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Evolution of the technological, sensory, and nutritional quality of gluten-free cookies: a critical review

Bruna Guedes de MELO[1], Bruna Lago TAGLIAPIETRA[1], Maria Teresa Pedrosa Silva CLERICI[1*]

Abstract

Understanding the scenario of the development of gluten-free products, the relationship with the public, and the present challenges is of paramount importance to advance the development of these products successfully. This review focuses on gluten-free cookies, with a discussion of the main results found for the different types of raw materials and their influence on product quality and the lack of innovation in new processes for such products. According to the presentation of the studies, the main challenges for the development of gluten-free cookies are the repetition of starchy raw materials and the processes that lead to technological and sensory results that displease consumers because they are being compared with the affective memory of the gluten-free product, which unbalanced the nutritional value of the products because they have high levels of carbohydrates and fat. In the food industry, innovations and changes are already occurring, such as the use of protein and fiber raw materials. However, it is still necessary to develop strategies dissociated from those used for gluten-free baked goods that are more personalized for this market, which, compared with wheat products with more than 2000 years of history, is in the first steps of development.

Keywords: gluten-free baked; quality; challenges; innovation.

Practical Application: The practical application is to increase the comprehension about the development of gluten-free cookies with better technological properties.

1 Introduction

The growing demand for gluten-free products is transforming the global food market. In 2019, the gluten-free market had revenues of more than 21.61 billion dollars, and a projection of 24 billion dollars is estimated in 2027 (Grand View Research, 2022). This increase may be caused by several factors, including the increase in more specific diagnoses for diseases related to gluten consumption, such as celiac syndrome, sensitivity to non-celiac gluten, and wheat allergy (Brouns et al., 2019). Many consumers also want to remove gluten from their diet as a lifestyle choice due to cultural, ecological, civic, historical, ethnic, and health issues (Worosz & Wilson, 2012), which indicates the break of food monotony, currently based on wheat, corn, rice, potato, and soy products.

According to the Gluten Intolerance Group, celiac syndrome affects approximately 1 in every 100 people worldwide (Singh et al., 2018). To avoid the possible complications caused by gluten and reduce abdominal and physical discomfort and difficulty in absorbing the nutrients caused by the disease, individuals need a restricted diet with total exemption from the consumption of wheat, triticale, rye, and barley for life (Di Sabatino & Corazza, 2009), which causes major changes in the lifestyle of individuals, as most products available on the market have gluten in their composition or risk of containing gluten, caused by the handling of gluten-free products and with gluten at the same environment.

Among the gluten-free products available in the market, the bakery segment stands out in the market in terms of value and volume, mainly because it has a wide variety, such as bread, cakes, cookies, snacks, breakfast cereals, and pasta products (Markets and Markets, 2021). Among these, cookies represent a large part of the products, being more consumed than bread when dealing with celiac people (Jnawali et al., 2016; Valitutti et al., 2017).

Cookies feature an extensive shelf life and versatility in the process, storage, purchase, and consumption (Silva et al., 2021). They are consumed by various age groups (Davidson, 2018), and among baked goods, they have the lowest requirements for gluten development to provide structure to the products (Di Cairano et al., 2018). However, as a consequence of gluten removal, there may be a decrease in protein, which generates products with increased carbohydrates and/or fats that negatively reflect on the nutritional quality of the cookies.

The development of gluten-free products is still a major challenge for the food industry, which seeks to find a three-dimensional network with properties similar to the gluten network, as observed in the studies by Clerici and El-Dash (2006), Clerici et al. (2009), and Silva et al. (2021) because the protein network has specific rheological characteristics, such as gas retention during expansion and formation of the alveolar structure in bread. Among the biscuit varieties, the laminates depend more on the extensibility of the gluten network, and the others,

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[1]*Universidade Estadual de Campinas, School of Food Engineering, Department of Food Science and Nutrition, Campinas, São Paulo, Brazil.*
*Corresponding author: mclerici@unicamp.br

like short-dough cookies, are very easy to make gluten-free (Davidson, 2018). Other challenges in the development of gluten-free foods are the acceptability of the product, due to the use of various raw materials. The cookies may be harder and have a dry and sandy sensation in the mouth, with an unpleasant appearance, color, and flavor (Di Cairano et al., 2018; Jnawali et al., 2016), in addition to lower nutritional value, considering that they have high-calorie content and lack proteins, fibers, minerals, and vitamins (Stantiall & Serventi, 2018). Due to the difficulty of the process and low production, gluten-free products have high added value and become less accessible to the population of middle to low social class.

Even with advances in research and consumer demand, there are still many gaps to be filled, as historically, these gluten-free products were regional and artisanal, with less industrialization. Thus, this review seeks to address the main raw materials used, as well as their technological, sensory, and nutritional limitations in the development of gluten-free cookies. Figure 1 presents a summary of the main aspects addressed in this review.

2 Gluten-free audience

Celiac disease diagnosed in any age group affects approximately 1.4% of the world's population (Markets and Markets, 2021), recognized as an autoimmune disease that causes inflammation of the intestinal microvilli (Hausch et al., 2002), whether throughout life, varying according to gender, age, and geographic location (Singh et al., 2018). Celiac disease can cause abdominal pain, weight loss, anemia, immunity disorders, osteoporosis, thyroid diseases, and vitamin and mineral deficiency due to chronic malabsorption (Green & Jabri, 2003). There is evidence that the disease has become systemic, attacking other organs, such as the skin, liver, bone, and brain (Rajput et al., 2022).

The disease was discovered in the European continent, but it also affects Caucasian individuals from North America, South America, and Oceania and non-Caucasian populations from Africa and Asia (Rajput et al., 2022). In Brazil, celiac disease affects approximately 2 million people, although many do not know the diagnosis because the symptoms can be confused with other intestinal diseases and/or nutritional deficiencies in the body (Fenacelbra, 2015). According to the Brazilian Celiac Association (Acelbra, 2021), the 2 million diagnosed cases are distributed mainly in six states, with approximately 35% in São Paulo, 13% in Santa Catarina, 5% in the Rio Grande do Sul, 5% in Rio de Janeiro, 5% in Paraná, and 5% in Minas Gerais. The other Brazilian states each represent less than 5% of the syndrome.

