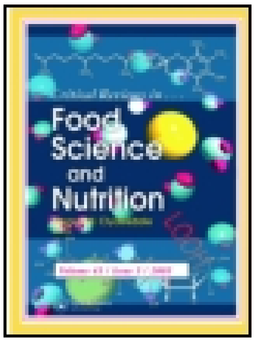

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REVIEW

Nutritional facts regarding commercially available gluten-free bread worldwide: Recent advances and future challenges

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ABSTRACT
Recently, there has been an increase in demand for gluten-free (GF) products due to the growing number of gluten-intolerant and healthy individuals choosing to follow a gluten-free diet. Gluten-free bread (GFB) is a staple food product; therefore, many recent studies have reported the nutritional properties of GFB. However, an overview of the current ingredients and nutritional labeling of GFB worldwide has not yet been provided. This review aimed to gather the latest information regarding the most used ingredients in GFB formulations and the nutritional quality of these products from different countries, based on studies published in the last decade (2010–2020). Our analysis showed that GFB had a lower protein and a higher fat content than gluten-containing bread, and the dietary fiber content was highly variable between countries. Some studies have revealed a high glycaemic index in most products, which is associated with the extensive use of rice flour and starch as the main ingredients in GFB formulation. Label information presented significant differences from the data obtained through the chemical analysis of fiber and other nutritional components. Micronutrient fortification is not common in the GFB. The nutritional quality of commercial GFB is a crucial issue that needs to be addressed.

KEYWORDS
Food labeling; gluten-free; glycaemic index; ingredient list; nutrition facts

Introduction

A considerable increase in the number of individuals following a gluten-free diet (GFD) can be attributed to the increased prevalence and awareness of gluten-related disorders, especially celiac disease (CD) (Ludvigsson and Murray 2019). In addition, increasingly healthy individuals are following this regimen probably because of a "health halo" effect (Christoph et al., 2018; Dunn, House and Shelnutt 2014; Prada et al., 2019)

The increasing demand and consumption of GF products is interesting to producers but also has important consequences for individuals with celiac and non-celiac conditions following the GFD (Xhakollari et al., 2019).

The demand for GF products is continuously growing, with a global market valued at USD 21.61 billion in 2019 and is projected to reach almost USD 24 billion by 2027 (Grand view research 2020). Recent studies have demonstrated the importance of verifying the true quality and clarifying the nutritional contribution of these products, investigating not only the nutrients present but also products with a lower glycaemic index (GI) and containing compounds with antioxidant capability (Fajardo et al. 2020; Krupa-Kozak and Lange 2019; Romão et al. 2020). Even with the considerable growth in the GF market, there is still little information regarding the nutritional characteristics of GF products and their physical properties and acceptability (Capriles, Santos, and Aguiar 2021; Romão et al. 2020).

Bread is the most researched GF product; however, it is nutritionally characterized by poor mineral, vitamin, and fiber content, in addition to high amounts of salt, fat, and available carbohydrates (Santos, Aguiar, and Capriles 2019; Romão et al. 2020). Many commercial gluten-free breads (GFBs) are characterized by unsatisfactory texture, low nutritional quality, and short shelf life (Capriles, Santos, and Aguiar 2021; Hanci and Jeanes 2019), and are expensive and less accessible. Technological and nutritional deficiencies are being addressed by testing new processing and storage techniques for GFB and using different compounds that are sources of nutrients and bioactive compounds (Bender and Schönlechner 2020; Capriles, Santos, and Aguiar 2021; Conte et al. 2019). Similar to conventional bread, GFB is also a staple food product, and many studies have focused on the nutritional characteristics and quality of GFB (Allen and Orfila 2018; Cornicelli et al. 2018; Fajardo et al. 2020; Guennouni et al. 2020; Hopkins and Soon 2019; Mohd Fauad, Kaur, and Shafie 2020; Santos, Aguiar, and Capriles 2019; Roman, Belorio, and Gomez 2019). However, the current components and nutritional labeling of GFB worldwide have not been reviewed. The present work aims to compile the components and nutritional facts of commercially available GFBs from different countries, based on studies published in the last decade (2010–2020), and to provide an overview of the recent advances and future challenges.

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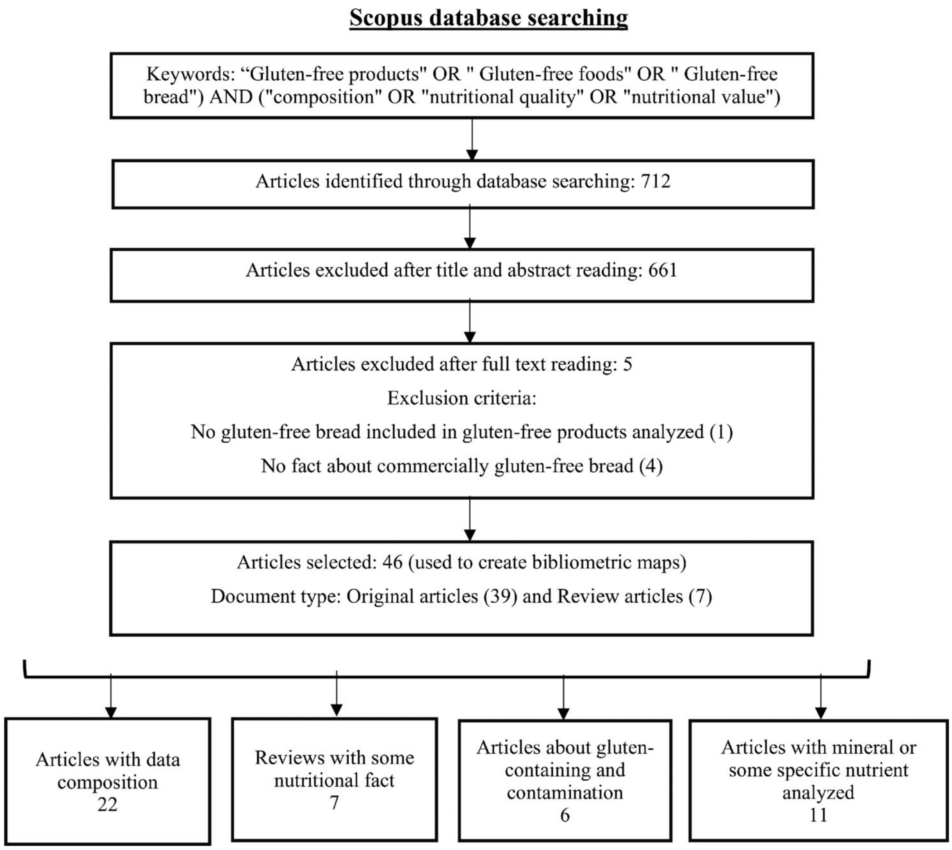

Figure 1. Flow diagram of literature search and selection criteria.

