably, aspects such as the response to unknown products that are related to past experiences, familiarity to the product, or attitudes of participants are relevant in the decision of consumers but cannot be registered by unconscious techniques such as eye-tracking, and can be only obtained when are self-reported by the participant.

Although it was not the objective of this study, the comparison of eye-tracker and laddering data also gave relevant information about children's behaviour during the experiment (what they looked at and the motivations they reported). In consumer research for children’s products, adults were initially used to test their food, however their preference and needs are different, that is why is important to conduct the test with children (Laureati, Cattaneo, Lavelli, Bergamaschi, Riso, & Pagliarini, 2017; Laureati, & Pagliarini, 2018). There is controversy regarding what methods to use and how to adapt them, or if this adaptation is needed. The main argument to use adapted methods is that children do not have the same competences as adults, and for example, their answers are few and short because they cannot express or verbalize their behaviour or ideas when they are complex. In this study, laddering plots for non-coeliac children were much less complex than for the other groups (coeliac children and adults), showing only few attributes and consequences behind the motivations of their choices. The number of fixations of these children during all the purchasing exercises was low. They mainly looked at the salient elements such as *biscuit image*, *product name*, and *cartoon character*, and hardly looked at the other elements. This indicates that the reason for the low complexity in the response of children is not due to a poor capability to verbalize their reasoning, but because they paid attention to only few elements and included fewer factors in their decision of biscuit selection. As also pointed out by Banister & Booth (2005), it is important to allow children to use their vocabulary and expressions in what they term “child-centric” approaches. These authors suggested children can be incredibly keen, able, and useful research participants when encouraged to get involved in the activity in an appropriate context, and an environment away from the influence of parents.

A limitation of this study was the low number of participants, due to the difficulty in recruiting coeliac children. However, it allowed drawing distinctive features in coeliac people behaviour during purchasing. Another limitation is that data were obtained in a simulated laboratory setting that allowed to control experiment conditions, but at the same time, could also lead to not fully reflect the real environment. As an example, supermarket included same number and variety of gluten-free and regular biscuits, that is not what consumers usually find at the supermarket aisle, which could have modified their behaviour. Further studies including more consumers and in a more real purchasing context might provide more representative and ecological results and stronger conclusions about coeliac consumers' behaviour.

5. CONCLUSIONS

This study conducted in a supermarket aisle context has shown what captures attention to coeliac children and their parents during the choice of biscuits and their motivations compared to non-coeliac ones.

In the purchasing context, coeliac children exhibit more goal-driven attention than non-coeliac children. They were more focused on the gluten-free information (words and symbols) and the list of ingredients and with a fixation profile closer to their parents. However, when reasoning the motives of their choice, coeliac children did not include being gluten-free but, similarly to non-coeliac children, they mainly included sensory attributes or ingredients they related to liking and pleasure. Different to the others, coeliac children were interested in the brand of the product and trying new products.

Parents of coeliac children were more concerned with the price of biscuits than those of non-coeliac children, but also differed in the biscuit attributes they associated to healthiness. Parents of coeliac children looking for healthiness, chose biscuits with a gluten-free certification symbol, a short list of ingredients, paid less attention to nutritional composition, and did not mention low fat and sugar content, which were the main concerns of the parents of non-coeliac children.

Combining eye-tracking and laddering techniques has proven to provide different and complementary information about consumer behaviour in a situational activity. It allows to better understand purchasing decisions and which factors affect consumer’s decisions unconsciously and consciously.

Supplementary Table 1. Frequency of mention (%) of descriptors by participants for each bread sample.

Descriptor	Frequency of mention (%)									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
artificial	0	2	2	0	1	4	5	2	3	1
bad appearance	0	11	0	1	1	5	6	1	4	3
bad taste	0	4	2	0	4	2	3	5	5	0
brittle	2	8	1	1	5	5	7	4	3	1
certification logo	8	14	2	4	1	14	16	0	1	2
crumbly	0	7	0	0	4	4	5	3	4	2
dry	2	10	1	2	3	7	9	1	5	2
good appearance	7	1	10	6	8	3	3	5	4	6
good taste	23	0	16	26	6	4	2	7	0	10
good texture	7	0	6	5	2	2	1	4	1	2
hard	0	15	1	2	1	7	15	1	6	1
healthy	7	2	4	9	3	1	0	2	0	5
known brand	3	4	6	8	2	0	0	1	1	4
lactose-free	5	1	6	6	7	0	0	5	1	0
much sugar	1	1	0	1	2	8	10	5	3	0
multigrain	7	0	0	4	0	0	0	0	0	1
no buy	0	7	1	0	4	12	13	4	11	5
no certification logo	0	0	1	1	2	0	0	8	3	2
not transparent package	1	0	0	0	0	2	1	0	14	1
palm oil	0	1	0	0	0	11	12	0	0	0
safety	4	2	6	8	2	3	3	1	1	3
small size	0	0	2	0	1	8	6	1	2	7
soft	2	1	10	3	9	1	0	8	2	3
sourdough	9	1	7	7	7	0	0	0	0	4
spongy	10	1	8	10	4	1	0	5	0	7
transparent package	2	1	5	3	4	0	0	5	0	0
trusty	9	4	8	8	1	1	3	5	0	1
white bread	0	10	13	0	8	0	4	10	10	0
with cereals	21	0	0	23	0	5	0	0	0	9
with fiber	2	0	0	2	0	1	0	0	0	5
with seeds	11	0	0	14	0	11	0	0	0	16

