

## Artículo de Revisión / Review Article

### Sorghum, an alternative cereal for gluten-free product

### Sorgo, un cereal alternativo para productos sin gluten

#### ABSTRACT

There is a growing demand for health foods, indicated by the number of searches including the terms "celiac disease" and "gluten free products". Most information is designed not only for celiac and gluten intolerant patients, but by others interested in obtaining additional health benefits from foods. Sorghum has been recently recognized as a cereal with functional properties, able to improve human health, but still of low direct human consumption. This review aims to illustrate the publication trends relating to sorghum for gluten free products and celiac disease. The scientific literature available in databases from the last twenty years was used. We perceived the need for further sensorial studies in order to understand the consumer expectations of gluten free products, considering the large varieties of colored sorghum grains that could be used to prepare different gluten free products.

Keywords: Meta-analysis; Antioxidant capacity; Sensorial analysis; Gluten free products.

#### RESUMEN

Existe una demanda creciente por alimentos saludables, indicado por el número de búsquedas sobre enfermedad celiaca y productos libres de gluten. La mayoría de la literatura atribuye esto, no solo a pacientes celíacos e intolerantes al gluten, pero también otras personas interesadas en obtener beneficios adicionales para la salud a partir de los alimentos que consumen. Además, el sorgo fue recientemente reconocido como un cereal con propiedades capaces de mejorar la salud humana, aunque aún con poco uso en la alimentación humana. Esta revisión tiene como objetivo probar las tendencias de publicaciones relacionadas con enfermedad celiaca y el potencial uso del sorgo para elaborar alimentos libres de gluten. Fue realizada una búsqueda sistemática en las bases de datos disponibles para los últimos 20 años. Los resultados permitieron percibir la necesidad de más trabajos relacionados con aspectos sensoriales para entender las expectativas de productos libres en gluten por parte de los consumidores, considerando la gran variedad de colores de granos de sorgo, esto podría ser usado para producir diferentes productos libres de gluten.

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Palabras clave: Meta-análisis; Capacidad antioxidante; Análisis sensorial; Productos libres de gluten.

#### INTRODUCTION

In the beginning of the 21st century, food security became a public priority concern led by social, political and environmental problems at different scales<sup>1</sup>. The movement is founded on the idea of adequate nutrition, freedom from hunger and that the government has the obligation to provide food security for vulnerable groups, as part of international and regional conventions, agreements and protocols<sup>2</sup>. It is important that vulnerable groups may also be assisted by food safety protocols, as it refers to the reduction of the

probability that certain food products may result in illness, injury, or even death.

Gluten-related disorders (GRDs) are triggered in certain individuals when products that contain gluten are consumed. Gluten is found in some cereals, such as wheat, barley or rye<sup>4</sup>. These individuals belong to a particular vulnerable group that is genetically and/or immunologically predisposed to suffer from GRD. This group can be subdivided into individuals suffering from allergies (wheat allergy), autoimmune diseases (celiac disease (CD) and diseases that are likely to be immune mediated (Non-celiac gluten sensitivity)<sup>5,6</sup>.

Consumers with different GRDs require more options to eat. On the other hand, the number of gluten free products (GFP) is growing due to an increase of consumers with gluten intolerance and others that avoid products containing gluten and follow a GFP diet for lifestyle reasons. Nevertheless, there are not enough GFP options and quality and quantity of these products have not kept up with the rising demand<sup>7,8</sup>. Improvement of GFP is a challenge for the food industry and the number of studies on this topic has been on the rise.

Currently, non-conventional cereals such as sorghum and millet are not considered important plants for human nutrition in most countries of Europe, and North and South America. In those regions they are produced mainly for animal feed. In contrast, sorghum and millet are major food sources in many African and Asian countries, not only for human consumption, but because they have been considered as interesting crops due to their agronomical characteristics. They are drought resistant and have a low fertilizer requirement<sup>10,11</sup>, which make them suitable to adapt in the new global warming scenario. In addition, sorghum is an interesting alternative for celiac patients and gluten intolerant consumers<sup>1</sup>.