3 Gluten-free cookie consumption and market

According to the Brazilian Association of Biscuit, Pastry and Industrialized Breads and Pastries (Abimapi, 2020) among baked goods, cookies are the best-selling category, remaining in this ranking since 2018, moving approximately US $90.063 billion in 2020. Worldwide, since 2018, cookie sales have been led by the United States with 2.66 million tons (Mt); India with 2.66 Mt; Brazil with 1.53 Mt; China with 1.31 Mt, and Russia with 1.11 Mt. Brazil had a national consumption *per capita* of 7.21 kg/inhabitant in 2020 (Abimapi, 2020). These data presented by the associations do not inform the numbers relative to gluten-free cookies, which leads to a lack of economic information on the entire production chain, from raw materials, industries, types of products, packaging, and consumer markets dedicated to this category of cookies.

4 Raw materials used in gluten-free cookies

Table 1 shows the state of the art of studies in the period from 2010 to 2021 of gluten-free cookies focusing on the raw materials used in the formulations. Analyzing the ingredients of the 31 studies presented in Table 1, it is clear that, in relation to total carbohydrates, 84% of the studies used refined sugar and only 6% of the products had no added sugar. Moreover, 6% had added artificial sweeteners (sucralose). In Brazil, Normative Instruction No. 75 of October 8, 2020 (Brasil, 2020), has recently come into force, defining the limits of added sugars for the purpose of frontal nutrition labeling declaration. This new legislation aims to clarify consumers, in a visible and simple way, about the high content of nutrients, such as sugar, fat, and sodium, that have relevance to health. These measures stimulate the reformulation of products and may be an incentive for the decrease or substitution of added sugars, which was not yet a concern of the researchers, from those analyzed in Table 1.

Regarding the addition of fiber, it is observed that 97% of the studies presented some ingredient source of fiber in its composition. It is also noticed (Table 1) that proteins are ingredients widely used in the preparation of cookies. Most studies (97%) used vegetable protein, often associated with animal protein (milk and eggs), which are added to the composition of products due to their technological functions in the dough.

Of the studies (Table 1), 100% used fats, of which 22% correspond to fats of animal origin (butter) and the others present a large variation between hydrogenated vegetable fat and some types of vegetable oils. Normative Instruction No. 75 (Brasil, 2020), mentioned above for sugars, also sets the limits for saturated fat added to products. Above 6 g/100 g of ready-to-eat product, there must be a "high in saturated fat" warning to inform consumers.

Other ingredients such as thickeners, sodium and ammonium bicarbonate, water, salt, enzymes, citric acid, soy lecithin, baking powder, vanilla, and black pepper flavoring were used in 45% of the formulations. The selection of raw materials and their quality characteristics still present challenges such as studies to verify their techno-functional properties and their effects on the formulations, as these data are often not presented, for example, particle size characteristics, water absorption, and emulsifying properties, among others that could contribute to the discussion of the technological results presented by gluten-free cookies.

The data discussed in this topic can also be clearly visualized in Table 1, through a colorimetric identification of the raw materials used in larger quantities in the development of gluten-free cookies, which was built based on the knowledge that the authors have about the ingredients. From this analysis, it is possible to identify the main limitations (Figure 1), as well as the repeatability of the ingredients, which will be discussed next.

Table 1. Compiled from studies of gluten-free cookies.

Cookie number	Type	Main raw material	S	F	VP	Sugar	Animal origin protein	Fat	Other ingredients	References
1	Cookie	Rice flour Corn flour Amaranth flour Expanded amaranth flour				Sugar	Eggs	Butter	Bicarbonate	De la Barca et al. (2010)
2	Cracker	Yellow pea starch Yellow Pea Protein Isolate Green lentil flour Red lentil flour Chickpea Flour Bean flour Yellow pea fiber Hydrocolloid gums				Sugar	nc	Oil	Water, baking powder, and salt	Han et al. (2010)
3	Cracker	Refined buckwheat flour Whole buckwheat flour Flaxseed soaked Sesame Corn meal				Sugar	nc	Vegetable fat	Baking powder, salt, and soy lecithin.	Sedej et al. (2011)
4	Cookie	Rice flour Buckwheat flour Carboxymethyl cellulose				Sugar and honey	nc	Vegetable fat	Salt, $NaHCO_3$, and DATEM	Torbica et al. (2012)
5	Cookie	Rice flour Corn flour Maize starch Inulin Lupine flour Arabic gum Guar gum				Sugar	Milk	Hydrogenated vegetable fat	Sodium bicarbonate and salt	Maghaydah et al. (2013)
6	Cracker	Hydrated chia Brown rice flour Hemp flour				Sugar	nc	Canola oil	Sodium bicarbonate, salt, and green tea leaves	Radočaj et al. (2014)
7	Cookie	Rice flour Corn flour Buckwheat flour				Sugar HFCS	Skim powdered milk	Butter	Transglutaminase, salt, and sodium ammonium bicarbonate	Altindag et al. (2014)
8	Cookie	Oatmeal flour Oat bran				Sugar	eggs	Oil	Citric acid, sodium bicarbonate, and ammonium	Duta and Culetu (2015)
9	Cookie	Trapa Nantans flour Potato starch				Sugar	Whey and skimmed milk powder	Vegetable fat	Sodium ammonium bicarbonate	Sarabhai and Prabhasankar (2015)
10	Cookie	Maize starch Quinoa flour Quinoa flakes				Sugar	Pasteurized egg powder	Corn oil	Sodium bicarbonate and salt	Brito et al. (2015)
11	Wafer sheet	Rice flour Corn flour Chestnut flour Buckwheat flour				nc	nc	Coconut oil	Sodium bicarbonate, salt, and soy lecithin	Mert et al. (2015)
12	Cookie	Raw and germinated amaranth flour				Sugar	Skim powdered milk	Fat	Sodium bicarbonate, salt	Chauhan et al. (2015)
13	nd	Buckwheat flour Acacia, guar, tragacanth, and xanthan gum				Sugar	nc	Hydrogenated vegetable fat	nc	Kaur et al. (2015)

Continue...

Table 1. Continuation.