REFERENCES

Antúnez, L., Vidal, L., Sapolinski, A., Giménez, A., Maiche, A., & Ares, G. (2013). How do design features influence consumer attention when looking for nutritional information on food labels? Results from an eye-tracking study on pan bread labels. *International Journal of Food Sciences and Nutrition, 64*(5), 515–527.

Arcia, P. L., Curutchet, A., Costell, E., & Tárrega, A. (2012). Influence of Expectations Created by Label on Consumers Acceptance of Uruguayan Low-Fat Cheeses. *Journal of Sensory Studies*, *27*(5), 344–351.

Ares, G., Giménez, A., Bruzzone, F., Vidal, L., Antúnez, L., & Maiche, A. (2013). Consumer Visual Processing of Food Labels: Results from an Eye-Tracking Study. *Journal of Sensory Studies, 28*(2), 138–153.

Atalay, A. S., Bodur, H. O., & Rasolofoarison, D. (2012). Shining in the center: Central gaze cascade effect on product choice. *Journal of Consumer Research, 39*(4), 848-866.

Ávila, B. P., Cardozo, L. O., Alves, G. D., Gularte, M. A., Monks, J., & Elias, M. C. (2019). Consumers' Sensory Perception of Food Attributes: Identifying the Ideal Formulation of Gluten-and Lactose-Free Brownie Using Sensory Methodologies. *Journal of food science*, *84*(12), 3707-3716.

Ballco, P., de-Magistris, T., & Caputo, V. (2019). Consumer preferences for nutritional claims: An exploration of attention and choice based on an eye-tracking choice experiment. *Food Research International*, *116*, 37-48.

Banister, E. N., & Booth, G. J. (2005). Exploring innovative methodologies for child-centric consumer research. *Qualitative Market Research: An International Journal, 8*(2), 157-175.

Bialkova, S., Grunert, K. G., Juhl, H. J., Wasowicz-Kirylo, G., Stysko-Kunkowska, M., & van Trijp, H. C. (2014). Attention mediates the effect of nutrition label information on consumers' choice. *Evidence from a choice experiment involving eye-tracking. Appetite, 76*, 66-75.

Bialkova, S., & van Trijp, H. (2010). What determines consumer attention to nutrition labels?. *Food quality and preference, 21*(8), 1042-1051.

Bialkova, S., & Van Trijp, H. C. M. (2011). An efficient methodology for assessing attention to and effect of nutrition information displayed front-of-pack. *Food Quality and Preference, 22*(6), 592–601.

Camargo, A. M. D., Farias, J. P. D., Mazzonetto, A. C., Dean, M., & Fiates, G. M. R. (2020). Content of Brazilian supermarket circulars do not reflect national dietary guidelines. *Health promotion international*, *35*(5), 1052-1060.

Capacci, S., Leucci, A. C., & Mazzocchi, M. (2018). There is no such thing as a (gluten-) free lunch: Higher food prices and the cost for coeliac consumers. *Economics & Human Biology, 30*, 84-91.

Chen, L., & Pu, P. (2010, June). Eye-tracking study of user behavior in recommender interfaces. In *International conference on user modeling, adaptation, and personalization* (pp. 375-380). Springer, Berlin, Heidelberg.

Costell, E., Tárrega, A., & Bayarri, S. (2010). Food acceptance: The role of consumer perception and attitudes. *Chemosensory Perception*, *3*(1), 42–50.

Di Cairano, M., Galgano, F., Tolve, R., Caruso, M. C., & Condelli, N. (2018). Focus on gluten free biscuits: Ingredients and issues. *Trends in Food Science and Technology*, *81*(September), 203–212.