The process and consumption of sorghum, as a whole grain, fulfill functional and nutritional properties, due to its considerable dietary fiber (from 8,5 - 26,3 g/100 g), micronutrients (mg/100 g) such as K (363,0 - 338,2), Mg (151,0 - 165,0), Ca (11,5 - 12,4), P (375,0 - 384,5), and Mn (1,3 - 1,4), Zn (2,1 - 2,5), among others, and phytochemicals, such as tannin sorghum (10,0 - 68,0 mg/g), total phenolic (1,4 - 3,2 mg gallic acid/g), and others, which are present in the pericarp<sup>1</sup>.

In developed countries, the consumption of sorghum, especially varieties with tannin, may promote intake of low calories associated with high antioxidant, dietary fiber content, with the consequent benefits for celiac disease, obesity and diabetes-related health problems<sup>11,14,15</sup>. Also, in developing countries, sorghum could represent an important income reduction mechanism in foreign grain import costs, hence the use of sorghum as a food for human consumption could help local economies additionally to their health benefits<sup>1</sup>.

This work evaluates the current knowledge and ongoing information on CD and sorghum. It examines three important aspects: 1) CD; 2) Sorghum, as an alternative for human nutrition and health and 3) a metadata analysis regarding CD, sorghum and sensorial publications in order to understand

the reasons why GFP are not sufficiently available worldwide.

### Data collecting

FAOSTAT was used to collect the latest (2014) available crop information regarding sorghum production; the search was performed in June 2017. The Google trends search engine, accessed in June (2017), was used to find the terms "gluten free" and "Celiac disease" from 2004 to 2016. Also, the Scopus bibliographic database was consulted for the period 1997 to 2016, using the words: "sorghum", "celiac", "sensorial analysis", "food" and additional combinations. These terms were searched in the title, abstract and keywords.

### Gluten-related disorders (GRD)

GRD can be classified into three groups: group 1, autoimmune disorders that includes CD, gluten ataxia (neurological manifestation of gluten intolerance) and dermatitis herpetiformis; group 2: allergies, e.g. wheat allergy (respiratory allergy, immediate food allergy, wheat-dependent exercise-induced anaphylaxis WDEIA, and urticaria; group 3: non-autoimmune and non-allergic disorders also called nonceliac gluten sensitivity (NCGS)<sup>5,16</sup>. Nonetheless, the difference according to Hollon<sup>17</sup>, a gluten exposure can be resulted in increase in intestinal permeability.

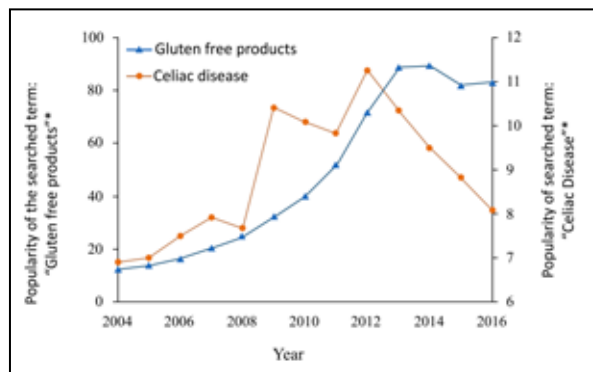
The World Gastroenterology Organization<sup>18</sup> defines CD as a chronic, multiple-organ autoimmune disease that affects the small intestine in genetically predisposed children and adults. CD is a result of both intrinsic (genetic) and extrinsic variables (environmental)<sup>19</sup>, other important factor to be considered is the immune dysregulation<sup>4</sup>. CD affects millions of people around the world and its prevalence is increasing<sup>20</sup>. CD affects 1 in 133 Americans, even though 1% of the U.S. population is thought to be afflicted with CD, with 97% of cases going undiagnosed<sup>21</sup>. On the other hand, CD is considered rare in Africa, China, Japan, Korea, Malaysia and immigrants from these countries, where consumption of wheat products is low<sup>22</sup>.

Concerning the proteins responsible for GRD, prolamin is present in cereal grains, e.g., wheat (gluten), rye (secalin), and barley (hordein) that are known to bring about allergic response or detrimental autoimmune reaction in certain individuals<sup>4,2</sup>.