Cookie number	Type	Main raw material	S	F	VP	Sugar	Animal origin protein	Fat	Other ingredients	References
14	Cracker	Waxy rice flour Pregelatinized cassava flour Corn flour Pea and soy protein isolate Xanthan gum HPM and carboxymethyl cellulose				Sugar and glucose syrup	Whey isolate. Milk powder	Palm oil, Margarine	Salt, yeast powder, ammonia powder, and soy lecithin	Nammakuna et al. (2016)
15	Cookie	Rice flour Konjac flour				Confectioner's sugar	Evaporated milk, Skimmed milk	Corn oil Butter	Baking powder and vanilla aroma	Akesowan (2016)
16	Cookie	Rice flour Maize starch Pea protein				Sugar	nc	Margarine	Sodium bicarbonate	Mancebo et al. (2016)
17	Cookie	Rice flour Canola protein isolate and concentrate Buckwheat flour				Sugar and honey	nc	Margarine	Sodium bicarbonate and salt	Gerzhova et al. (2016)
18	Cracker	Brown rice flour Carboxymethyl cellulose Powdered apple pomace				Sugar	nc	Oil	Sodium bicarbonate and salt	Mir et al. (2017)
19	Cookie	Rice flour Tartaric buckwheat flour (*Fagopyrum tataricum* L. Gaertn) Buckwheat tartar malt				Granulated sugar	nc	Butter	Baking powder	Molinari et al. (2018)
20	Cookie	Rice flour Seed meal of *Medicago sativa* L (alfalfa seed flour)				nc	Eggs	Butter without salt	Baking powder	Giuberti et al. (2018)
21	ns	Banana flour				Sugar	Skim powdered milk	Vegetable fat		Gutiérrez (2018)
22	Cookie	Indian quinoa flour				Sugar	Skim powdered milk	Vegetable fat	Sodium bicarbonate and salt	Jan et al. (2018)
23	ns	Corn flour Pregelatinized rice flour Cassava starch Chestnut flour Vegetable fiber Guar Gum flour HPMC				Sucrose	nc	Butter	Flavoring, salt, and baking powder	Paciulli et al. (2018)
24	Cookie	Rice flour Corn flour Potato flour Rice starch Maize starch Raspberry fiber Blueberry fiber Guar gum				Granulated sugar, Glucose syrup	Egg powder	Vegetable fat	Salt and baking powder	Šarić et al. (2019)
25	Cookie	Rice flour Sweet potato flour Fermented and unfermented *Agaricus bisporus* polysaccharide flour Xanthan gum				Sugar	Skim powdered milk	Margarine	Sodium bicarbonate	Sulieman et al. (2019)

Continue...

Table 1. Continuation.

Cookie number	Type	Main raw material	S	F	VP	Sugar	Animal origin protein	Fat	Other ingredients	References
26	Short dough	Cassava flour Inulin Xanthan gum				Sugar	Eggs	Vegetable fat	Salt and baking powder	Lu et al. (2020)
27	Cracker	Rice flour Whole buckwheat flour *Opuntia monacanth* flour Mucilage of *Opuntia monacanth* Sour cassava starch Xanthan gum Carboxymethyl cellulose				Sugar	nc	Sunflower oil	Salt, sodium bicarbonate, powdered and dry yeast, α-amylase enzyme, and MFA	Dick et al. (2020)
28	Cookie	Rice flour Chickpea flour Acacia gum Apricot gum Karaya gum				Sugar	Instant skimmed milk powder and egg white	Vegetable fat	Baking powder	Hamdani et al. (2020)
29	Cookie	Corn endosperm flour Whole grain cornmeal Extruded whole cornmeal. Corn meal + germ bran				White sugar	nc	Margarine	Sodium bicarbonate	Paesani et al. (2020)
30	Cracker	Brown rice flour Polished rice flour Polished boiled rice White bean flour Baked beans Flaxseed Xanthan gum Dehydrated onion flakes				nc	nc	Extra virgin olive oil	Salt and baking powder	Silva et al. (2021)
31	Cookie	Rice flour with ↑ amylose content Carboxymethyl cellulose				Sucralose	Skim powdered milk and egg white	Butter	Salt and black pepper	Naseer et al. (2021)

DATEM: diacetyl tartaric acid esters of distilled monoglycerides; HFCS: high-fructose corn syrup; nc: not contain; ns: not specified; HPMC: hydroxypropylmethylcellulose; ↑: high; S: starch; F: fiber; VP: vegetable protein.

4.1 Starches

Starches are used in the food industry as ingredients to improve texture and as thickener and stabilizer agents (Schmiele et al., 2019) in the technological structures of products (Horstmann et al., 2017). Of the 31 studies presented in Table 1, rice was the most used raw material (62.3% of the studies) due to its light color, mild flavor, and neutral effects that it promotes in baked goods (Rosell & Marco, 2008); maize was present in 35.5% of the formulations and has the characteristic of providing color and brightness to the products, being consumed in different food crops (Serna-Saldivar & Carrillo, 2018). Starch was present in all studies evaluated, without any exception, which portrays the importance of this ingredient in the technological and sensory contributions of the products; however, depending on the starch source in relation to the glycemic index (GI) and its respective added amount, this influences the availability of carbohydrates with high GI and the nutritional value of the products. Advances in the use of other starchy sources with higher protein contents compared with cereals, such as chestnut flour, lentil flour, and *Agaricus bisporus* (present just one study each other), amaranth flour, bean flour, chickpea flour, quinoa flour, *Trapa nantans flour,* and oatmeal flour (present in the same percentage, like 6.5% of the studies), and buckwheat flour (present in 25.8% of the studies), may provide greater healthiness when combined with the balance of the other raw materials that offer benefits in the formulation.

4.2 Legumes

Legumes represent protein sources with an amino acid profile capable of complementing cereal proteins because they are rich in tryptophan and lysine and deficient in methionine (Baptist, 1954; Kan et al., 2017), which demonstrates that this combination can provide a balanced and efficient protein source to improve nutritional quality in the development of gluten-free products. Countries producing legumes have added such ingredients to their formulations, as observed in the Brazilian study by Silva et al. (2021), who developed gluten-free cookies from rice and bean flours, which are widely used products in local cuisine.