Do Nascimento, A. B., Fiates, G. M. R., Dos Anjos, A., & Teixeira, E. (2014). Gluten-free is not enough-perception and suggestions of celiac consumers. *International Journal of Food Sciences and Nutrition, 65*(4), 394–398.

Duerrschmid, K., & Danner, L. (2018). Eye tracking in consumer research. In *Methods in Consumer Research, Volume 2* (pp. 279-318). Woodhead Publishing.

Fernández-Miaja, M., Martín, J. J. D., Treviño, S. J., González, M. S., & García, C. B. (2021). Study of adherence to the gluten-free diet in coeliac patients. *Anales de Pediatría (English Edition), 94*(6), 377-384.

Ford, A., Eadie, D., Adams, J., Adamson, A., White, M., & Stead, M. (2020). Parents' and carers' awareness and perceptions of UK supermarket policies on less healthy food at checkouts: a qualitative study. *Appetite, 147*, 104541.

García-Madariaga, J., López, M. F. B., Burgos, I. M., & Virto, N. R. (2019). Do isolated packaging variables influence consumers' attention and preferences?. *Physiology & behavior, 200*, 96-103.

Gidlöf, K., Anikin, A., Lingonblad, M., & Wallin, A. (2017). Looking is buying. How visual attention and choice are affected by consumer preferences and properties of the supermarket shelf. *Appetite, 116*, 29-38.

Graham, D. J., Lucas-Thompson, R. G., Mueller, M. P., Jaeb, M., & Harnack, L. (2017). Impact of explained v. unexplained front-of-package nutrition labels on parent and child food choices: a randomized trial. *Public health nutrition*, *20*(5), 774-785.

Gross, S. M., Pollock, E. D., & Braun, B. (2010). Family influence: Key to fruit and vegetable consumption among fourth-and fifth-grade students. *Journal of nutrition education and behavior*, *42*(4), 235-241.

Grønhøj, A., & Gram, M. (2020). Researching family food decision making processes: highlights, hits and pitfalls when including young children’s perspectives. *Qualitative Market Research*. https://doi.org/10.1108/QMR-03-2019-0048

Gutowski, E. D., Weiten, D., Green, K. H., Rigaux, L. N., Bernstein, C. N., Graff, L. A., Walker, J.R., Duerksen, D.R., & Silvester, J. A. (2020). Can individuals with celiac disease identify gluten-free foods correctly?. *Clinical nutrition ESPEN, 36*, 82-90.

Hashim, I. B., McWatters, K. H., Rimal, A. P., & Fletcher, S. M. (2001). Consumer purchase behaviour of irradiated beef products: A simulated supermarket setting. *International Journal of Consumer Studies*, *25*(1), 53–61.

Jnawali, P., Kumar, V., & Tanwar, B. (2016). Celiac disease: Overview and considerations for development of gluten-free foods. *Food Science and Human Wellness*, *5*(4), 169–176.

Juhász, A., Colgrave, M. L., & Howitt, C. A. (2020). Developing gluten-free cereals and the role of proteomics in product safety. *Journal of Cereal Science*, *93*, 102932.

Keller, K. L., Kuilema, L. G., Lee, N., Yoon, J., Mascaro, B., Combes, A. L., Deutsch, B., Sorte, K., & Halford, J. C. (2012). The impact of food branding on children's eating behavior and obesity. *Physiology & behavior*, *106*(3), 379-386.

Köster, E. P. (2009). Diversity in the determinants of food choice: A psychological perspective. *Food Quality and Preference*, *20*(2), 70–82.

Laureati, M., Cattaneo, C., Lavelli, V., Bergamaschi, V., Riso, P., & Pagliarini, E. (2017). Application of the check-all-that-apply method (CATA) to get insights on children's drivers of liking of fiber-enriched apple purees. *Journal of Sensory Studies, 32*(2), e12253.

Laureati, M., & Pagliarini, E. (2018). New developments in sensory and consumer research with children. In *Methods in Consumer Research, Volume 2* (pp. 321-353). Woodhead Publishing.

Lebwohl, B., Sanders, D. S., & Green, P. H. R. (2018). Coeliac disease. *The Lancet*, *391*(10115), 70–81.

MacCulloch, K., & Rashid, M. (2014). Factors affecting adherence to a gluten-free diet in children with celiac disease. *Paediatrics and Child Health (Canada)*, *19*(6), 305–309.

Morais, E. C., Cruz, A. G., Faria, J. A. F., & Bolini, H. M. A. (2014). Prebiotic gluten-free bread: Sensory profiling and drivers of liking. *LWT - Food Science and Technology*, *55*(1), 248–254.