Materials and methods

The Elsevier *Scopus* database was explored using the following research string: ("Gluten-free products" OR "Gluten-free foods" OR "Gluten-free bread") AND ("composition" OR "nutritional quality"" OR "nutritional value").

No restrictions regarding language were stated. The papers were screened by reading the title and abstract and by a full-text reading and exclusion of the duplicated selected articles. All reviews and original papers that investigated and reported nutrition and ingredient facts or chemical and GI data of commercial yeast-leavened GFB during the last 10 years (2010–2020) were included, while other papers that were not pertinent to GFB were excluded (Figure 1).

All items from the citation information (e.g. authors, document title, year, and citation count), bibliographical information (e.g. affiliations), abstract, and keywords using the search terms were selected and exported in CSV format and used to construct a keyword co-occurrence bibliometric map and a co-authorship network of the respective countries using the VOSviewer software v1.6.15 (Leiden University, The Netherlands).

Among the selected papers, those which included the ingredient list ($n = 4$) were used to create word clouds from the frequency of the ingredients used in the GFB. Common components of all types of leavened bread formulations, such as sugar, salt, and yeast were excluded, as GFBs are normally composed of these ingredients, and no new information can be obtained about GFB composition from these. Thus, we identified the most common components (one cloud showed the first-named ingredient, and the second cloud represented the five main ingredients presented in each list, as most GFBs were made from a mixture of flours and starches). The 2021.1 XLSTAT® software (Addinsoft, USA) was used for this analysis.

Results

Bibliometric analysis

Based on the inclusion criteria, forty-six records were selected and used to create the bibliometric maps (Figures 2 and 3).

A minimum of five occurrences were selected to integrate the keyword analysis in VOSviewer. There were 473 keywords in total, resulting in 27 connected items divided into three clusters (Figure 2). The largest cluster (in red) had 11 referenced keywords, which were related to studies on the quality of GFD in CD. These studies principally analyzed carbohydrate, sugar, sodium, saturated fatty acid, calcium, iron, and zinc content to verify the composition of the GF products. The second cluster (in green) presented seven keywords mainly related to comparative studies between GFB and gluten-containing bread (GCB), where most of the studies show the nutritional value and GI differences and evidence of the food handling of these products. The third cluster (blue) presented seven keywords that indicated studies on GF product analysis regarding the food packaging, showing papers that investigated the commercial products

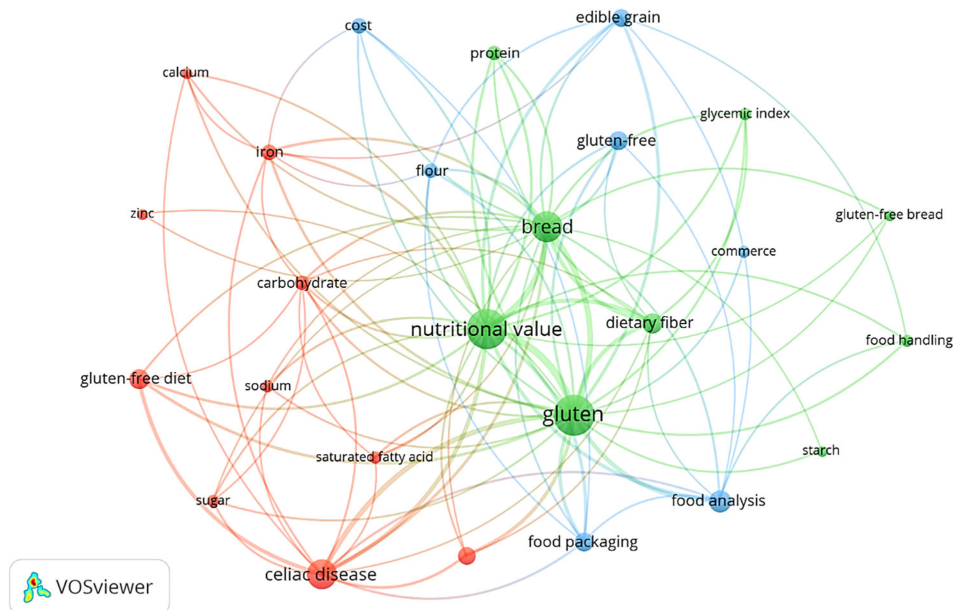

Figure 2. Keyword co-occurrence network from articles on nutritional profile of commercial gluten-free bread.
*Size of the bubbles represents more frequently used terms while thicker connectors correspond to more frequent co-occurrence of terms. Source: Scopus database (2010-2020). A minimum of 5 occurrences was adopted to integrate keywords analysis using the VOSviewer software.