Patients with GRD must avoid foods containing gluten (prolamin proteins coming from wheat, rye and barley) their entire lives<sup>4</sup>. Adults generally are conscious and able to prevent the consumption of GFP (e.g., baked goods and pasta) in daily life events, such as meetings and birthdays, particularly in Western diets. This situation becomes more difficult when travelling to locations where GFPs are not easily found, requiring persons to take their own food with them. But, the situation is much worse when children are affected, as they do not understand the reasons they must restrict their diets. The relationship with other kids and psychological status may be affected as they see their classmates and friends eating all foods containing gluten. Therefore, the entire family is affected with the restriction,

which imposes changes in food habits<sup>21</sup>.

From 2004, an increase in the number of searches using the term “CD” was observed up to 2012 when the number began to decline. The popularity of the term “GFP” in Google steadily increased until 2013 and remained stable to 2016 (Figure 1). The steep increase in CD articles in 2008 may be attributed to the increase of awareness influenced by international media events, mainly occurring in developed countries such as the USA, Italy and United Kingdom. When comparing the percentage of searches of both terms, CD is considerably lower (12 % of the number of searches in google in 2012) whereas GFP reached 89% in 2013 (Figure 1). Although searches for CD decreased, GFP kept increasing, which shows a clear concern and/or influence of health seeking issues of lifestyle change that may or may not be related to CD. According to Witczak<sup>23</sup>, the market for GFPs is growing all over the world, as well as plant alternatives to make GFPs such as corn, potato, cassava, rice, sorghum, millets, buckwheat, amaranth, quinoa, legumes, flaxseed, chestnut, carob germ flour, lupin.



**Figure 1.** Trends in search related terms: “Gluten free products” and “Celiac disease” (www.google.com.trends), accessed in June, 2017. \* Searched terms are relative to the total number of Google searches.

NCGS or simply, gluten sensitivity are reactions against gluten that involved neither allergic nor autoimmune mechanisms, nevertheless, the symptoms of NCGS could be similar to those of CD. The most prevalent NCGS disorders are abdominal pains, skin (eczema), headache, diarrhea, among others<sup>5,6</sup>. The diagnosis is difficult because there are no specific laboratory markers for NCGS. Thus, diagnosis alternative are conducted by exclusion, which begins by eliminating CD, then wheat allergy, following by a GFP diet. As a result, the diagnosis could be made by an open challenge (monitored re-introduction of gluten containing foods)<sup>5</sup>.

Wheat allergy is defined as an adverse immunologic reaction to wheat proteins which prevails in an average of 18% of food allergies. The clinical manifestations are similar to other food allergies that present symptoms on the skin and in the respiratory track<sup>16</sup>. In wheat allergy, immunoglobulin

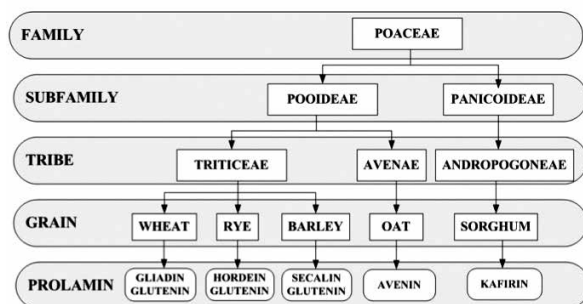
E is cross-linked by repeated gluten peptides (eg, Ser-Gln-Gln-[Gln-]Pro-Pro-Phe). Additionally, the release of immune mediators such as histamine from basophils and mast cells are induced by non-gluten proteins. On the other hand, CD is an autoimmune disorder, which is diagnosed based on serologic markers such as serum antibodies against tissue transglutaminase-2, followed by intestinal biopsy<sup>5</sup>.