Nielsen, N. A., Bech-Larsen, T., & Grunert, K. G. (1998). Consumer purchase motives and product perceptions: A laddering study on vegetable oil in three countries. *Food Quality and Preference, 9*(6), 455–466.

O'Brien, M. C., McConnon, A., Hollywood, L. E., Cuskelly, G. J., Barnett, J., Raats, M., & Dean, M. (2015). Let's talk about health: Shoppers' discourse regarding health while food shopping. *Public Health Nutrition, 18*(6), 1001–1010.

Pechey, R., & Monsivais, P. (2015). Supermarket Choice, Shopping Behavior, Socioeconomic Status, and Food Purchases. *American Journal of Preventive Medicine, 49*(6), 868–877.

Peschel, A., & Orquin, J. (2013). A review of the findings and theories on surface size effects on visual attention. *Frontiers in Psychology, 4*, 902.

Pieters, R., & Wedel, M. (2004). Attention capture and transfer in advertising: Brand, pictorial, and text-size effects. *Journal of marketing, 68*(2), 36-50.

Piqueras-Fiszman, B., Velasco, C., Salgado-Montejo, A., & Spence, C. (2013). Using combined eye tracking and word association in order to assess novel packaging solutions: A case study involving jam jars. *Food Quality and Preference, 28*(1), 328–338.

Pliner, P., & Saunders, T. (2008). Vulnerability to freshman weight gain as a function of dietary restraint and residence. *Physiology & behavior*, *93*(1-2), 76-82.

Pontual, I., Amaral, G. V., Esmerino, E. A., Pimentel, T. C., Freitas, M. Q., Fukuda, R. K., Sant'Ana, I. L., Silva, L. G., & Cruz, A. G. (2017). Assessing consumer expectations about pizza: A study on celiac and non-celiac individuals using the word association technique. *Food Research International*, *94*, 1–5.

Puerta, P., Laguna, L., Vidal, L., Ares, G., Fiszman, S., & Tárrega, A. (2020). Co-occurrence networks of Twitter content after manual or automatic processing. A case-study on "gluten-free". *Food Quality and Preference, 86*, 103993.

Punch, S. (2002). Research with children: The same or different from research with adults?. *Childhood, 9*(3), 321-341.

Reynolds, T. J., & Gutman, J. (1988). Laddering theory, method, analysis, and interpretation. *Journal of advertising research, 28*(1), 11-31.

Rashid, M., Cranney, A., Zarkadas, M., Graham, I. D., Switzer, C., Case, S., Molloy, M., Warren, R.E., Burrows, V., & Butzner, J. D. (2005). Celiac disease: evaluation of the diagnosis and dietary compliance in Canadian children. *Pediatrics, 116*(6), e754-e759.

Salvucci, D. D., & Goldberg, J. H. (2000). Identifying fixations and saccades in eye-tracking protocols. *Proceedings of the Symposium on Eye Tracking Research & Applications - ETRA '00,* 71–78.

Singh, P., Arora, A., Strand, T. A., Leffler, D. A., Catassi, C., Green, P. H., Kelly, C. P., Ahuja, V., & Makharia, G. K. (2018). Global Prevalence of Celiac Disease: Systematic Review and Meta-analysis. *Clinical Gastroenterology and Hepatology*, *16*(6), 823-836.e2.

Terblanche, N. S. (2018). Revisiting the supermarket in-store customer shopping experience. *Journal of Retailing and Consumer Services*, *40*, 48-59.

van Herpen, E., van den Broek, E., van Trijp, H. C. M., & Yu, T. (2016). Can a virtual supermarket bring realism into the lab? Comparing shopping behavior using virtual and pictorial store representations to behavior in a physical store. *Appetite*, *107*, 196–207.

Varela, P., Antúnez, L., Silva Cadena, R., Giménez, A., & Ares, G. (2014). Attentional capture and importance of package attributes for consumers' perceived similarities and differences among products: A case study with breakfast cereal packages. *Food Research International, 64*, 701–710.

Wedel, M., & Pieters, R. (2007). A review of eye-tracking research in marketing. *Review of marketing research, 4*, 123–147.

Xhakollari, V. and Canavari, M, 2019. "Celiac and non-celiac consumers' experiences when purchasing gluten-free products in Italy". *Economia Agro-Alimentare, 21*(1). 29-48. 2019.