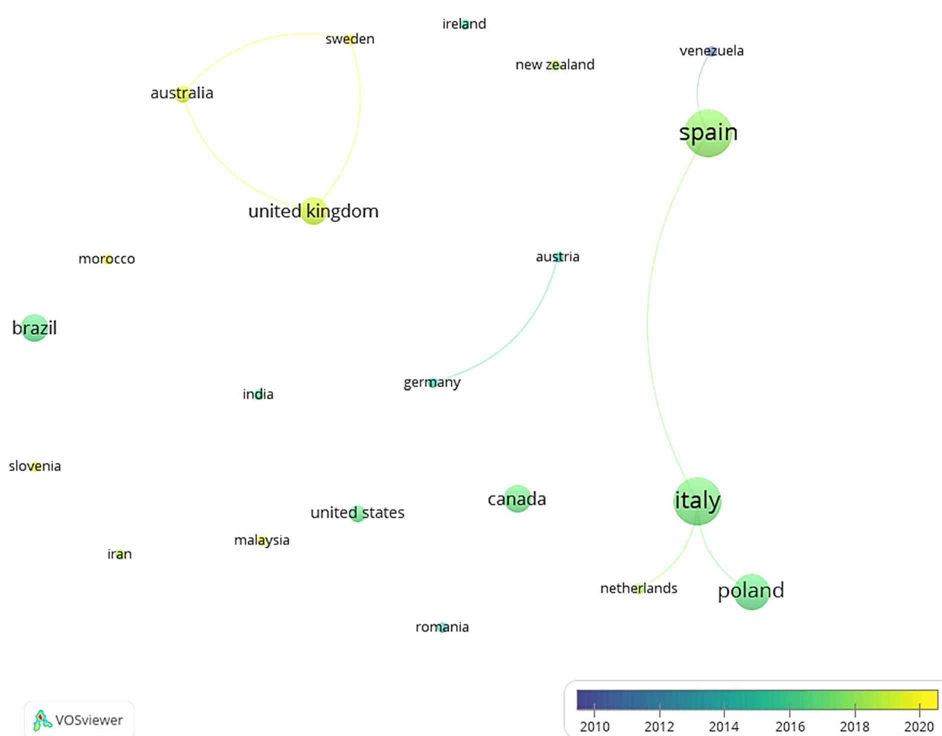

Figure 3. Scientific production of countries in the field of nutritional profile related to gluten-free bread articles from Scopus database (2010 – 2020).
*Size of the bubbles represents higher scientific production while thicker connectors correspond to co-authorship between countries

available, where the flours and edible grains were used, and the cost of these products was mostly provided. Figure 2 showed that apart from "gluten" and "bread," "nutritional value" and "celiac disease" were the keywords most frequently used in studies focused on commercial GF products. This information is extremely important for patients with CD, because strict GFD is currently the only available and effective treatment.

The distribution of publications concerning commercial GFB published in 2010–2020 based on the country of origin and distinguishing the most recent research on this topic is presented in Figure 3. The co-authorship of analyzed publications was derived mainly from 10 countries, indicated by the green (Spain, Italy, Poland, Venezuela, and Netherlands), yellow (United Kingdom, Sweden, and Australia), and blue (Germany and Austria) clusters.

Most of the papers (52%) from Spain, Italy, and Poland were associated with the nutritional facts of commercial GFB, while the most recent studies were from the United Kingdom, Sweden, and Australia (Figure 3).

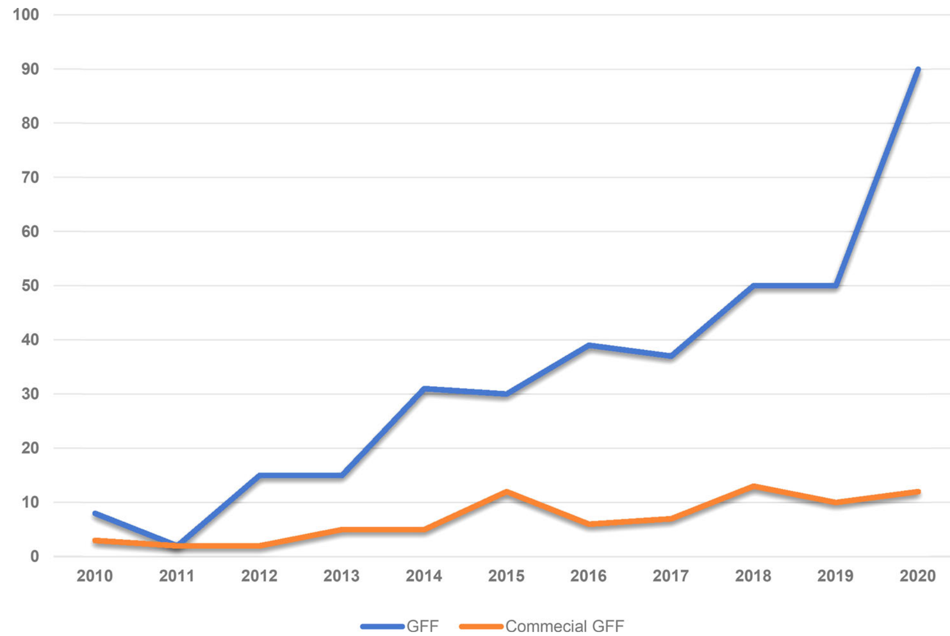

Figure 4. Comparison of annual scientific production of reviews and original articles about gluten-free foods (GFF) and commercial gluten-free foods (Commercial GFF), terms in title, abstract and keywords registered from Scopus (2010 until 2020).

Figure 4 shows a pronounced increase in the number of publications on GF food in the last decade, while publications regarding commercial GF food remained at the same level. This clearly points out the problem of insufficient knowledge regarding the characteristics, in particular the nutritional quality of GF foods in the market. Therefore, further research focused on the quality of commercial GF food is needed to clarify the industry's response to the published scientific data on GF food, in addition to analysis of the nutritional value of these products.

Promoting collaboration between academia and industry is important to recognize common trends to improve the quality of currently available products and to develop new ones with even better characteristics. The transfer of promising research to commercial products as well as designing research to resolve or improve problem areas in the current commercial reality is a crucial aspect that must be addressed (Capriles, Santos, and Aguiar 2021).

Description of studies

Among the 46 papers used to create the bibliometric maps, only 19 provided information about the GFB composition from label information and/or chemical analysis. The profiles of the 19 studies are listed in Table 1.

As presented in Table 1, over the last 10 years, many gluten-containing (GC; N = 7,122) and GF (N = 3,153) food products have been investigated and compared. Among the GF products studied, 935 were GFBs. Most studies on GFB were performed in Spain (29.8%), Brazil (20%), and Italy (15.1%), suggesting an increasing interest in research and development on GF product. In contrast, in the United States, Morocco, Australia, Germany, Austria, Canada, France, and Finland, where a relatively lower number of investigations on GFB occur, studies with a higher number of GF products are needed to clarify any tendencies in these countries. In the study by Roman, Belorio, and Gomez (2019), 26 GFB from the United States were included, but the quality of these products was not evaluated. According to Markets and Markets (2020), the United States is the leading country in the global GFP market, but studies analyzing the quality of the available GF products are rare.