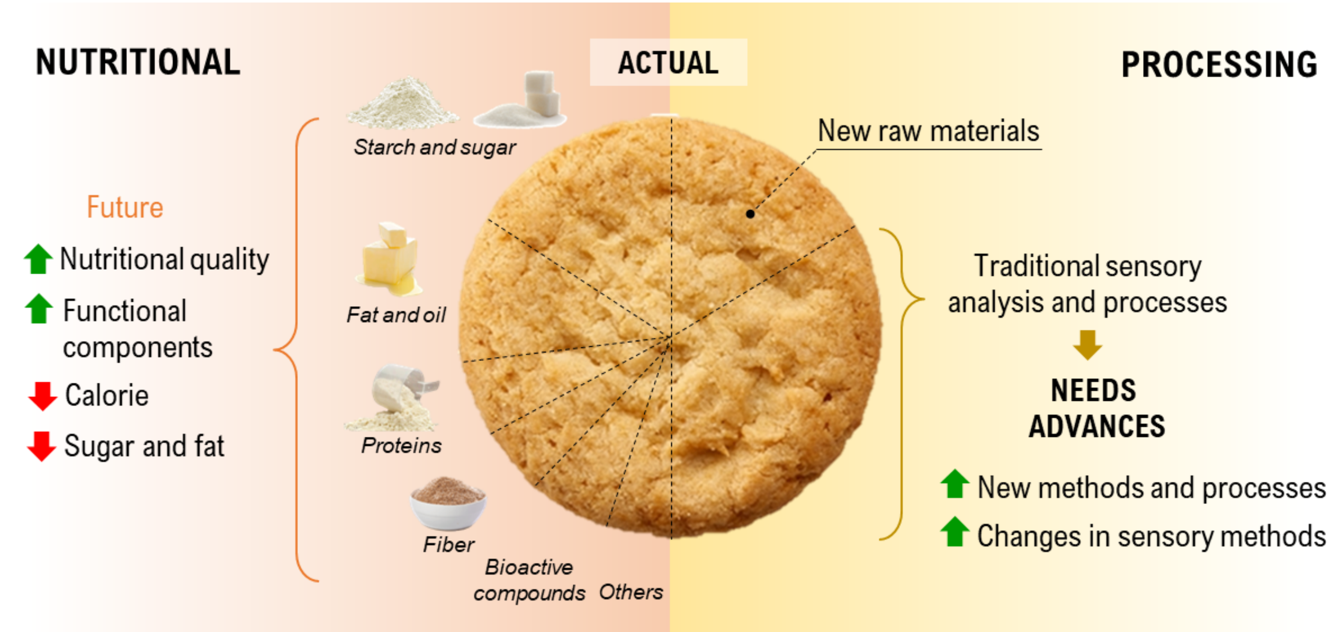

Figure 1. Summary of the main aspects addressed in this review.

However, it is observed that plant protein sources are not added to many cookies (Table 1) and are present in 21 formulations (65%). Of the studies that added protein sources, the flours varied between pseudo cereals buckwheat flour (present in 16.1% of the studies) and amaranth (present in 6.5% of the studies); legumes: chickpea (present in 6.5% of the studies), lentil, lupine, and alfalfa seed (present in one studied each other), bean (present in 6.5% of the studies), pea protein isolate (present in 9.7% of the studies), and oilseeds: *Trapa nantans,* hemp, and canola protein isolate (present in one studied each other).

Table 1 shows that there is still a path to be traveled that should be stimulated, even if these raw materials not only have a higher cost but will also provide greater nutritional benefit to the product. There are also no studies highlighting the techno-functional properties of proteins and their influence on the quality of gluten-free cookies.

4.3 Fibers

Table 1 shows that the fibers are being added in the studies in pure form such as yellow pea, vegetable (without origin specification), raspberry, and blueberry, which are present only once in the studies. Fiber has also been found in the form of flour and bran, such as oatmeal flour and bran, green and red lentil flour, whole buckwheat flour, *Trapa Nantans Flour*, chestnut flour, konjac flour, tartaric buckwheat flour, alfalfa seed flour, fermented and unfermented *A. bisporus* polysaccharide flour, *Opuntia monacanth* flour and mucilage, whole grain cornmeal and extruded whole cornmeal (present in one studied each other), quinoa flour and flakes, amaranth flour, chickpea flour, hemp flour (present in 6.5% of the studies each other), brown rice flour (present in 9.7% of the studies), corn flour (present in 22.6% of the studies), and buckwheat flour (present in 25.8% of the studies). Also, the fibers were found in another way, such as inulin, hydrated chia, dehydrated onion flakes, powdered apple pomace, flaxseed soaked and sesame, hemp flour (present in one studied each other), and flaxseed (present in 6.5% of the studies) among others. Although there is the presence of fibers in several studies, it is not clear whether all the sources were first added to the formulations for the purpose of fiber. It was observed that there was no concern with the balance in relation to soluble, insoluble, and prebiotic fiber in the formulations, which indicates that progress can also be made in this area.

4.4 Hydrocolloids

The gums act on the technological properties of the products, influencing the viscosity and texture properties (Xu et al., 2020). They are also characterized as soluble fibers, with the ability to promote beneficial health effects (Spiller et al., 2001). As observed in Table 1, hydrocolloids are present in 45% of the studies (Dick et al., 2020; Hamdani et al., 2020; Han et al., 2010; Kaur et al., 2015; Lu et al., 2020; Maghaydah et al., 2013; Mir et al., 2017; Nammakuna et al., 2016; Naseer et al., 2021; Paciulli et al., 2018; Šarić et al., 2019; Silva et al., 2021; Sulieman et al., 2019; Torbica et al., 2012) with technological objectives, where the authors did not report that the purpose of its application was as a fiber source, probably due to the concentrations used, which were lower than 2%.

4.5 Sugar

Regarding the substance that has the property to give a sweet taste to the products and provide an improvement in texture and flavor (Davidson, 2018), sugar is present in almost all articles, which means it was present in 28 studies (Table 1). Despite the technological and sensory advantages of sugars in the products, excessive consumption contributes to overweight, obesity, and the development of chronic diseases (Arnone et al., 2022) which promotes an impasse in the desired nutritional improvements in gluten-free cookies.