Xhakollari, V., Canavari, M., & Osman, M. (2019). Factors affecting consumers' adherence to gluten-free diet, a systematic review. *Trends in food science & technology, 85*, 23-33

General discussion of results

GENERAL DISCUSSION OF RESULTS

This Thesis focuses on the application of innovative approaches in sensory and consumer science for a better understanding of mechanisms implied in texture perception of gluten-free products and also of coeliac consumers' response to gluten-free products. The studies carried out deal with three very different aspects:

- How to gather and treat data from Twitter messages to get consumers' opinion and concerns in the "every-day" context.
- How knowledge about oral trajectory of gluten-free breads can help to explain dynamics of texture perception.
- Understanding coeliac consumers' response to gluten-free products through the combination of eye-tracking and self-reported techniques.

1. Coeliac consumers' opinion. How to manage Twitter information

Obtaining coeliac consumers' perceptions and responses towards gluten-free products is a challenging task due to the difficulty in recruiting coeliac participants for conducting consumer studies. For this reason, Twitter has been proposed in this Thesis as a source of information to understand concerns and opinions about gluten-free.

The analysis of messages posted on Twitter allowed to learning about the relevant aspects for consumers who tweet about gluten-free. In general, they mentioned five food products critical for the lack of gluten (bread, cake, cookie, pizza and beer), situations of consumption (social events, weekdays, places, occasions, celebrations or day moments), ideas associated to prepare gluten-free foods at home (recipes, culinary preparations, ingredients), recommendations about where to get them (supermarkets, bars, restaurants), and also positive sensations describing the consumption of these products (delicious, tasty, good, enjoy or happy).

Among the relevant products for people talking about gluten-free, bread was especially concerning for them, as was the most mentioned product in the tweets. Related to this product, they frequently talked about recipes, flour, seeds, different flour sources (rice, chickpea, quinoa, buckwheat, wheat, corn and whole grain), home-made baking, breakfast or burger. Other baked goods as cake, cookie and pizza were associated with recipes, ingredients for preparing them (fruits, chocolate or nuts for cake and cookie, and cheese, tomato, bacon or onion for pizza), or particular moments and occasions when these products are usually consumed (breakfast, dessert, birthday or weekend). Pizza was also referred to places where to get this gluten-free product as supermarkets, food chains and restaurants. In the case of beer, specific brands and types (craft, Ipa or Pilsen) were relevant, as well as places where to have a drink (bar, home, restaurant), supermarkets to purchase beer or also occasions and social contexts (friend, tapa, share or Saturday).

Recently, a study performed by Meleo-Erwin, Basch, Fera, & Smith (2020) explored posts regarding coeliac disease on Instagram. They did not look into specific product categories, but observed that the topics frequently posted referred to managing coeliac disease, pictures of food, gluten-free diet or giving support and advice regarding the disease. Although our study did not specifically address coeliac consumers or disease, similar concerns related to health and coeliac disease were found in users talking about “gluten-free” (diet, coeliac disease, alert, food intolerances, prevent, contamination, avoid or nutrition).

From a methodological point of view, our study shows Co-occurrence networks as a useful tool for plotting and interpreting Twitter data. They give relevance to the main aspects of the messages by representing its frequency (occurrence), but also put them in context and in relation to the other terms (co-occurrence). On one hand this technique has proven to be more practical and convenient than other methods based in the frequency of mention of terms (word clouds, word counting) that in addition require a qualitative analysis by an exhaustive reading of the messages in order to know the context of the term and avoid misinterpretation (Vidal, Ares, Machín, & Jaeger, 2015). On the other hand, analysis through co-occurrence networks is easier and simpler to implement than algorithms-based techniques, which require specific skills for programming and can bias the interpretation of data, given that they are usually based on an external source of information for the classification of the text units.

Our study has also addressed a practical question about data pre-processing when using co-occurrence networks for analysing tweets. The question was if pre-processing steps need to include qualitative analysis (manual) for obtaining meaningful information. Co-occurrence networks obtained from data processed through qualitative analysis and automatically processed data were compared showing that the information provided was similarly meaningful in both cases. We have proved that the process can be automated, avoiding manual pre-processing and allowing to manage the massive amount of available data online in an easy and feasible way. For food industry, this methodology represents a useful tool as an alert system to get information about what is said online regarding a product or brand, and also to monitor how these mentions change over time.

It should be taken into account some considerations about the information obtained from social media. Despite being spontaneous and voluntary, people tend to express only what users want to show and in the way they wish to be seen by others. In addition, and as also pointed by Vidal, Ares, & Jaeger (2018), the content available online is not representative of the entire population, but only of the users having access to the Internet, which should be beard in mind when drawing conclusions and making generalizations from online data. Furthermore, the information collected also depend on the capabilities of the application used to extract the information, and it is not always possible to obtain certain type of data, as the gender, age, or location from where the message is posted. Even when using payment platforms, that usually provide some additional personal information of users, this can be difficult to be accessed.