Ingredients and nutritional labeling

Despite the growing GFB market, studies on the nutritional profile of commercial GFB in different countries are scarce, and only few provide an ingredient list of the analyzed products. Thus, we identified information about the ingredients used in GFB in only four studies from the last three years (Allen and Orfila 2018; Santos, Aguiar, and Capriles 2019; Tres et al. 2020; Romão et al. 2020). These studies provided a list of the most frequently used ingredients that were indicated in 40, 128, 20, and 12 GFB labels, respectively, totaling 200 products. The data from these studies showed the profile of GFB available in Brazil, the United Kingdom, and Spain and were used to create the word clouds (Figure 5).

Among the 11 GFB components that appear at the first position on the ingredient list, rice flour and water stand out, followed by starches from cassava and maize (Figure 5A). Whole rice flour is also frequently indicated as a component of commercial GFBs in Brazil and is among the top ingredients on the list. As whole rice flour is used in larger amounts, it can contribute to a higher dietary fiber and protein content in these GFBs (Santos, Aguiar, and Capriles 2019).

In this study, the first five ingredients used in each GFB formulation—labeled for each product—are shown in Figure 5B. Of the 64 compounds mainly present in GFB, cassava

Table 1. Details of studies that investigated and reported the nutritional facts of commercially available gluten-free bread (GFB) provided on the package labels or displayed online. Capriles et al. (2021)

Reference	Country	Year of data collection	Number of products [a] GC	GF	Categories	Number of GFB	Origin of products/GFB [b]
Matos Segura and Rosell 2011	Spain	na	na	11	bread	11	Spain
Do Nascimento et al. (2014)	Brazil	2011	162	168	bread, cake mix, snacks, cookie, cereal, chocolate, pasta, and cake	15	Brazil
Kulai and Rashid 2014	Canada	2012/13	60	71	breads, cake mixes, cereals, cookies, crackers, flours, frozen foods, granola bars, pastas and processed meats	9	Canada and United States
Miranda et al. 2014	Spain	2012/13	289	206	cookies, bakery-patisserie, pasta, breakfast cereals, cereal bars, baby formulas, flour, dough/ pastry/pizza, cakes and breads	62	Spain
Mazzeo et al. 2015	Italy	Na	na	60	cookies, breakfast products, sweet products, breads, pizzas, savory snacks, pasta dishes and flours	36	Italy
Missbach et al. 2015	Austria	2014/15	126	63	flour/bake mix, bread and bakery, pasta and cereal based, cookies and cakes, snacks and convenience	12	Austria
Wu et al. 2015	Australia	2013	2576	637	breads, breakfast cereals and pasta, cereal bars, cake mixes/cakes and sweet biscuits, ice cream, chips, cured meats, and sugar-based confectioneries	54	Australia and Italy
Scazzina et al. 2015	Italy	Na	na	10	bread, cake, biscuit and pasta	3	Italy
Foschia et al. 2016	Ireland	Na	na	27	bread	27	Ireland
Allen and Orfila 2018[c]	United Kingdom	2017	61	49	brown bread, white and seeded bread and pasta	40	United Kingdom (C = 10, P = 31) Italy (C = 1, P = 9)
Cornicelli et al. 2018	Italy	Na	349	235	biscuits, rusks, snacks, bread, pasta, bread substitutes and wheat flour	40	Italy
Santos, Aguiar, and Capriles 2019[c]	Brazil	2017	na	128	regular GFB (alternative and traditional ones)	128	Brazil (C = 24, P = 122) Italy (C = 1, P = 6)
Roman, Belorio, and Gomez (2019)	Spain Data are also collected by online search tools for some products available in other countries	2018	na	228	regular and dry/crispy GFB	211	Spain (C = 7, P = 29), Italy (C = 4, P = 48), Canada (C = 1, P = 5), Brazil (C = 6, P = 35), Ireland (C = 2, P = 11), United States (C = 3, P = 26), Sweden (C = 1, P = 12), United Kingdom (C = 3, P = 26), France (C = 1, P = 5), Germany (C = 2, P = 12), Finland (C = 1, P = 5), Australia (C = 1, P = 14)
Hopkins and Soon 2019	England	Na	209	190	breads, flours, biscuits, cakes, pasta, ready melas and crackers	26	England
Romão et al. 2020[c]	Brazil	2019	na	12	traditional and whole/ multigrain bread	12	Brazil
Lappi et al. 2020	Sweden	2019	234	58	breads	58	Sweden

(continued)

Table 1. Continued.

Reference	Country	Year of data collection	Number of products [a] GC	GF	Categories	Number of GFB	Origin of products/GFB [b]
Fajardo et al. 2020	Spain	2016 /19	629	629	alcoholic beverages, frozen dairy desserts, bread, pasta, breakfast cereals, fine bakery ware, cereal or cereal-like milling and prepared food products.	152	Spain
Tres et al. 2020[c]	Spain	2017	14	20	breads	20	Spain
Guennouni et al. 2020	Morocco	2019	278	184	flour and bake mix, bread and bakery products, pasta and cereal products, cookies and cakes, drinks, and spreads	15	Morocco
Lavriša et al. 2020	Slovenia	Na	2279	326	bread and bakery products, meat and meat products, fish and fish products, milk, breakfast cereal, pasta	26	Slovenia
Babio et al. 2020	Spain	Na	na	2247	Cereal and cereal by-products (breads and bakery products), meat and meat products, fish and fish products, choc0late, ready meals, yoghurt, ice cream, pasta, flour, drinks, baby food, nut, fruits and fats and oils	50	Spain
Mohd Fauad, Kaur, and Shafie 2020	Malaysia	Na	65	41	Bread and bakery products, pasta, flours	7	Malaysia

Adapted and updated data from Capriles, Santos, and Aguiar (2021) with permission from Elsevier.
[a]GC – gluten-containing; GF – gluten-free.
[b]Number of companies -C and products - P evaluated by country,
[c]Articles used to create words-cloud.
na - not available information.

starch and rice flour can be distinguished, followed by eggs, potato and maize starches, and water.

The word clouds reveal that GFBs are mainly starchy foods. Starchy ingredients can contribute to technological bread properties; however, to improve the GFB characteristics, starches are usually blended with other ingredients. According to Roman, Belorio, and Gomez (2019), maize starch yields loaves with higher volumes but dry and crumbly textures, whereas rice flour yields bread with lower volumes than those of maize starch but improves the texture and acceptability. Starches from cassava and potato result in bread with lower volumes than those made with maize starch, but these ingredients can improve textural attributes and acceptability when used in starch/flour base mixtures.

