Sorghum and Western Style Breads

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Due to the extreme weather conditions, caused by the climate change, the usual wheat harvest yield and quality in the Western countries were difficult to maintain in the past few years. The altered wheat quality was primarily characterized by a rising protein content. The application of high protein wheat flours in baking products leads to baking difficulties due to its elastic dough behavior. As these issues will further face the Western cereal cultivation, heat resistant cereals, like sorghum, are attracting increasing interest. A partial substitution of wheat with sorghum might offer one possible solution to address the current challenging situation. To introduce sorghum in the Western cereal and baking industry, the grain and its unique chemical and rheological properties need to be more widely promoted. Until now, several authors have conducted studies in order to emphasize the high potential of sorghum. The aim of the present review is to broaden the current knowledge of the chemical, rheological and baking properties of sorghum in comparison to wheat.

Keywords: sorghum ; western bread ; rheology ; baking ; wheat sorghum blends

1. Introduction

The wheat grain industry already experienced the effects of the climate change in the past few years. Dry climate with low rainfall was responsible for crop failures of wheat. According to a study, 60% of the current wheat growing areas could be affected by insufficient water supply by the end of this century [1]. However, due to the climate change not only wheat harvest losses happened, but also the wheat protein contents increased in the last few years [2]. A suitable solution must be found to compensate for the loss of wheat in the grain and baking industry and to deal with the altered quality. A possible way to address these challenges could be the use of food additives or to import wheat from other countries. A more sustainable, customer-friendly and innovative option could be the use of regional grains, preferable gluten-free grains, in wheat products. A partial replacement by gluten-free cereals might offer an option in order to compensate for the changed protein content of wheat. Sorghum, which is gluten-free and heat resistant, presents a promising grain in this context. The use of sorghum in wheat products could be a possible future solution to counteract the high climate-induced protein content of wheat. In addition, end products consisting of sorghum can gain valuable nutrients [3].

In order to introduce sorghum into the Western diet, the nutritional and technological challenges have to be considered. Mainly the altered protein composition, due to the absence of gluten results in changed dough rheological parameters and end-product qualities [4][5][6][7]. However, like other cereals sorghum contains tannins, trypsin inhibitors and phytic acids, which are known to impair protein digestion and mineral absorption [8]. Sometimes these values are higher than in other cereals. In addition, sorghum prolamins, called kafirins, are known to have a low digestibility, especially in prepared foods [9], which is mainly due to their crosslinking properties upon processing. Sorghum possesses higher crosslinking properties than wheat for example. However, if this protein cross-linking could in turn offer beneficial viscoelastic properties in food is still unknown [10].

2. Classification and Morphology of Sorghum

Although sorghum is not well known in the West, it is the fifth most produced cereal worldwide. In Africa sorghum is considered to be the most important cereal. Outside of Africa production takes place mainly in India, USA, Australia, and Argentina, whereby sorghum in the USA and in Australia is mostly used as animal feed. Five races are known under sorghum: *bicolor*, *kafir*, *caudatum*, *durra* and *guinea*. All combinations from those mentioned races are called intermediate races. Of all races, *Sorghum bicolor* Moench is mainly cultivated [11]. According to Taylor there are different classification systems of sorghum. Some of them seem to be complex. However, like wheat and maize sorghum is classified into the grass family *Poaceae* as can be seen in Figure 1. Sorghum belongs, like maize, to the subfamily *Panicoideae* and to the tribe *Andropogoneae* [12]. Due to the botanical relationship sorghum is often compared to maize.

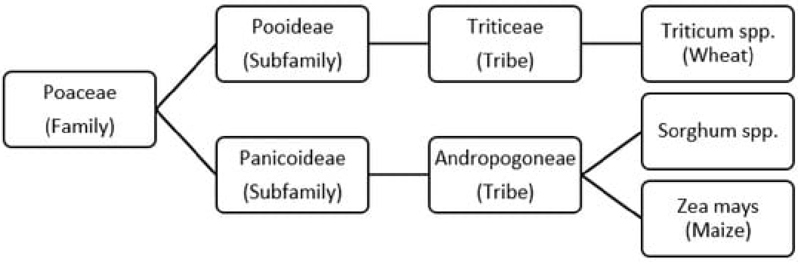

Figure 1. Family tree of sorghum. Modified according to Taylor [12].

The structure of a sorghum kernel is comparable to the structure of a corn kernel, but in general, a sorghum grain is smaller. Awika et al. [13] determined the diameters of different sorghum kernels to range between 1.7–2.7 mm, and the thousand kernel weight of different varieties was between 15.2–38.8 g. The extent of the pericarp thickness and the presence of a testa is variety dependent [13]. Both sorghum and maize, have an endosperm with a floury and a corneous part [14]. Sorghum kernels appear in color nuances of white, red, brown and black (Figure 2).