2. Oral trajectory of gluten-free breads in relation to dynamics of texture perception

Different commercial gluten-free breads were studied in relation to instrumental texture and how they behave in mouth during consumption to better understand the factors involved in the perception of texture sensations. Commercial gluten free breads showed a wide variation in mechanical properties and structure but also on how behave in mouth (fragmentation pattern, saliva incorporated and consistency and adhesiveness of the bolus formed). Texture sensations perceived during consumption also varied among breads: hard or soft sensations were dominantly perceived at the beginning; dry, spongy, crumbly and compact at initial and intermediate stages; sandy and pasty at intermediate and final stages; and sticky sensation was dominant only at final stages of consumption.

For each texture sensation, relation with structure, mechanical properties and oral processing features were established to understand the mechanism implied in its perception. Hard, soft, dry and spongy sensations perceived at the beginning of consumption were found to be related to the initial structure and mechanical properties of bread. Breads perceived as hard showed high values of instrumental hardness and low springiness. Those perceived as soft and spongy showed lower values of hardness and high springiness. Crumbly and sandy sensations have been associated to the breakage pattern of bread, being both sensations dominantly perceived in breads that broke down into a greater number of small particles. Compact sensation was found to be related to structures having a high number of small air cells and to a low amount of saliva incorporation. Bolus mechanical properties were found to explain relevant attributes at the end of consumption. The sensation of pasty was elicited by cohesive bolus and the sticky sensation was associated to bolus with high values of adhesiveness.

Comparison of dynamic sensory perception on regular and gluten-free breads has been performed for the first time on commercials breads. It has allowed identifying critical texture sensations in the gluten–free breads in the market, which were hardness (or absence of softness), crumbliness, dryness, sandiness, and the lack of sponginess and pastiness. However, differences in the perception of these sensations were also observed within the gluten-free group. Depending on the gluten-free bread both in-mouth behaviour and texture sensations were close or far from those containing gluten. Texture improvements in those gluten-free breads close to regular ones, seemed to be achieved by including more fat, emulsifiers or other additives as shown by the longer list of ingredients in gluten-free bread labels (Gobbetti, et al., 2018; Naqash, Gani, Gani, & Masoodi, 2017; Roman, Belorio, & Gomez, 2019).

However, as shown in Chapter 3 of the present Thesis, an extensive list of ingredients is a concern for coeliac consumers. In this context, it was decided to evaluate to what extent breadmaking conditions (time of fermentation and water hydration in dough) can be used to tailor the structure, in-mouth behaviour and texture sensations of gluten-free breads.

Gluten-free breads presenting different structure and mechanical properties, obtained by varying the fermentation time and water hydration, showed to affect the in-mouth behaviour and oral activity. Increasing time of fermentation made that breads broke down easily into smaller particles that were more homogeneous in size, requiring less time and chews to form the bolus. Breads with lower hydration required to incorporate more amount of saliva during mastication to get a bolus suitable to swallow. In general, consistency and adhesiveness of bolus decreased with long fermentation, and increased with short fermentation and low humidity of gluten-free bread, which was less consistent and adhesive.

Dynamics of texture perception of gluten-free breads also varied depending on the breadmaking conditions. Breads perceived as aerated and less dry, which are desirable sensations in gluten-free breads at the beginning of consumption, were those with longer fermentation. In subsequent stages of mastication, the sensations gritty, difficulty to form and swallow the bolus, and having sticky particles were similarly perceived in all breads. Notably, the major differences observed in texture perception at the beginning of mastication were explained by the initial structure of the bread and how it fragmented, which varied according to the fermentation time. The variations in baking conditions studied here have been shown to improve the texture sensations at the beginning of chewing, but those perceived at middle and final stages of mastication still remains to be improved. Therefore, other strategies based on compositional and/or processing aspects might be taken into account to achieve gluten-free breads that fragment in particles of adequate size and that allow to easily form a cohesive bolus, which would elicit desirable sensations also at middle and final stages of consumption.

3. Coeliac consumers' response to gluten-free products through the combination of eye-tracking and self-reported techniques

Although main constraints of coeliac consumers for adhering to a gluten-free diet have been identified, no studies are found until now about the characteristics and information on packages of gluten-free products that are relevant and useful for coeliac consumers.