These studies show great variability among the main ingredients of GFBs in different countries. According to Santos, Aguiar, and Capriles (2019), GFBs available in Brazil frequently contain rice flour and cassava starch as the main ingredients (70% of the analyzed GFBs). In the United Kingdom, rice flour and maize starch are frequently used in GFB formulations (87% and 77% of the analyzed GFBs) (Allen and Orfila 2018), whereas, in Spain, the most used ingredient of GFB is maize starch, which is present in all the analyzed GFBs (Tres et al. 2020).

Altogether, 154 different ingredients used in GFB formulations were identified (Figure 5C); however, we filtered out the ingredients common to all leavened breads, such as sugar, salt, and yeast (identified as dry, fresh, chemical, and extracts), leaving 147 ingredients used in the GFB preparation. Thus, besides rice flour and starches, the word clouds show the presence of other ingredients such as additives, which are frequently used in GFBs. Among the additives, hydrocolloids such as xanthan gum and hydroxypropyl methylcellulose and the mold inhibitor calcium propionate were the most frequently identified GFB components. The functions of these additives are explained in detail by Roman, Belorio, and Gomez (2019) and Capriles, Santos, and Aguiar (2021). However, as shown in Figure 5A and B, these additives are not the main ingredients of GFBs, but they are used for a specific purpose in small quantities (Roman, Belorio, and Gomez 2019).

Soybean flour is also frequently used as a GFB ingredient (Figure 5C), which can be used to mimic—to some extent—the viscoelasticity of gluten but also as an ingredient responsible for increasing the protein content in GFBs (Shin, Kim, and Kim 2013). Santos, Aguiar, and Capriles (2019) suggest a classification of GFBs based on the main ingredients declared on the label. They showed that identification of the predominant ingredients (the first three on the list) used in the GFBs clarified the real characteristics of the products, as these ingredients were used in the highest amounts, affecting the nutritional composition of the bread to the highest extent.

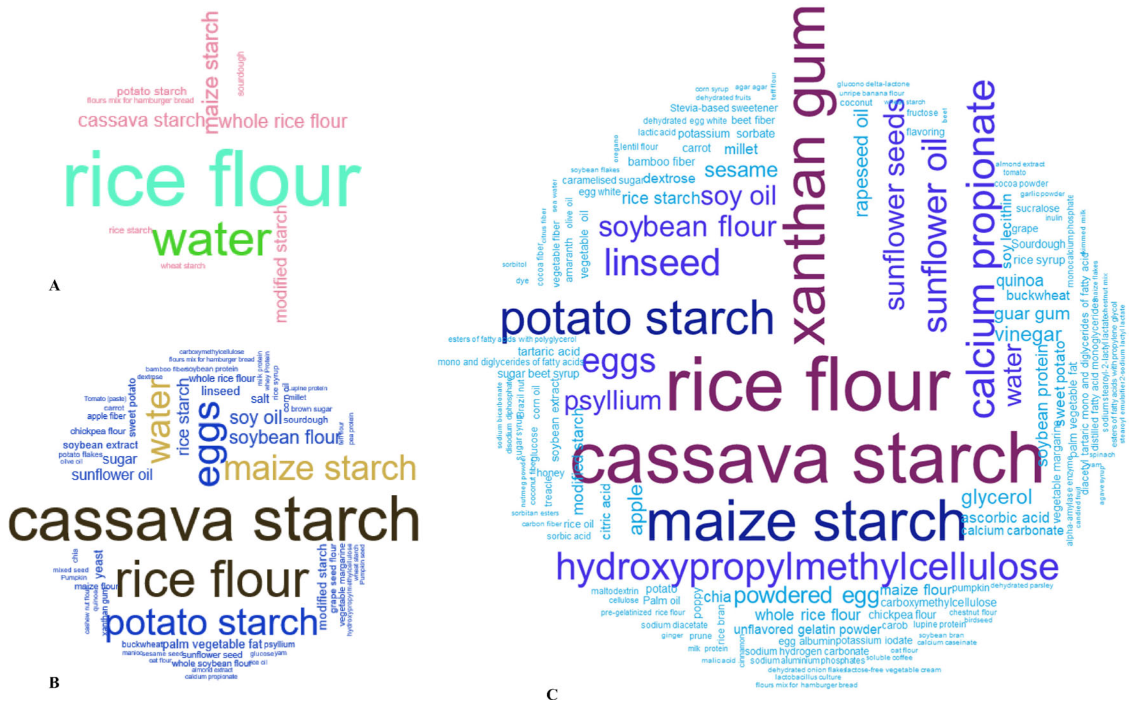

Figure 5. Word clouds created from ingredient lists of commercially available gluten-free bread (GFB) from selected articles.
A – The first ingredients declared in GFB labeling; B – The five main ingredients declared in GFB labeling; C – All ingredients declared in GFB labeling (excepted salt, sugar, and yeast)

As indicated in Figure 5C, psyllium fiber and linseed are frequently used in GFBs. However, these ingredients were not regularly labeled among the five main ingredients on the list (Figure 5A and B), suggesting their low amounts in GFBs.

The nutritional characteristics of the commercial yeast-leavened GFBs are presented in Table 2. Nutritional information determined in studies on GFBs derived from product package labels and/or chemical analyses, collected by searches conducted on grocery stores or websites dealing with GF products. Information on nutritional package labels differs depending on the regulations of each country. Thus, some nutrients have not always been declared.

The studies presented in Table 2 indicated a broad range of energy values and nutrient contents of GFBs, which resulted from differences in formulations and moisture content, which depended on the levels of water incorporated and were retained after baking. These are both associated with the starch/flour base, hydrocolloids, and the type and quantity of fibers used in the product (Roman, Belorio, and Gomez 2019; Capriles, Santos, and Aguiar 2021).

The reported average carbohydrate, protein, and fat contents varied significantly (1.6, 2.3, and 3.7 times, respectively) between the studies (Table 2). The difference was even greater for sugar (2.9) and dietary fiber (13.7). This may reflect the difference in the preference of consumers that can be country-specific or indicate a market development observed as the emergence of a wide range of GF products with varying raw material compositions.