Figure 2. Sorghum field in Hörsching, Austria (©Rumler, 2020).

However, the color of the pericarp is not always indicative of the appearance of sorghum flour. For example, a sorghum kernel which owns a red pericarp, may have a light endosperm color. Therefore, if special food colors are required, the insertion of sorghum fraction flours may be useful in order to achieve appropriate food appearances [15].

3. Chemical and Nutritional Properties of Sorghum

3.1. Protein

The protein content in sorghum can be comparable to the protein content of wheat [5][16]. However, Tasie and Gebreyes [17] found a wide range of 8.20–16.48% between different sorghum whole grain varieties. Attempts have often been made to identify correlations between nutrients and the sorghum kernels color. Whether the protein content differs between red and white sorghum is still poorly understood. A research of Galan et al. [18] detected a higher protein content in red whole grain sorghum flour, while Yousif et al. [19] and Srichuwong et al. [20] figured out a higher protein content in whole grain white sorghum flour.

In sorghum protein the predominant fraction is the prolamin fraction, which is called kafirin. According to a study almost half of the sorghum protein belonged to the kafirin fraction (47.7%), followed by the glutelin fraction (24.1%) and the albumin and globulin fraction (18.8%) [21]. Regarding the kafirins, four types of kafirins, occurring in form of protein bodies, can be mentioned: alpha-, beta-, gamma-, and delta-kafirin. Alpha-kafirins are the most common kafirins found in sorghum [10][22]. Detailed amino acid analyses have been carried out by Mohapatra et al. [23]. The most common amino acids found in whole grain sorghum were glutamic acid (44.38 mg/100 g protein), arginine (28.34 mg/100 g protein), aspartic acid

(20.50 mg/100 g protein), leucine (16.50 mg/100 g protein) and glycine (16.22 mg/100 g protein) [23]. The limiting acid is lysine, as for most other true cereals [24].

Sorghum proteins have been gaining much attention due to their ability to crosslink, in particular upon cooking. Authors believe that this kafirin cross linking is connected to low protein digestibility of sorghum. In this context a comparison of the digestion of kafirins and zeins was performed by Emmambux and Taylor [9]. The authors analyzed the digestibillity of sorghum and maize meal as well as the digestibillity of aqueous tertiary butanol extracted kafirin and zein. In order to evaluate the influence of heat on sorghum and maize digestibillity, the samples were undertaken a boiling and a pressure cooking treatment. Already in the untreated state, the maize meal and extracted zeins showed a higher digestion rate than the sorghum meal and kafirins. However, after boiling and pressure cooking this difference was even more obvious. Authors detected that sorghum kafirins (obtained from decorticated sorghum kernels) were more polymerized by disulfide bridges during the cooking process than the zeins [9]. Same authors further pointed out, that sorghum proteins were not only able to form complexes between each other, but also had the ability to connect with condensed tannins and tannic acids [25]. This leads to the suggestion that sorghum kernel dehulling or the usage of condensed tannin free sorghum varieties might offer a higher digestibillity. However, crosslinking interactions According to Hamaker and Bugusu [10] sorghum proteins are embedded within protein bodies and therefore hard to access, but on the other hand they may show viscoelastic behavior in food. However, several questions remain unanswered at present. Fundamental investigations are still needed in order to determine the properties of kafirins.

3.2. Carbohydrate

Carbohydrate amounts between 67.5–76.4% were found in different whole grain sorghum varieties from Ethiopia [17]. Pontieri et al. [26] found that five varieties of refined sorghum, which were grown in Italy, the USA or Uganda, had an average carbohydrate content of 75.23% in dry matter. Starch is the main component of carbohydrates and is located in the endosperm. Srichuwong et al. [20] reported a starch content of 72.2% and 73.8% in dry matter in white and red whole grain sorghum, with amylose contents of 25.8% and 24.6% respectively. However, there is a wide range of amylose content in sorghum varieties, and even waxy varieties, which have high amylopectin contents occur in the wild [27]. The diameter of starch granules was measured to be between 5–35 µm and they appeared as polygonal and spherical [20], but also more unusual granules shapes, which researchers called “doughnut-shaped”, were occasionally discovered in sorghum kernels [28]. Miafo et al. [29] determined the content of free sugars in sorghum refined flour of 30.35 mg/g sorghum flour. Sucrose made up the largest proportion (12.42 mg/g), followed by maltose (4.25 mg/g) and fructose (4.22 mg/g). The usage of sorghum flour might offer a sugar reduction possibility in bakery products as it has already a unique sweet taste itself. As humans are tending more and more towards balanced diets, sensory trials are required in order to state if sorghum can partially replace household sugar.