## Sorghum

Sorghum is a low cost cereal crop characterized by its efficient use of water, resistance to drought and poor soil requirement fertility, as it originated from arid regions of Africa, although there are reports mentioning that it is also native to India<sup>5</sup>. Currently, it can be found in other arid zones of Australia, Central, South America, and North America<sup>25,26</sup>. Sorghum is the major source of carbohydrates, energy and proteins in African and Asian countries. These regions produce different sorghum food types<sup>27</sup>, including breads, tchapalo or sorghum beer, popped sorghum, and porridge, among others<sup>28</sup>. In most industrialized countries such as the USA, Europe and other developing countries like Mexico, Brazil, Argentina, among others, sorghum is mainly used for feed<sup>8,29</sup>.

Since 1977, sorghum yield has been growing more than any other crop in drought and semiarid areas around the world, as reported by Bookwalter, Warner<sup>26</sup>. In addition, as mentioned by de Mesa-Stonestreet<sup>21</sup>, “sorghum utilization helps in food security issues because it is a drought resistant crop that easily withstands harsh cultivating conditions in impoverished regions of Asia and Africa”. This sentence is a clear call for awareness that food security is an urgent topic of discussion with respect to global warming.

Sorghum is currently the fifth most produced cereal, following maize, wheat, rice, and barley. Sorghum belongs to the Poaceae family, like wheat, rye, barley, and oat (Figure 2), but from a different subfamily, Panicoideae. Wheat, rye and barley are classified in the same tribe (triticeae), whereas oat and sorghum are divided in avenae and andropogoneae, respectively.



**Figure 2.** Taxonomy of Poaceae family and their typical proteins, adapted from: Kupfer and Jabri<sup>4</sup>; de Mesa-Stonestreet, Alavi<sup>21</sup>; Vallabhaneni, Bradbury<sup>40</sup>.

According to Ratnavathi and Patil<sup>29</sup>, sorghum is known for its nutritional quality. Nevertheless, the global direct consumption is low and it is considered a marginal crop when compared rice, wheat and maize. Concerning its nutritional value, in a study of 100 sorghum genotypes, cultivated under controlled water stress condition, Queiroz<sup>30</sup>, reported minimum and maximum values (g/100g) of the following components: carbohydrates (54,6 - 77,2), proteins (7,8 - 19,0), dietary fiber (8,5 - 26,3), lipids (1,6 - 5,0) and ash (0,9 - 2,8). Sorghum prolamins are named kafirins, which are considered safe for celiac patients<sup>12</sup>.

The consumption of sorghum in countries with obesity and diabetes problems may contribute to reduced digestibility, which in turn, it is an attractive option for developing sorghum based low calorie health foods<sup>32,33</sup>. The major phenolic compounds present in sorghum are ferulic acid (120,5 - 652,1 µg/g)<sup>35,12</sup>, p-coumaric acid (41,9-68,1 µg/g)<sup>35,12</sup>, vanillic acid (30,1 - 61,4 µg/g)<sup>12</sup>, condensed tannins (proanthocyanidins), 3-deoxyanthocyanins, 4-coumaric acid, 4-hydroxybenzoic acid, caffeic acid, caffeoylglycerol and coumaroylglycerol<sup>12,34,35</sup>. The secondary metabolics present in sorghum grain has the highest level of antioxidants, that can vary from 2,5 to 17,5 µM trolox/g (ABTS), from 12,8 to 27,7 µM trolox/g (DPPH) and 1,0 to 28,4 µM trolox/g (FRAP), when compared to other cereals<sup>12,35,3</sup>.

Sorghum is a good source of vitamins, particularly E and B complex, and minerals<sup>28</sup>. Also, most sorghum genotypes are rich in bioactive compounds like phenolic compounds<sup>12,37</sup>, exact amount varies depending on the sorghum genotype. Other bio-actives present in sorghum grains are flavonoids (45,9 - 58,8 µg/100 g)<sup>35</sup>, condensed tannins, (19,2 - 67,4 µg/100 g)<sup>35,37,38,39</sup>, vitamin E (tocopherols/tocotrienols between 1,5 and 117,9 µg/100g)<sup>38</sup>, carotenoids (Lutein from 0,4 to 63,4 µg/100 g and Zeaxanthin from 1,4 to 58,8 µg/100 g)<sup>40</sup>, anthocyanins (3-Deoxyanthocyanin, from traces to 45 µg/100 g)<sup>32</sup> favoring an increased antioxidant capacity, that has been studied by many authors<sup>10,12,26,32,37</sup>.