Considering the wide range of values, commercial GFBs showed extensive variability in the carbohydrate content (14–84%), the principal component of GFBs due to the use of flours and starches as the main ingredients. GFBs have a similar carbohydrate content as that of white and whole wheat breads, which contain 49.2% and 43.1% carbohydrates, respectively, (USDA 2020a, 2020b).

The fat content in commercial GFBs differs significantly, ranging from 1% to 19%, and is considered to be higher than that in conventional white wheat bread (3.3 g) (USDA 2020b). GFB crumbs are usually dry, therefore addition of high amounts of fat to GFB formulations is a common technological practice to improve softness and consumer acceptance (Capriles, Santos, and Aguiar 2021; Roman, Belorio, and Gomez 2019). However, the saturated fat content (0–5%) was not high, which might be explained by the widespread use of vegetable oils instead of fat in GFBs (Roman, Belorio, and Gomez 2019).

With respect to proteins, GFBs also presented extensive differences (0–11%), principally being recognized as containing low protein content compared to white wheat bread (8.8 g) (USDA 2020a).

Sugar content varied from 0% to 24%. According to Roman, Belorio, and Gomez (2019), this content can be higher than the actual content usually measured in the final product, considering that most of the added sugars are consumed during the fermentation process. According to Roman, Belorio, and Gomez (2019) and Santos, Aguiar, and Capriles (2019), the formulations of 13% and 52% of the GFBs, respectively did not contain any added sugar.

The sodium content ranges from 5 to 1,292 mg/100 g, with an average value of 427 mg/100 g, close to that reported for white (490 mg/100 g) and whole-wheat breads (450 mg/100 g) (USDA 2020a, 2020b). Roman, Belorio, and Gomez (2019) emphasize that there is no need to use high amounts of salt and sodium in GFBs, as the role that salt plays in breadmaking i.e., strengthening the dough, improving its

Table 2. Average nutritional facts of commercially available yeast-leavened gluten-free breads (GFBs) obtained from studies on labeling information and/or chemical analysis (100 g of product). Capriles et al. (2021)

Reference	Country	Number of GFB	Calories (kcal)	Protein (g)	Fat (g)	Saturated fat (g)	Carbohydrates (g)	Sugars (g)	Dietary Fiber (g)	Salt (g)	Sodium (mg)
Matos Segura and Rosell 2011	Spain	11	274	3.33 (2 – 11)	6.8 (1 – 16.6)	na	49.9 (43 – 73)	na	na	na	na
Do Nascimento et al. (2014)	Brazil	15	243	4.4	4.9	0.6	42.8	na	0.7	na	358.3
Kulai and Rashid 2014	Canada	9	271	5	7.7	0.9	44	na	4.2	na	na
Miranda et al. 2014	Spain	62	331	3.5	7.4	3.03	61.2	4.9	3.9	1.5	584
Mazzeo et al. 2015	Italiy	36	279	3.9	6.5	1.1	48.7	3.7	4.9	na	na
Missbach et al. 2015	Austria	12	274 (213 – 344)	4.1 (0 – 8)	4.6 (1 – 9)	1.5 (0 – 5)	53.4 (39 – 82)	5.8 (0 – 19)	3.7 (1 – 8)	na	387.9 (5 – 791)
Wu et al. 2015	Austrália	54	262	6.2	na	1.1	na	3.6	6	na	524
Scazzina et al. 2015	Italy	3	222 (214 – 228)	3.07 (2.4 – 5.7)	4 (2.5 – 5.7)	na	40.94 (37.8 – 44.6)	3.30 (2.5 – 4.1)	4.8 (3.2 – 4.1)	na	na
Foschia et al. 2016	United Kingdom	27	na	4 (1.5 2.7)	9.6 (3 – 10)	1.1 (0 – 1)	na	4.3 (2 – 5)	6 (2 – 4)	1.3 (0.7 – 1.1)	na
Allen and Orfila 2018	United Kingdom	40	252 (193 – 299)	6 (2 – 9)	7 (2 – 11)	0.7 (0 – 1)	39 (29 – 49)	2 (0 – 9)	7.7 (5 – 11)	1 (0.6-1.1)	394
Cornicelli et al. 2018	Italy	40	252	4.3	5.7	1.2	43.3	3.4	5.9	1.3	na
Santos, Aguiar, and Capriles 2019	Brazil	128	240 (118 – 406)	5.2 (0 – 26)	5.6 (2 – 18)	0.6 (0 – 2)	42 (14 – 84)	na	2.8 (0 – 10)	na	308 (28– 1292)
Roman, Belorio, and Gomez (2019)	Spain and others countries	211	258 (118 – 381)	3.9 (1 – 10)	6.3 (0 – 19)	0.9 (0 – 5)	46.1 (22 – 84)	4.6 (0 – 24)[b]	5.2 (0 – 12)[b]	1.1 (0.2 – 4)	433.4
Hopkins and Soon 2019	England	26	245	7.2	5.2	0.86	41	2.67	7.24	1	0
Romão et al. 2020	Brazil	12	226 (162 – 262)	5.2 (2 – 8)	2.6 (0 – 4)	na	41.5 (32 – 52)	na	9.6 (6 – 17)	na	na
Lappi et al. 2020	Sweden	58	260	3.4	4.2	0.7	49	4.6	5.4	1	na
Fajardo et al. 2020	Spain	152	284	2.7	5.7	2.2	52.4	5.2	5.8	1.4	na
Tres et al. 2020	Spain	20	258	3.0	5.3	1.2	48.1	3.3	4.7	1.7	na
Guennouni et al. 2020 [a]	Morocco	15	241	3.5	5.2	0.6	46.0	5.2	6.4	1.3	na
Lavriša et al. 2020	Slovenia	26	301	5.0	na	na	na	3.2	na	1.3	na
Babio et al. 2020	Spain	50	274	2.2	5.1	0.8	54	3.1	na	na	570
Mohd Fauad, Kaur, and Shafie 2020	Malaysia	7	329	6.7	1.8	na	69.9	na	4.3	na	na

Adapted and updated data from Capriles, Santos, and Aguiar (2021) with permission from Elsevier.
Values are average and range. na – not available information.
[a]Value are median.
[b]Information about sugar and fiber are available for 176 and 186 products, respectively.