To assess sweetness, Naseer et al. (2021) proposed using the sucralose sweetener, characterized as a high-intensity sweetener capable of not providing calories to the individual's body. The amount added (680 mg/100 g of the weight of the flour) in the respective study is within the recommended amount of adequate dietary intake, which is 5 mg/kg of body weight/day according to the U.S. Food and Drug Administration (2022a).

4.6 Lipids

The lipids confer flavor, texture, tenderness, and crunchiness to the baked goods (Marcelino & Marcelino, 2012) with a technological effect on gluten-free cookies. According to Table 1, the lipid sources varied between margarine (present in 16% of the studies), butter (present in 19.3% of the studies), vegetable fat (present in 26% of the studies), oil (present in 32% of the studies), and hydrogenated vegetable fat (present in 6.5% of the studies). In addition to the wide variety of caloric sources via lipids, it is observed that they are present in high amounts in the formulations, which results in cookies with 9.7–40% fat (Table 3) and can negatively affect the nutritional balance of the products. Cookies in general (with and without gluten) have high-fat content in the formulation, as they help in the texture and chewability of the product. In addition, fat coats flour, which interferes with the hydration of proteins and the formation of the gluten network (Davidson, 2018). Studies focusing on fat replacement and reduction have been increasing (ITAL, 2020).

5 Technological properties

The technological analyses were applied to the gluten-free cookies, varying in the characteristics of hardness, rupture, expansion, and spread ratio, as shown in Table 2.

The expansion property is reflected in the volume and crunchiness of the cookies and depends on the presence and quantity of some ingredients able to provide structure and gas retention in the mass as protein isolate and hydrocolloids, such as xanthan gum, hydroxypropyl methylcellulose (HPM), carboxymethyl cellulose, pea, and soy protein isolate (Nammakuna et al., 2016). Starch also interferes with the expansion of the products, as observed in the studies by Brito et al. (2015) and De la Barca et al. (2010), which were prepared with amaranth and quinoa flour, respectively.

The spread ratio is an analysis that dictates the ratio of the width to the thickness of the cookies, portraying an important parameter to evaluate the increase in thickness after baking (Bolarinwa et al., 2019); thus, a higher factor represents a higher yield of the baked product (Jan et al., 2018). According to Okpala et al. (2013), the spread ratio is inversely proportional to the thickness, being present in 15 studies with values ranging from 4.60 W/T in the cookie formulated with rice, corn, lupine, and gum flours (Maghaydah et al., 2013) to 15.59 W/T in the cookie formulated only with rice flour and konjac flour (Akesowan, 2016). According to Naseer et al. (2021), gums reduce the spreading rate due to the increase in mass viscosity. The dimensions of the cookies can be influenced by various proportions of flour, starch, and protein (Mancebo et al., 2016) and by binomial time and temperature (Jan et al., 2018).

Hardness was commonly evaluated in 77.4% of the studies, ranging from 1.89 N (Akesowan, 2016) to 75.7 N (Brito et al., 2015), representing the maximum force (N) to break the cookie (Jan et al., 2018). The ingredients present in the formulations influence the hardness parameter of the cookies, being able to interact and form a rigid mass. For example, fiber has the potential to interact with proteins during cooking, which may result in greater cookie hardness (Naseer et al., 2021), as observed in Table 1 for studies (Brito et al., 2015; Duta & Culetu, 2015; Giuberti et al., 2018; Hamdani et al., 2020; Jan et al., 2018; Kaur et al., 2015; Paciulli et al., 2018; Paesani et al., 2020). The presence of sugar also has the potential to promote the highest hardness because, when cooled, it converts its physical state into vitreous (Jan et al., 2018), which explains the variations in the parameter in cookies with the addition of this ingredient.

The rupture was the second least performed analysis by the authors, with the presence in 29% of the studies of gluten-free cookies (Altindag et al., 2014; Gerzhova et al., 2016; Han et al., 2010; Mancebo et al., 2016; Mert et al., 2015; Mir et al., 2017; Paciulli et al., 2018; Silva et al., 2021; Sulieman et al., 2019) with values ranging from 0.34 (Mancebo et al., 2016) to 2.73 mm (Altindag et al., 2014). According to Mancebo et al. (2016), the presence of protein may decrease the crack resistance of cookies, corroborating the studies by Han et al. (2010) and Mancebo et al. (2016) because they obtained the lowest rupture values with the presence of green lentil, red lentil, chickpea, bean flour, and pea protein, respectively. As the hardness property is proportional to the breaking strength (Nammakuna et al., 2016), both studies did not obtain the highest values in hardness.

Analyzing Table 2, the color of the cookies has high luminosity (parameter L*), a more yellowish color (parameter b*), and low reddish color (parameter a*). The difference in color varies according to the ingredients used in the formulation, depending on the type of flour, fibers, and proteins added, and raw materials with light hues provide higher luminosities. Torbica et al. (2012) found higher values of a* and b* in cookies with more chromatic characteristics for red and yellow, due to the source of protein and fiber from buckwheat and carboxymethylcellulose (CMC). The cookies made only with the flour of gluten-free mixtures (i.e., corn flour, pregelatinized rice, and cassava starch) developed by Paciulli et al. (2018) showed higher L* intervals when compared with the nut flour formulations (source of starch and fiber), which had higher values of a* and b*. Color analysis was not performed in 22.5% of the studies (De la Barca et al., 2010; Gutiérrez, 2018; Kaur et al., 2015; Lu et al., 2020; Molinari et al., 2018; Naseer et al., 2021; Sedej et al., 2011).

6 Sensory properties

The cookies were mostly subjected to sensory analysis (Table 2), except for the studies by De la Barca et al. (2010), Gutiérrez (2018), Molinari et al. (2018), Nammakuna et al. (2016), Paciulli et al. (2018), and Šarić et al. (2019). According to those observed in the articles, no sensory studies evaluated people with some level of restriction to gluten, in which only Han et al. (2010) performed the sensory analysis with a substantial number of unidentified consumers of gluten-free products.

Table 2. Technological and sensory properties of gluten-free cookies.