Firstly, the visual attention of adult coeliac consumers and their response to gluten-free bread packages were investigated, as well as the impact of the presence of the gluten-free certification logo and the brand (specific or non-specific of gluten-free). Both factors showed to affect their visual behaviour. When the certification logo was not present, consumers looked more to the list of ingredients and nutritional facts or gluten-free symbol, which might have provided them the information that they require to assure that the product is suitable for consumption. Brand was also an element conferring trust to coeliac consumers, as in bread packages of a specific brand of gluten-free products, they fixated less on the gluten-free symbol or the list of ingredients. As they probably recognised the brand, did not need to check the information regarding gluten-free.

Certification logo did not have an impact on the trust perceived by these consumers. This result was unexpected, as this certification logo should give confidence to these coeliac consumers concerned about the absence of gluten in the food they purchase. It was found that in general, the coeliac consumers that participated in the study considered all the breads safe for consuming, as revealed by the high values of trust obtained. It can be inferred that, although the presence of this element did not affect the values of trust, it affected their visual behaviour and the elements of the label they looked, facilitating the task when present. This observation evinces that coeliac consumers are instructed in the task of evaluating and choosing gluten-free products, and they know what elements they have to inspect to assure that the product is suitable for consumption.

The type of brand showed to be a relevant factor in the perception of expected acceptability, having those breads of a specific brand of gluten-free products in general higher values of expected acceptability. However, other characteristics of the bread packages also influenced their expectations of liking. The concern of coeliac consumers for texture properties in gluten-free breads was highlighted, as shown by the features that they mentioned when describing the breads: those that were described as spongy or having good texture or soft, were related to higher values of expected liking, while those described as dry, brittle, hard, with bad appearance or not having a transparent package, were the less accepted. Other features were also appreciated by these consumers, as being a white or multi-grain bread, having a good taste, seeds or sourdough.

In a second work, visual attention and motivations driving biscuits purchasing decision of coeliac children and their parents were studied in comparison to non-coeliac children and their parents in a supermarket aisle context.

The fixations received by the different elements on the biscuit packages and the motivations reported for choosing the biscuits were found to vary among groups according to the coeliac condition, the age or both factors.

The four groups had in common that they all fixated their gaze on the name of biscuits, the image displaying the biscuits and when present, on the cartoon character, probably to figure out if they would like the biscuits.

However visual attention on brand name, nutritional information, list of ingredients, price, claims and symbols varied among groups. Coeliac condition affected the number of fixations, being higher for coeliac participants, especially when comparing the children groups. Coeliac children looked at the biscuits package differently from non-coeliac children, dedicating more attention to ingredients and gluten-free words and symbols, similarly to their parents. In general, the price was an element that attracted the attention of parents from both groups.

Regarding motivations, pleasure was found to be the most important reason for choosing a biscuit for both groups of children, but the attributes leading to that final value were different. Characteristics of the biscuits as having cream, chocolate, good taste, good texture or being a known product were mentioned by both groups of children, but coeliac children also reported others as being an unknown product that they would like to try or also being from a known brand.

For parents as well, liking and getting pleasure was the reason that most mentioned for choosing a biscuit. Both for parents of coeliac and non-coeliac children, health was also an important reason, but they differed in the attributes of the biscuits associated to health: for parents of coeliac children, these attributes were the presence of gluten-free certification symbol and a shorter list of ingredients; and for parents of non-coeliac children, less amount of fat and sugar. Further, for parents of coeliac children, other motivations were also important, as the trust, conferred by a product of a known brand, or a better family economy by purchasing biscuits with an appropriate price.

The joint use of eye-tracking and self-reported techniques combined allowed us to obtain different and complementary information, revealing both the non-conscious and conscious response behind the choices that coeliac consumers of different ranges of age make when purchasing gluten-free products as bread or biscuits.

This Thesis includes two studies using eye-tracking technique in different set-up conditions (evaluation on a screen or purchase in a simulated supermarket). The visual attention registered from participants evaluating one by one bread packages on the computer screen can be not much realistic because they are force to look at each packages and to both sides but when shopping at supermarket they have all products available at the same time and they look what they want. The advantage of the set-up conducted on a screen is that the profile of fixations of each consumer can be registered for all products, allowing a deeper analysis. The visual attention registered when purchasing a product in a simulated supermarket context provided more ecological data of what they would normally do, but only from those products that the participant “decides” to look, and not from all the products included in the study.

The type of analysis of eye-tracking data was also different in both set-up conditions: when the evaluation of products is performed on the screen, fixations are counted automatically. On the contrary, analysis of data obtained in the simulated supermarket requires visualising the recordings one by one, and to manually count fixations on each product and element. In addition, the analysis has to be performed by various researchers and reach a consensus, making this process long and tedious if the number of participants and/or products is high.

Summarizing, this Thesis has investigated the use of novel sensory and consumer techniques to face challenges in product development for groups of consumers with specific needs. The investigation has provided knowledge about the usability, practicality and scope of each technique.