Table 3. Classification of the fiber content obtained from label information and chemical analysis of commercial gluten-free breads available in Brazil and Spain

			Classification of fiber content from label information (n) *					
			Low (< 3g/100)		Source (≥ 3g/100g)		High (≥ 6g/100g)	
Reference	Country	N	LI	CA	LI	CA	LI	CA
Santos, Aguiar, and Capriles (2019)	Brazil	128	75	–	36	–	17	–
Roman, Belorio, and Gomez (2019)	Spain and other countries	186	–	–	186	–	–	–
Larretxi et al. (2020)	Spain	11	–	–	11	1	–	10
Romão et al. (2020)	Brazil	12	8	–	2	–	2	12

*Codex Alimentarius Comission (2013). Label information: LI, CA = Chemical analysis.

handling, and reducing the yeast fermentation rate is not necessary in GF breadmaking.

GFBs are generally made with refined raw materials, and neither raw materials nor finished products are treated with micronutrients, as observed in the nutritional facts of commercially available GFBs in Canada (Kulai and Rashid 2014), Australia (Wu et al. 2015), Italy (Morreale, Angelino, and Pellegrini 2018), the United Kingdom (Fry, Madden, and Fallaize 2018), and Brazil (Capriles, Santos, and Aguiar 2021; Roman, Belorio, and Gomez 2019). Allen and Orfila (2018) and Roman, Belorio, and Gomez (2019) found that some micronutrients were used to enrich GFBs with iron (7%), B group vitamins (5%), calcium (5%), and folic acid (5%).

As shown in Table 2, the dietary fiber content in GFB varied widely from 0% to 17%, which could be explained by the variations in the GFB formulations.

Table 3 shows the studies that analyzed the classification of commercially available GFB in Brazil and Spain, according to the fiber content criteria adopted by Codex Alimentarius Comission (2013). Only four studies analyzed the fiber content of commercial GFBs and reported the content classification (low, source, or high). Chemical analysis, was performed in only two of them, presenting controversial differences between the fiber content in the label information and the results of the chemical analysis, indicating the need for more studies with chemical analysis to evaluate the composition of commercial GFBs (Larretxi et al. 2020; Matos Segura and Rosell 2011; Romão et al. 2020).

Larretxi et al. (2020) found a discrepancy in the fiber content, where chemical analysis revealed a higher fiber content than that was present on the label (9.8% and 5.5%, respectively). In Brazil, Romão et al. (2020) performed a chemical analysis of 12 GFBs, all of which showed discrepancies between chemical analysis and label information, indicating lower fiber content in the latter.

In Brazil, Santos, Aguiar, and Capriles (2019) reported low fiber content, similar to that of Brazilian GFBs reported by Roman, Belorio, and Gomez (2019). Both studies showed a fiber content lower than 3%, while Romão et al. (2020) showed a high fiber content (9.6%). Fiber content differences are associated with the number of samples chemically analyzed, derived from a restricted collection only with products found in local commerce performed by Romão et al. (2020), while Santos, Aguiar, and Capriles (2019) and Roman, Belorio, and Gomez (2019) identified higher numbers of GFBs available in metropolitan regions using e-commerce analysis.

Word clouds revealed that GFBs are still classified as starchy foods, because they are mainly produced using refined flours and starches, which are responsible for the high carbohydrate content of these GF products and are also recognized as products with high fat and low protein and mineral content, with a wide range of fiber content.

Thus, it should be stated that despite the many studies on GFBs, knowledge about the nutritional value of commercial GFBs available on the market is still insufficient. It should be enhanced based on the latest nutritional data from various countries and the actual analytical results of the nutritional properties of commercial GFB. This is particularly important, because this knowledge may contribute to elucidation of the mechanism by which the GFB components affect the quality of the final product. Only reliable knowledge allows us to indicate what should be improved in commercial GFB and in which direction future research should go.

Discussion

GFB produced globally is composed of numerous raw ingredients and additives that result in a great variation in the nutritional composition of commercial products in different countries, while the majority of them present low nutritional value. These products are still recognized as being high in fat and low in protein content and, in some cases, low in dietary fiber. The high lipid content in bakery products may be due to the addition of animal or vegetable fats and emulsifiers (mono- and di-glycerides of fatty acids) to improve palatability and texture of the bread and reduce the rate of staling (Houben et al., 2012). Some of these nutritional drawbacks can be amended by the use of nutrient-dense ingredients that are rich in valuable proteins; these include whole naturally gluten-free cereal flours, pseudocereals, nuts, and pulses (Capriles, dos Santos, and Arêas 2016).

As GFB are principally composed of carbohydrates, their GI can be higher than that of their gluten-containing counterparts (Berti, Riso, Monti and Porrini, 2004). Romão et al. (2020), through in vivo studies, indicated that there was no significant difference in GI between white and wholemeal GFB. The incorporation of fibers such as psyllium and inulin or the use of fiber-rich raw materials in GFB formulations such as chickpea flour can help diminish the glycaemic response by reducing the digestion and absorption rate and the quantity of available carbohydrates (Capriles and Arêas 2013; Fratelli et al. 2018; Santos et al. 2021a).

Another concern about commercial GFB is the deficiency of vitamins and trace elements needed in a healthy and balanced diet. Commercial gluten-free flours are not obligatorily fortified or enriched in a way that regular wheat flour is, and they generally contain lower folate, B-group vitamin (niacin, thiamin, and riboflavin) (Thompson 2000; Thompson et al. 2005, Yazynina et al. 2008), and mineral (including calcium, iron, and zinc) (Melini and Melini 2019) levels. Besides, as CD is characterized by gluten-induced villous atrophy, vitamin D deficiency is common in this condition (Drabińska et al. 2018), and the level of vitamins A and E in celiacs is decreased too (Romańczuk et al. 2016).

Only a few data are currently available regarding the vitamin and mineral content of GF products, despite nutritional deficiencies emerging from the analysis of the nutritional status of CD patients on a GFD (Kinsey, Burden, and Bannerman 2011; Rybicka and Gliszczy 2017). According to Rybicka and Gliszczy (2017), GF products with alternative ingredients (buckwheat, millet, chickpeas, oats, amaranth, teff, and quinoa) had a higher mineral content than that of products made with usual flours and starch (from rice, potato, and maize), demonstrating the use of alternative ingredients as a promising approach to improve the micronutrient content of GF products. Another way to improve the mineral content of these products may be to create a mandatory fortification for GF flours with minerals and vitamins (calcium, iron, folic acid, niacin, and thiamin), similar to that for wheat flour. GF products with a higher micronutrient content are extremely important for improving the health of individuals who must follow the GF diet (Allen and Orfila 2018; Capriles, dos Santos, and Arêas 2016; El Khoury, Balfour-Ducharme, and Joye 2018).