Cookie number	Type	Technological				Color			Sensory			References
		Hardness	Breaking strength	Expansion	Spread ratio (W/T)	L*	a*	b*	Tasters		Acceptability level	
									Celiac	Non-celiac		
1	Cookie	10.8 N	nd	5.84	nd	nd	nd	nd	nd			De la Barca et al. (2010)
2	Cracker	~ 5.7 N	~0.36 mm	nd	nd	~79	~ 3	~ 30		x	Nice	Han et al. (2010)
3	Cracker	nd	nd	nd	nd	nd	nd	nd		x	Nice	Sedej et al. (2011)
4	Cookie	nd	nd	nd	nd	48.19–61.03	9.51–19.40	35.26–46.16		x	Nice	Torbica et al. (2012)
5	Cookie	nd	nd	nd	4.60–4.90	70.10–72.02	-2.87 to -2.94	35.80–35.90		x	Nice	Maghaydah et al. (2013)
6	Cracker	nd	nd	nd	nd	33.84–46.47	4.13–6.12	6.05–16.65		x	Nice	Radočaj et al. (2014)
7	Cookie	976.0–2295.2g	1.52–2.73 mm	nd	5.02–5.90	53.34–57.37	11.02–12.18	35.11–40.11	nd			Altindag et al. (2014)
8	Cookie	18.3–29.3 N	nd	nd	nd	76.31–78.43	3.00–4.12	22.05–24.45		x	Nice to moderate	Duta and Culetu (2015)
9	Cookie	13.1–34.0 N	nd	nd	4.75–6.14	ni	ni	ni		x	Nice	Sarabhai and Prabhasankar (2015)
10	Cookie	8.7–75.7 N	nd	0.7–2.2 $cm^3.g^{-1}$	nd	58–90	nd	nd		x	Nice	Brito et al. (2015)
11	Wafer	-15 to 38 N	~4–10 N	nd	nd	~55–75	~-1 to 9	~22–36		x	Moderate	Mert et al. (2015)
12	Cookie	42–50.53 N	nd	nd	7.44–7.95	61.70–63.25	6.70–7.15	23.93–25.05		x	Low overall acceptance for raw amaranth flour	Chauhan et al. (2015)
13	nd	27.62–42.30 N	nd	nd	7.16–7.64	nd	nd	nd		x	Good general acceptance for buckwheat flour with gums	Kaur et al. (2015)
14	Cracker	68.75–653.18 g	nd	20.08–73.03%	nd	49.70–52.50	31.70–34.30		nd			Nammakuna et al. (2016)
15	Cookie	1.89–3.48 N	nd	nd	10.99–15.59	58.88–63.07	11.14–11.25	28.19–29.89		x	Nice to moderate	Akesowan (2016)
16	Cookie	22.37–28.30 N	0.34–0.57 mm	nd	4.90–8.15	70.95–78.63	0.22–6.77	19.61–26.68		x	Nice to moderate	Mancebo et al. (2016)
17	Cookie	1300.0–2500.0 g	6–12	nd	5.12–7.20	41.38–59.61	2.51–9.53	18.01–34.16		x	Nice	Gerzhova et al. (2016)
18	Cracker	nd	1667.5–2042.1 g	nd	nd	41.38–56.09	10.05–14.84	27.32–30.34		x	Nice	Mir et al. (2017)
19	Cookie	nd	nd	nd	nd	nd	nd	nd	nd			Molinari et al. (2018)
20	Cookie	52.00–58.20 N	nd	nd	5.00–5.60	54.20–72.70	1.30–5.90	27.00–33.50		x	Moderate	Giuberti et al. (2018)
21	nd	nd	nd	nd	nd	nd	nd	nd	nd			Gutiérrez (2018)
22	Cookie	34.05–58.09 N	nd	nd	5.89–7.26	46.08–56.90	nd	nd		x	Nice to moderate	Jan et al. (2018)
23	nd	18–65 N	0.4–1.2 mm	nd	nd	58.04–87.70	0.32–8.04	12.01–19.03	nd			Paciulli et al. (2018)
24	Cookie	576–1402.03 g	nd	nd	5.44–6.34	nd	nd	nd	nd			Šarić et al. (2019)
25	Cookie	748–1590 g	775–1399 g	nd	5.70–6.56	41.01–50.52	5.45–9.29	15.00–22.21		x	Nice to moderate	Sulieman et al. (2019)

Continue...

Table 2. Continuation.

Cookie number	Type	Technological				Color			Sensory			References
		Hardness	Breaking strength	Expansion	Spread ratio (W/T)	L*	a*	b*	Tasters: Celiac	Tasters: Non-celiac	Acceptability level	
26	Short dough	2.01–3.53g	nd	nd	nd	nd	nd	nd			Good general acceptance for xanthan gum by electronic nose	Lu et al. (2020)
27	Cracker	14.50–17.71 N	nd	nd	nd	47.76–71.00	0.14–3.00	18.17–23.62		x	Nice to moderate	Dick et al. (2020)
28	Cookie	30–50 N	nd	nd	7.5–8.3	55.01–56.03	2.03–4.01	32.10–35.10		x	Nice to moderate	Hamdani et al. (2020)
29	Cookie	30.71–69.47 N	nd	nd	6.43–12.20	57.90–70.90	9.87–11.91	33.33–37.17		x	Nice	Paesani et al. (2020)
30	Cracker	15.46–26.26 N	0.47–1.82 mm	nd	nd	57.07–63.83	7.38–11.03	25.08–29.22		x	Nice to moderate	Silva et al. (2021)
31	Cookie	31.00–48.90 N	nd	nd	4.76–7.19	nd	nd	nd		x	Nice	Naseer et al. (2021)

nd: not determined; ni: not identified.

Although sensory analysis is very present in the evaluation of these products, the conduct in the choice of participants contradicts the desired advances due to the sensory source of gluten-free products in the panelists, which can generate negative evaluations of gluten-free cookies. However, these products are usually developed in traditional food laboratories, where raw materials with gluten and gluten-free are handled, which does not guarantee the absence of any remnants of the protein in the medium. This scenario may justify not conducting sensory research with a specific audience. According to U.S. Food and Drug Administration (2022b), the product is allowed to have a maximum of 20 parts *per million* (ppm) or 20 mg/kg of protein, and the ELISA immunological method approved by Codex Alimentarius in 2006, which detects the presence and amount of the protein network in the formulation, was not performed by any of the studies cited.