Social networks research is a quick tool to picture consumers’ opinions, providing actionable information for first stages of development of products or in the design of communication strategies in public health campaigns. It could be also applied to monitor consumers’ opinion regarding a product or a topic over time for marketing departments or for public health entities as an alert system. Although it does not provide direct answer to specific questions of the researcher, it does allow to explore the consumer in a natural context. In addition, it is a technique affordable in resources of time and money.

Food oral processing approach includes multidisciplinary techniques as rheology, chewing activity, particle size distribution and sensory perception to gain knowledge on the mechanisms involved in food texture perception. Main outputs imply gaining knowledge on the mechanisms of perception, that can be very useful to define strategies for improving complex sensory attributes, but do not give direct indications for product improvement. The techniques are complex in the management and data analysis, and the research involves a considerable amount of time and money.

Eye-tracking methodology provides information about visual attention of consumers when faced to a product packaging or in a purchasing context (supermarket). This is useful in the design of messages or packages to communicate specific information. Eye-tracking technique provides complementary knowledge to self-reported techniques to better understand choice, liking or trust of consumers. However, eye-tracking data alone do not provide actionable information. In screen-based studies, the experimental set-up is complicated to get non-biased data. In real context set-up, the manual analysis makes the technique quite time-consuming.

REFERENCES

Gobbetti, M., Pontonio, E., Filannino, P., Rizzello, C. G., De Angelis, M., & Di Cagno, R. (2018). How to improve the gluten-free diet: The state of the art from a food science perspective. *Food Research International, 110*, 22-32.

Meleo-Erwin, Z., Basch, C. H., Fera, J., & Smith, B. (2020). #celiacdisease: The Use of Instagram in Contending with Chronic Illness. *Journal of Consumer Health on the Internet, 24*(1), 35–42.

Naqash, F., Gani, A., Gani, A., & Masoodi, F. A. (2017). Gluten-free baking: Combating the challenges-A review. *Trends in Food Science & Technology, 66*, 98-107.

Puerta, P., Laguna, L., Tárrega, A., & Carrillo, E. (2022). Relevant elements on biscuits purchasing decision for coeliac children and their parents in a supermarket context. *Food Quality and Preference 98,* 104496.

Roman, L., Belorio, M., & Gomez, M. (2019). Gluten-free breads: The gap between research and commercial reality. *Comprehensive reviews in food science and food safety, 18*(3), 690-702.

Vidal, L., Ares, G., Machín, L., & Jaeger, S. R. (2015). Using Twitter data for food-related consumer research: A case study on "what people say when tweeting about different eating situations." *Food Quality and Preference, 45*, 58–69.

Vidal, L., Ares, G., & Jaeger, S. R. (2018). Application of Social Media for Consumer Research. In G. Ares & P. Varela (Eds.), *Methods in Consumer Research, Volume 1: New Approaches to Classic Methods* (pp. 125–155). Woodhead Publishing.

Conclusions

CONCLUSIONS

1. Twitter is a good source to observe consumers' behaviour and opinions in their daily life as a kind of digital ethnographic tool. As shown for gluten-free, Twitter shows which products are relevant on the topic for the users, as well as the aspects related to the context of preparation, consumption or purchasing.
2. Co-occurrence networks are useful to analyse and summarize the huge amount of users' messages on social media. As shown in this Thesis, the analysis of Twitter messages using co-occurrence networks can be automatized without the need of manual analysis, and thus, it represents a promising tool to monitor changes in users' opinions about a specific product or topic.
3. In commercial gluten-free breads, critical texture properties that still need to be improved are those perceived during bread fragmentation and bolus formation, such as crumbly, sandy, compact, pasty and sticky. Accordingly, strategies for improving texture of gluten-free breads should be focused on tailoring breads breakage and bolus formation in mouth.
4. Coeliac consumers in general showed high trust in commercial gluten-free breads, especially in brands specific of gluten-free products. The presence of certification logo does not affect trust level of coeliac consumers, but it facilitates its assessment, as consumer need to pay less attention to the list of ingredients and nutritional facts.
5. Coeliac children behave as consumers differently from non-coeliac children. As their parents, the visual attention on biscuit packages of coeliac children is more focused on gluten free messages but also on the list of ingredients. Reasons for choice of coeliac children and their parents include other aspects that are not expressed by non-coeliac ones such as price, seeking for variety and a short list of ingredients.

6. The combination of eye-tracking and self-reported techniques provide complementary information for gaining insight into consumers' response to food products and for determining the role of the different factors in the decision making process.