This review reveals an urgent need for studies on the nutritional composition of GF products, not just based on label information but also on chemical analysis, as meaningful discrepancies have been found between the two sets of data. Further studies are required in countries that are the leaders in GFB production such as the United States to monitor the ingredients and nutritional labeling and to track product formulation changes and new market trends aimed at nutritional enhancement. Recently, Fajardo et al. (2020) noted a small reformulation in GF foods from Spain, determined as a change in the type of fat declared in the composition and a salt reduction. Therefore, the authors draw attention to the constant need for studies regarding GF food composition to verify any reformulation and nutritional improvements. Morreale, Angelino, and Pellegrini (2018) developed a score-based method to evaluate the nutritional quality of GF bakery products, which can be used in the food industry to reformulate the products. This method classifies the nutritional quality of the products, aiding any reformulation that may be necessary.

Studies on commercial GFB composition are still scarce, and further research is required to investigate the nutritional profile of these products from different countries, especially studies regarding micronutrient content, to evaluate the need for the fortification of GF products, as well as the mandatory fortification of the main GF flour/starch bases.

The nutritional quality of commercial GFB is a crucial issue that needs to be addressed. Current data show a significant variation in the nutrient content and energy value of commercial GFBs, which is a direct consequence of the marked differences in the composition, caused by the use of numerous ingredients and a wide range of additives. To increase the amount of nutrients and health-promoting bioactive compounds in the diet of gluten-intolerant patients, the list of basic GFB formulation ingredients should be extended/supplemented with whole grain flours and nutrient-rich ingredients, but more importantly, enriched GFBs should be easily available to consumers.

Our research group has been applying design of experiments and response surface methodology to optimize GFB formulations based on alternative nutrient-dense raw materials blended with traditional GF raw materials like rice flour and cassava, potato or maize starches that yield GFB with improved nutritional quality and sensory profiles. Our results show that is feasible to use a higher proportion of alternative flour ($50-100\%$ flour weight basis - fwb), like sorghum, millets, amaranth, quinoa, buckwheat, chickpea, unripe banana, and beans, to prepare well-accepted (overall linking ≥ 7 in a 10 cm hydride hedonic scale) and nutritionally superior products than conventional GFBs (Capriles, Santos, and Aguiar 2021). These new GFBs present a high consumer overall acceptability score, similar or better than control GFB, and some were even comparable to their wheat bread counterparts. Compared to white GFB, this new whole grain GFB presented a 2.5 to 5 times increase in total fiber content, can be considered "high in fiber" or "fiber source", and present $9-22$ g whole grain/50g of bread portion. In a recent preliminary study, we showed the potential of whole grain flours to produce accepted GF rolls (Drub et al. 2021). It is important to notice that sensory analyses were performed with healthy subjects and a good evaluation of acceptability by this group implies a closer similarity to regular WB. This could be considered a particularly good aspect of the analyses. However, further investigations using sensory tests with GF consumers, especially those with CD, will be made to verify whether the developed product meets their requirements.

Our research group has also been applying the design of experiments and response surface methodology to optimize fiber enriched GFB quality. Impressive results were obtained by Fratelli et al. (2018), showing that the psyllium (P) and water (W) interactions improve the bread quality by yielding a better loaf volume, softer crumbs and improved bread appearance as well as enhancing the sensory acceptability scores. The formulation prepared with 17.14% P and 117.86% W (fwb) results in acceptable GFB with nearly a four-fold increase in the fiber content and 33% decreased glycemic response, presenting low-glycemic index (GI $= 50$) and low-glycemic load (GL $= 9$), while the control GFB presented high GI ≈ 70 and high GL ≈ 14 (Fratelli et al. 2018). In a continuous study, Fratelli et al. (2021) investigated the potential of P in delaying GFB staling. Crumb firming was observed during 72 h of storage, especially for GFB control, which had a crumb firmness 8-fold higher than that of the

WB. The P-enrichment reduced the crumb firming ratio by 75% and maintained an acceptable texture, comparable to that of WB during the storage time. The addition of 17.14% P to the formulation delayed bread staling, resembling physical and sensory properties of WB samples during 72 h of storage. So, this approach seems to be promising to overcome some of the limitations of GF breadmaking (Fratelli et al. 2021).

Santos et al. (2020) obtained an optimum combination of 75% chickpea flour (CF) and 5.5% P (fwb) that improves GFB quality by yielding a better loaf volume and crumb texture, enhancing the appearance, texture, and overall acceptability scores. Likewise, a double increase in protein, dietary fiber and resistant starch contents was obtained, reducing the GI and GL, and increasing satiety index (Santos et al. 2021a). In a continuous study, Santos et al. (2021b) reported that CF and its combination with P were promising for reducing and delaying GFB staling, thus maintaining acceptability, softness, and freshness after 7 days of storage, according to the perceptions of consumers with and without gluten-related disorders.

In short, all those new healthier GFBs have good consumer appeal and could help to increase the consumption of whole grain, fiber, and bioactive compounds. Other promising nutrient-rich formula are described in the literature reviews of Capriles, dos Santos, and Arêas (2016, Capriles, Santos, and Aguiar 2021), Conte et al. (2019), and Bender and Schönlechner (2020).

Despite the results of scientific studies proving that it is possible to use nutrient-dense raw materials or functional and nutritional ingredients to obtain nutritionally improved and sensory acceptable GFB, those are still applied in low levels in commercial products worldwide, as showed in this review. Thus, making these high-quality baked products widely available to consumers suffering from gluten-related diseases must become the common interest of GFB researchers and producers.

Disclosure statement

No potential conflict of interest was reported by the authors.

Credit authorship contribution statement

Etiene Aguiar: Data curation, Investigation, Methodology, Writing - original draft. **Fernanda Santos:** Data curation, Investigation, Methodology, Writing - original draft. **Urszula Krupa-Kozak:** Writing - review & editing. **Vanessa Capriles:** Conceptualization, Methodology, Data curation, Investigation, Visualization, Writing - review & editing.

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