Whole sorghum contains a notable amount of dietary fibers, which is mostly located in the outer layers of the sorghum kernel. A study carried out in 2012 showed a total dietary fiber content between 9.13–15.09 g/100 g that has been detected in eight sorghum varieties, whereby the soluble fiber part ranged between 0.15–0.88 g/100 g [30]. Authors compared the fiber content determined in whole grain sorghum, dehulled sorghum and sorghum bran. It was found that the bran fraction had the highest value with 41.38 g/100 g, followed by 26.34 g/100 g in whole grain sorghum and 11.53 g/100 g in hulled sorghum [31].

3.3. Fat

Whole grain sorghum flour is known for its high fat content (3.5%) especially compared to wheat (2% in whole wheat) [3]. Fat is mostly located in the sorghum germ (Taylor, 2003). The most common fatty acids are linoleic acid (18:2), followed by oleic acid (18:1) and palmitic acid (16:0), with average contents of 43.86%, 37.98% and 13.07% in refined sorghum flour, respectively [26]. The ratio of saturated to unsaturated fatty acids was found to be 0.27–0.37 [32]. Knowledge is lacking if high fat contents in sorghum flour play a crucial role within shelf life. However, [33] were able to extend the storage time of sorghum flour from 15 days to several months by means of heat treatments. As sorghum is mostly harvested in Africa, knowledge about sorghum milling in the Western countries was rare until very recently. It was not clear whether a high fat content in sorghum brings difficulties within a milling process. However, in 2021 authors concluded that sorghum flour can be provided via commercial wheat mills [15].

3.4. Micronutrients

Sorghum is known for having a valuable micronutrient profile. Istianah et al. [5] determined 1.64% ash in dehusked sorghum. However, it seems that micronutrient contents vary to a great extend among different varieties [17][34]. Tasie and Gebreyes (2020) identified ash contents between 1.1–2.3% in dry matter of different whole grain sorghum flours from Ethiopia. Regarding the micronutrients, amounts of phosphorus ranged between 112.5–327.7 mg/100 g, of sodium between 2.2–6.2 mg/100 g, of magnesium between 62.0–207.5 mg/100 g and of calcium between 9.5–67.2 mg/100 g [17]. Varieties with a particularly high mineral content exist, like for example the variety Tabat with phosphorus quantities of 350 mg/100 g, sodium of 14.5 mg/100 g, magnesium of 329 mg/100 g and calcium of 24.5 mg/100 g extracted sorghum flour [35].

3.5. Secondary Plant Products

Although people in the Western hemisphere are increasingly turning to alternative cereals with valuable ingredients, like amaranth or buckwheat, sorghum is still unknown. However, sorghum also offers a lot of promising health-promoting components. A review pointed out that especially sorghum polyphenols, as they have antioxidative effects, can help preventing chronic diseases, like improvement of insulin sensitivity, reduction of fat accumulation, or reduction of mild chronic inflammation [36]. Therefore, many research studies are interested in measuring the polyphenol content of sorghum, regardless of the research question. It can be stated with certainty, that polyphenols vary enormously among the biodiversity of sorghum. However, despite this interest, little research tended to focus on the context between polyphenols and sorghum colors. While researchers found that the polyphenol content of whole grain wheat (92.4 mg/100 dry matter) and whole grain white sorghum (95.2 mg/g dry matter) was similar, whole grain red sorghum had a significantly higher content of 203.5 mg/g dry matter [20]. Higher polyphenol levels in whole grain red sorghum flour than in whole grain white sorghum flour were confirmed by further studies [19][37]. If polyphenols are determined in more detail, flavonoids and phenolic acids are mainly mentioned. Wide ranges of phenolic acids were reviewed in the past. However, in red sorghum, as well as in white sorghum, ferulic acid was found to be the most predominant phenolic acid [38]. Among all flavonoids, special attention has been paid to the tannins, chemically named proanthocyanidins. Tannins are known to reduce sorghum digestibility [8]. There are low tannin and high tannin sorghum varieties, both naturally occurring. Tasie and Gebreyes [17] examined 35 whole grain sorghum flours from Ethiopia and detected tannin contents between 1.3–3337.2 mg/100 g dry matter. They also reported that condensed tannins and tannin acids in sorghum can form complexes with kafirins. Such a complex formation is one reason to lower sorghum protein digestibility. There was no evidence that other phenolic compounds, such as catechin or flavonoids, can bind kafirin [9]. A decreased protein digestion of tannin containing sorghum compared to non-tannin sorghum was also detected by Wedad et al. [39]. As condensed tannins are not present in wheat [14], it is questionable if using tannin rich sorghum varieties in a wheat blend leads to nutritional advantages. Besides phenolic acids and flavonoids, carotenoids also offer antioxidant properties. Luteolin, zeaxanthin and beta-carotene were found in amounts of 122.3 mg/kg, 25.2 mg/kg and 27.0 mg/kg, respectively, in white sorghum [40].

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