Consequently, sorghum is considered a functional food<sup>12,14,41</sup>. It has been recently reported that sorghum presents anticarcinogenic and antimutagenic properties<sup>28,32,38</sup>, as well as reducing cardiovascular disease, diabetes and obesity<sup>32</sup>. In addition, the health use of sorghum proteins for CD patients and different levels of gluten intolerant consumers has been extensively reported<sup>8,12,21,26,28,32</sup>.

### Sorghum-made food product

Most products produced with sorghum are found in India and some African countries<sup>25,39</sup>. In West Africa the consumption of sorghum beverages (alcoholic and non-alcoholic) is common. Examples include: Dolo (Burkina Faso), Burukutu (Ghana), Pito (Ghana), Gowé (Benin) and Ran-noodo<sup>42</sup>. The combination of sorghum and maize is called Kunu and is found mainly in northern Nigéria<sup>43</sup>. In a review by Ratnavathi and Patil<sup>29</sup>, the authors compiled a list of foods made from sorghum and its mixture with other cereals. Some of them are described below:

*Tortillas* are a traditional Mexican food, conventionally based on calcium oxide treated maize, also called nixtamalization, this same process is also carried out with sorghum to produce very fine circles that is baked<sup>44</sup>.

*Roti or bhakri* is made with a fine whole sorghum flour that is baked on rolling<sup>45</sup>.

*Injera* is a bread made from fermented dough for about 48 h and baked for 2-3 min<sup>46</sup>.

*Kanji or ambali* is a porridge prepared from whole sorghum flour of low consistency that is consumed in the southern parts of India, Africa and Central America<sup>47</sup>.

*Tô* is made from decorticated sorghum grain that is milled into a flour, that is cooked for about one hour in water (1:4) with small amount of tamarind or lemon juices and allowed to cool (1 h)<sup>48</sup>.

*Annam* is made of dehulled boiled sorghum grains in water (1:3) until grain softness is achieved, and then the excess of water is drained off<sup>45</sup>.

*Upma* is a breakfast food or snack prepared with wheat semolina and polished milled sorghum. It is made with a little oil in a sauce pan and seasoned with grains like chickpeas along with mustard and cumin seeds<sup>47</sup>.

*Sankati* is a type of thick porridge made from grits or flour of milled sorghum grain that is boiled for 10 min with water (1:3). Then, fine flour is added by stirring for about 3 min and 10 cm diameter balls are made, eaten fresh or stored overnight<sup>43</sup>.

*Dosa and Idli* are fermented breakfast foods. Idli is made in molds and steam cooked, while Dosa is a thin, oily pan cake<sup>47</sup>.

*Muruku, chakkalu and namak* (Snack foods) are made by frying blended sorghum flour. These products could compete with snacks made from corn, rice and wheat<sup>29</sup>.

*Ugali* is main made of brown sorghum, but also with white grains that is served as a stiff porridge<sup>49</sup>.

*Ogi* is made from dehulled or whole milled sorghum and is cooked with water, vegetables, meat and other ingredients to produce a type of soup<sup>50</sup>.

*Kisra* is prepared by mixing 60% whole sorghum flour and 40% water and then fermented for 12-24 h until a sour taste is obtained<sup>51</sup>.

*Couscous* is a coarse granulated sorghum flour (whole or dehulled) with water it is turned into agglomerated particles that are consumed with milk and other sauces<sup>49</sup>.

The partial or total substitution of wheat with local flours originated a basted bakery product like bread (whole sorghum), plum cake and biscuits, noodles and pasta. Popping sorghum is a common product too. On the other hand, the extrusion cooking technology has opened a wide variety of products with high commercial values based on the good extrusion qualities of sorghum (in some cases it presents similar properties of extruded corn and rice products)<sup>29</sup>.