Given the methodologies of sensory analyses shown in Table 2, it was observed in 45.2% of the studies that the participants were trained and semi-trained panelists (Chauhan et al., 2015; Duta & Culetu, 2015; Giuberti et al., 2018; Hamdani et al., 2020; Han et al., 2010; Jan et al., 2018; Kaur et al., 2015; Maghaydah et al., 2013; Mert et al., 2015; Naseer et al., 2021; Radočaj et al., 2014; Sarabhai & Prabhasankar, 2015; Sedej et al., 2011; Torbica et al., 2012), and in 29% of the studies, they performed the sensory with individuals without any training, named consumers (Akesowan, 2016; Brito et al., 2015; Dick et al., 2020; Gerzhova et al., 2016; Mancebo et al., 2016; Mir et al., 2017; Paesani et al., 2020; Silva et al., 2021; Sulieman et al., 2019).

Sensory tests are repeated frequently, such as the descriptive method quantitative descriptive analysis (Duta & Culetu, 2015; Radočaj et al., 2014; Sarabhai & Prabhasankar, 2015; Sedej et al., 2011) and the affective acceptance test for the attributes of taste, aroma, texture, appearance, crunchiness, and color, with the results of overall good acceptability for gluten-free cookie samples (Akesowan, 2016; Brito et al., 2015; Chauhan et al., 2015; Dick et al., 2020; Duta and Culetu 2015; Gerzhova et al., 2016; Giuberti et al., 2018; Hamdani et al., 2020; Han et al., 2010; Jan et al., 2018; Kaur et al., 2015; Maghaydah et al., 2013; Mancebo et al., 2016; Mir et al., 2017; Naseer et al., 2021; Paesani et al., 2020; Radočaj et al., 2014; Silva et al., 2021; Sulieman et al., 2019; Torbica et al., 2012).

It can be observed that the training sessions held for the participants evaluated the sensory attributes with a focus on technological properties such as crunchiness, chewability, hardness, burst, and mouthfeel, as seen in the studies by Duta and Culetu (2015), Hamdani et al. (2020), Han et al. (2010), Jan et al. (2018), Lu et al. (2020), Naseer et al. (2021), Radočaj et al. (2014), Sulieman et al. (2019), and Torbica et al. (2012). The articles did not detail how the training was conducted, how the participants were selected, or whether products with or without gluten were used. Combining the facts, there are questions about the conduct performed because there is a possibility that the training is conducted with not gluten-free cookies, creating sensory memories and applying the same parameters to the gluten-free cookies, which again portrays the search for standardization and similarity of products with gluten.

These arguments elucidate questionable positions of the food industry and science for these products in question. The gluten-free public still faces difficulties due to the lack of nutritional, sensory, technological, and economic improvements of the products and does not have the freedom to choose because of the small diversity of portfolios and high cost of the products.

7 Nutritional properties

Gluten-free cookies are characterized by a formulation rich in fat and sugar (Table 3), which causes concern regarding their nutritional quality. The use of highly refined flours and starches with a low amount of dietary fiber makes the cookies highly caloric products.

Table 3. Nutritional properties of gluten free cookies.

Cookie number	Type	Nutrients (%)				Caloric value		Carbohydrate Digestibility			Reference
		Carbohydrates	Dietary fiber	Fat	Protein	30 g	100 g	HI	GI	GL	
1	Cookie	73.76	nd	15.45	9.0	141*	470*	nd	nd	nd	De la Barca et al. (2010)
2	Cracker	70.79	5.40	13.30	10.68	133.6	445.6	nd	nd	nd	Han et al. (2010)
3	Cracker	52.3–46.7	9.2–11.8	25.2–27.2	10.2–11.4	142.5*	475*	nd	nd	nd	Sedej et al. (2011)
4	Cookie	nd	nd	nd	nd	nd	nd	nd	nd	nd	Torbica et al. (2012)
5	Cookie	68.74–68.85	11.77–14.96	12.61–12.87	13.91–13.95	130.5*	435*	nd	nd	nd	Maghaydah et al. (2013)
6	Cracker	32.33–56.00	4.91–12.26	22.06–24.86	6.47–16.40	102*	340*	nd	nd	nd	Radočaj et al. (2014)
7	Cookie	nd	0.32–0.68	18.81–20.04	4.34–5.55	nd	nd	nd	nd	nd	Altindag et al. (2014)
8	Cookie	26.78–37.38	14.66–22.83	18.21–19.80	11.92–13.82	126.5*	419.1–27.6	nd	nd	nd	Duta and Culetu (2015)
9	Cookie	nd	nd	nd	nd	nd	nd	nd	nd	nd	Sarabhai and Prabhasankar (2015)
10	Cookie	63.11	11.00	18.69	7.09	15.9	56.1	nd	nd	nd	Brito et al. (2015)
11	Wafer	nd	nd	nd	nd	nd	nd	nd	nd	nd	Mert et al. (2015)
12	Cookie	nd	9.93–13.97	nd	nd	nd	nd	nd	nd	nd	Chauhan et al. (2015)
13	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	Kaur et al. (2015)
14	Cracker	nd	nd	nd	nd	nd	nd	nd	nd	nd	Nammakuna et al. (2016)
15	Cookie	nd	nd	nd	nd	nd	nd	nd	nd	nd	Akesowan (2016)
16	Cookie	nd	nd	nd	nd	nd	nd	nd	nd	nd	Mancebo et al. (2016)
17	Cookie	nd	nd	nd	nd	nd	nd	nd	nd	nd	Gerzhova et al. (2016)
18	Cracker	nd	3.01–7.61	16.28–17.46	6.27–7.67	nd	nd	nd	nd	nd	Mir et al. (2017)
19	Cookie	59.90–77.70	0.80–17.80	14.50	5.28–6.20	105.4–129.3	351.4–431.1	32.6–42.1	57.6–62.8	nd	Molinari et al. (2018)
20	Cookie	nd	3.90–16.50	14.05–16.02	9.00–22.00	nd	nd	68–59	nd	nd	Giuberti et al. (2018)
21	nd	nd	nd	nd	nd	nd	nd	nd	44.0–85.8	nd	Gutiérrez (2018)
22	Cookie	nd	nd	nd	nd	nd	nd	nd	nd	nd	Jan et al. (2018)
23	ne	nd	nd	nd	nd	nd	nd	nd	nd	nd	Paciulli et al. (2018)
24	Cookie	nd	0.15–7.45	nd	nd	nd	nd	nd	nd	nd	Šarić et al. (2019)
25	Cookie	65.09–70.46	4.02–5.23	14.13 to 15.09	8.68–11.68	132.5–134.5	441.9–448.4	nd	nd	nd	Sulieman et al. (2019)
26	Short dough	nd	nd	nd	nd	nd	nd	nd	nd	nd	Lu et al. (2020)
27	Cracker	71.34–77.13	2.0–6.58	11.51–13.26	3.61–3.98	416*	416*	nd	nd	nd	Dick et al. (2020)
28	Cookie	nd	nd	nd	nd	nd	nd	nd	nd	nd	Hamdani et al. (2020)
29	Cookie	nd	3.05–10.00	nd	nd	nd	nd	nd	nd	nd	Paesani et al. (2020)
30	Cracker	62.86–70.69	6.13–10.42	9.77–11.61	7.99–11.52	117.9*	393*	nd	nd	nd	Silva et al. (2021)
31	Cookie	43.93	4.66	40	9.10	171.6	572	8.9–9.6	45.1–48.1	17.5	Naseer et al. (2021)