### Metadata analysis

The number of scientific publications regarding the term "celiac" was higher (Figure 3a) than any other, totalizing 24.239

(from 1997 to 2014). When the term “celiac and food” (Figure 3a) was used, the number of publications drastically reduced from thousands to hundreds per year totaling 2.382, which represented about 10% of the search term “celiac”. Although the number of publications was low when “food” term was considered, there is a steady increase in publications that it is believed traditional and nontraditional foods have been investigated and/or developed.

When compared to “celiac”, the term “sorghum” appeared in 13.594 research articles (Figure 3b), whereas “sorghum” and “food” terms totaled 2.210 published works, indicating that sorghum for food uses are comparably low and still deserves attention. By combining “sorghum” and “celiac” terms, only 54 articles were found (Figure 3d). The first articles that considered these terms appeared in 2004 and in 2016 the just three mentioned the term.

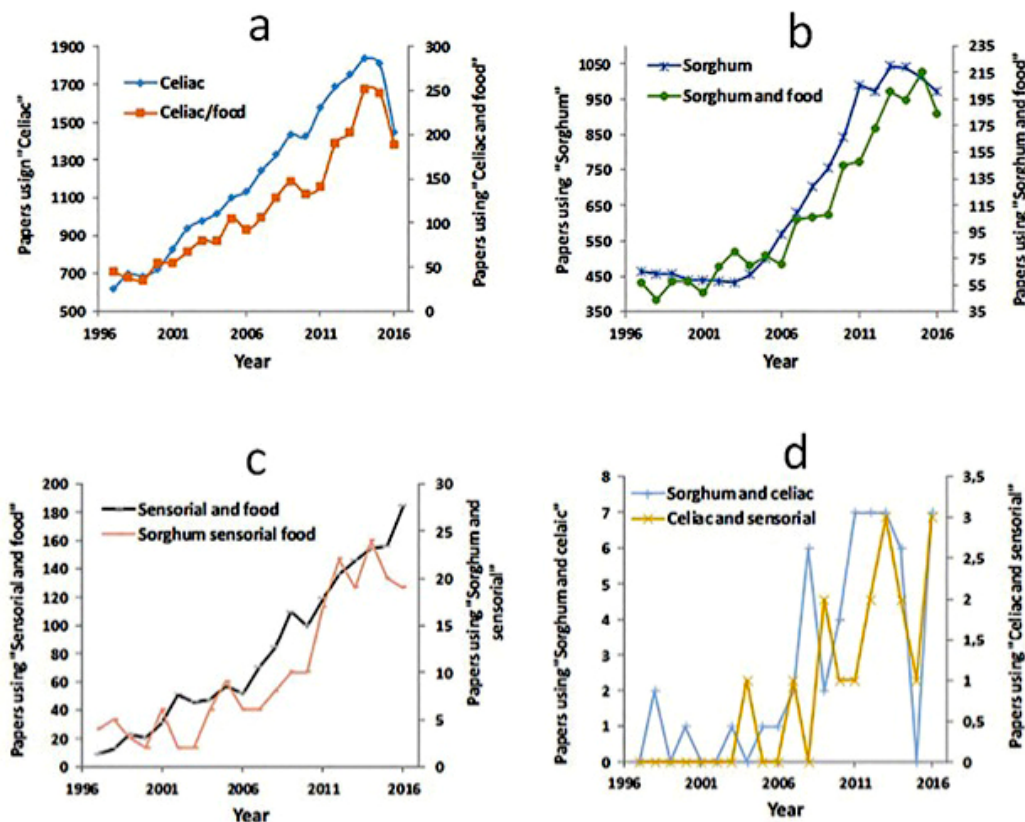
In order to develop a food product, it is very important to have it evaluated by sensory analyses. By following a market rule, “sensorial” and “food” terms were also searched for in scientific publications. As expected, a considerable number of articles was found (1,608) from 1997 to 2016 and expressive growth over the years (Figure 3c).

When “sorghum” and “sensorial food” terms were searched, only 200 articles were found (Figure 3c). It is worth

noting that only 17 articles were found when “celiac” and “sensorial” were searched together (Figure 3d), indicating a strong need to develop new sorghum food products for CD patients with good quality and acceptance<sup>23</sup>. Sensorial studies and characterization are the key to evaluate and develop products<sup>52</sup>.

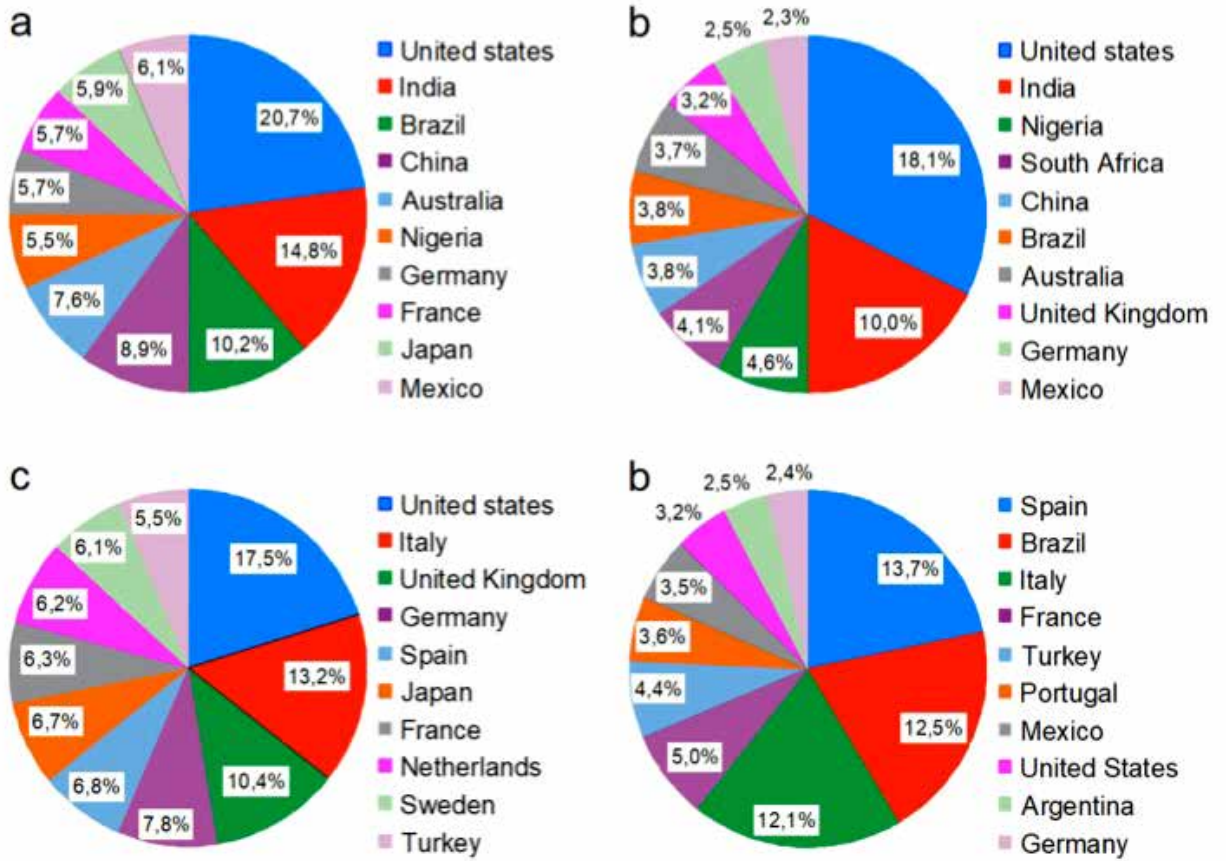
The USA, India, Brazil and China are the countries with almost 55% of published articles on sorghum (Figure 4a). The countries with research based on developing food for humans using sorghum are USA, India, Nigeria, South Africa, China and Brazil with almost 45% of articles (Figure 4b). The USA and European countries appear to be mainly concerned with CD (Figure 4c), as opposed to African and countries from the Indian sub-continent, where CD is believed to be scarce<sup>18</sup>. Data analysis also revealed three countries where sensorial analysis in food is emphasized (Figure 4d): Spain (13,7%), Brazil (12,5 %) and Italy (12,1%).