GI: glycemic index; GL: glycemic load; HI: carbohydrate hydrolysis index; nd: not determined; *kcal calculated by the authors.

Analyzing the fiber content of all the studies of gluten-free cookies presented in Table 3 and comparing with the Brazilian legislation (Brasil, 2012, 2020), only one cookie (Duta & Culetu, 2015) has a high content of dietary fiber, and 19.3% are considered sources of fiber dietary (Chauhan et al., 2015; Giuberti et al., 2018; Maghaydah et al., 2013; Radočaj et al., 2014; Silva et al., 2021; Torbica et al., 2012), considering that, for a food to be declared a "source" of dietary fiber, it must contain at least 2.5 g in the portion, and to be" high " content," 5 g is needed in the portion, and the portion is defined as 30 g (Brasil, 2012, 2020).

Depending on the digestion rate, starch can be classified into rapidly digestible starch (RDS) and slowly digestible starch

(SDS), which are completely digested in the small intestine at different times (Rashmi & Urroj, 2003) and resistant starch (RS), which is the starch fraction not degraded by enzymes (Fuentes-Zaragoza et al., 2011). Regarding digestibility, several in vitro methods have been developed to predict the glucose response of food and classify it in relation to the potential to increase postprandial glucose in the blood (Singh et al., 2010).

Differences in starch hydrolysis rates were observed among the cookies that evaluated digestibility (Giuberti et al., 2018; Gutiérrez, 2018; Molinari et al., 2018; Naseer et al., 2021). Giuberti et al. (2018) partially replaced rice flour with increasing levels of alfalfa seed flour and found a decrease in RDS and an increase in RS. Legume seeds, due to the inherent properties of starch and dietary fiber content, have fewer RDS and higher SDS and RS contents than cereal grain starches (Sandhu & Lim, 2008). RS is associated with numerous health benefits, such as control of cholesterol levels, decreased GI, and prevention of colorectal cancer (Polakof et al., 2013).

Molinari et al. (2018) developed cookies with tartaric flour and with tartaric malt, and the results showed slower digestion and decreased GI of the cookies when compared with the control (rice flour), probably due to the higher content of dietary fiber and RS, which are related to a reduction in the glycemic response. The hydrolysis of starch depends mainly on its structural characteristics (i.e., morphology of the starch granules, amylose/amylopectin ratio, molecular structure, and degree of branching) as well as the presence of other constituents of the food matrix, such as proteins and lipids (Singh et al., 2010).

In addition to the sources of legumes that are incorporated into cookies to improve digestibility and nutritional value, Naseer et al. (2021), seeking to develop gluten-free cookies with a low GI, demonstrated that GI and glycemic load (GL) decreased with increasing CMC concentration. Hydrocolloids are related to the increase in viscosity and form a coating on the surface of the starch granules, which limits the hydrolysis of these granules due to the restricted diffusion of α-amylase (Singh et al., 2010). The relationship between CMC and decreased GI and GL can be attributed to the CMC-starch-fat interactions developed in the cookies during cooking (Naseer et al., 2021).

Regarding nutritional properties, studies have shown many limitations, and less information is known regarding the nutrients and digestibility of gluten-free cookies. The development of cookies is still following the same standard as the cookies developed for the non-celiac population (cookies with gluten), without concern with the nutritional properties necessary to serve the celiac population, which, due to dietary restrictions, require nutritionally more attractive products.

8 Future perspectives

From this review, it is evident that there is a gradual improvement in the formulations of gluten-free cookies and a stagnant effect on innovation in processes and their respective processing conditions in gluten-free cookies. However, innovation in the development of gluten-free products has moved slowly, which slows advances in science and praises the presence of many research strands to be filled, as there are still recurrent attempts to fit this food niche into the standards of wheat products, for example, which causes gaps in the nutritional and sensory aspects and promotes improvements in the technological area of cookies.

With a potential market open for development, it is expected to encourage and strengthen an increasing number of gluten-free products, causing necessary changes throughout the food system to expand scientific investment and public policies in this area, train and value researchers with a focused vision for this food niche, build all the necessary dedicated and specific laboratories for gluten-free products, and strengthen the importance of such products within academia, increasing their visibility throughout the scientific sector.

There are long paths to explore and improve, but they are necessary to promote the desired changes, break the repetitive patterns of development, and expand the growth and innovation of gluten-free products, especially cookies that are relevant, due to their practical consumption and extended shelf life. Thus, these advances range from improvements in sensory, nutritional, and technological properties to the achievement of social, economic, and cultural freedom.

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