A list of published data from the last few years (2015-2017) on the use of sorghum food applications is displayed in Table 1. It is worth noting that only recently, a growing concern on producing acceptable foods using sorghum that combine good sensorial appeal and health benefits is observed. The list shows a scarce number of technical publications that evaluate sorghum products using sensorial techniques.



**Figure 3.** Number of scientific articles from 1997 to 2016 using Scopus metadata. This search was carried out in June, 2017.





**Figure 4.** Top ten countries in publications regarding the searched terms: a) "sorghum", b) "sorghum and food", c) "celiac" and d) "sensorial and food" by employing Scopus metadata. This search was carried out in June, 2017.

**Table 1.**

An overview of recent (last two years) publications using sorghum as directly consumed food product.

Title	Sensorial study	Reference
Mashing with unmalted sorghum using a novel low temperature enzyme system: Impacts of sorghum grain composition and microstructure	No	Holmes et al. <sup>53</sup>
Sorghum and roasted coffee blends as a novel extruded product: Bioactive compounds and antioxidant capacity	No	Chávez et al. <sup>12</sup>
Comparing sorghum and wheat whole grain breakfast cereals: Sensorial acceptance and bioactive compound content	Yes	Anunciação et al. <sup>38</sup>
Peroxidases from root exudates of <i>Medicago sativa</i> and <i>Sorghum bicolor</i> : Catalytic properties and involvement in PAH degradation	No	Dubrovskaya et al. <sup>54</sup>
Resistant starch content among several sorghum ( <i>Sorghum bicolor</i> ) genotypes and the effect of heat treatment on resistant starch retention in two genotypes	No	Teixeira et al. <sup>15</sup>
Physicochemical properties of sorghum and technological aptitude for popping. Nutritional changes after popping	No	Llopart and Drago <sup>13</sup>
Nutritional composition of sorghum [ <i>Sorghum bicolor</i> (L.) Moench] genotypes cultivated without and with water stress	No	Queiroz et al. <sup>31</sup>
Composition, in vitro digestibility, and sensory evaluation of extruded whole grain sorghum breakfast cereals	Yes	Mkandawire et al. <sup>33</sup>
Proline over-accumulation alleviates salt stress and protects photosynthetic and antioxidant enzyme activities in transgenic sorghum [ <i>Sorghum bicolor</i> (L.) Moench]	No	Reddy et al. <sup>55</sup>
Tocochromanols and carotenoids in sorghum ( <i>Sorghum bicolor</i> L.): Diversity and stability to the heat treatment	No	Cardoso et al. <sup>56</sup>
Dual modification of native white sorghum ( <i>Sorghum bicolor</i> ) starch via acid hydrolysis and succinylation	No	Mehboob et al. <sup>57</sup>
Process optimization for a ready-to-serve breakfast smoothie from a composite milk-sorghum base	Yes	Rani et al. <sup>58</sup>
Sorghum-cowpea composite porridge as a functional food, part II: Antioxidant properties as affected by simulated in vitro gastrointestinal digestion	No	Apea-Bah et al. <sup>59</sup>
Effect of heat treatment of sorghum flour on the functional properties of gluten-free bread and cake	Yes	Marston et al. <sup>60</sup>
Utilization of sorghum, rice, corn flours with potato starch for the preparation of gluten-free pasta	Yes	Ferreira et al. <sup>61</sup>

## CONCLUSIONS

The consumption of GFPs has experienced an exponential increase in the last few years, particularly from 2006. This outstanding increase was not only caused by the rise in incidence of CD and gluten intolerance, but also due to the consumer's concern for eating healthy foods—absent

of gluten, but with beneficial increments of dietary fiber, bioactive compounds and antioxidant capacity. In this review, we have shown that sorghum grain has important functional food characteristics. Thus, it can be considered a health food alternative for the population, particularly, for persons with CD and those with lower levels of gluten

intolerance. However, it was also observed and demonstrated here, based on the online search engines, that there are limited number of GFP. Also, more sensorial studies are the key to meet the challenge of developing palatable GFP based in sorghum.

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