Potential of sorghum grain for malt and beer production

Abstract

Sorghum has a relatively lower price compared to other brewing cereals, and consequently has potential as an alternative substrate for lager beer brewing and especially represents an excellent option for gluten-free beers. Attributes such as extracts, proteins, total nitrogen and free amino nitrogen content of sorghum malt and the wort obtained from mashes indicate that sorghum is potentially an alternative substrate for conventional beer brewing in the tropics. In alcohol industry, some distillers prefer sorghum varieties with high starch and less protein contents. The variation in biochemical compositions among sorghum varieties affects the optimal malting conditions and characteristics of the grains. The degree of steeping and temperature, and germination capacity, kilning temperature and the intrinsic enzyme activity determine sorghum grain malt quality.

Keywords: *Sorghum, Malting, Malt quality, uses*

Introduction

Sorghum is the most important and old world cereal crop that was domesticated in Africa (Dahlberg *et al.,* 2011). A large variety of wild and cultivated sorghums are grown in the tropics and subtropics of the world (Ratnavathi *et al.,* 2016). It is the fifth most important crop which is cultivated in tropical, subtropical, and arid areas in different parts of the world (Rooney and Waniska, 2000). India, Nigeria, the USA, Argentina and Ethiopia are the largest producer of sorghum (FAO, 2014; Ratnavathi et al., 2012). It is used for food, feed, ethanol, beverages, breweries and industrial products (Ratnavathi *et al.,* 2016; Reddy *et al.,* 2004). In addition, unlike wheat, barley and rye, sorghum contains no gluten proteins, which are the causative agent for coeliac disease, and thus sorghum has great potential to be used for the production of gluten-free foods and beverages (Taylor *et al.,* 2006). It has been malted for centuries and is used for the production of baby food and traditional alcoholic and nonalcoholic beverages (Trust *et al.,* 1995).

Traditionally, barley is the cereal chosen for malting and is used predominantly for brewing beer in the world (Mather *et al.*, 1997). Especially barley in Europe and sorghum in African used to produce the necessary enzymes and to modify the starch and protein (Okosun, 1999). The production of opaque and lager beers requires the importation of malt barley in tropical regions because the cultivation of barley is challenging. This problem forced the beer industries found in tropics to utilize tropical cereals for germination and malting. Sorghum has been malted for centuries and is used for the production of baby food and traditional alcoholic and nonalcoholic beverages. It has been considered as potential material to make beer due to its fermentative capacity. As a result, the brewers try to totally or partially replace the barley malt with other less expansive cereals to reduce costs (Kordialik-Bogacka *et al.,* 2019).

The substitution of barley malt with adjuncts like sorghum in brewing has the potential to reduce the cost of raw materials and to create a unique beer flavour/aroma (O'Rourke, 1999; Ogbeide, 2011; Schnitzenbaumer *et al*., 2013). The cost of malted barley is roughly double to that of sorghum. Fortunately, beer industries are expanding and needs to offer new alternatives that meet consumer requirements. Due to its fermentative capacity, sorghum has been considered as potential material to make beer (Kordialik-Bogacka *et al.,* 2019). Sorghum grains are very interesting but also very different brewing adjuncts even though its beer is produced on limited scale. Its versatility makes sorghum a very promising crop for exploitation in Europe (Berenji and Dahlberg, 2004). Research studies with sorghum as a brewing raw material are progressing rapidly and making a great impact in brewing despite the earlier misunderstanding that malted sorghum produces insufficient hydrolytic enzymes (Archibong *et al.,* 2015). Also, research reports on extracts, proteins, total nitrogen and free amino nitrogen content of sorghum malt and wort obtained from mashes indicate that sorghum is potentially an alternative substrate for beer brewing (Owuama, 1999).

As cited in Owuama & Okafor (1990), sorghum was first considered as brewing adjunct in conventional lager beer production during the Second World War. Thenceforth, there has been remarkable progress towards the use of sorghum as an adjunct or as a substitute for barley in beer brewing because it is consistent in terms of composition, availability and produces a spectrum of fermentable sugar and dextrin similar to that produced by malted barley after it has undergo enzymatic conversion. In Africa, research showed that sorghum is malted widely to provide an important raw material used in brewing (Archibong *et al.,* 2015). Sorghum has a sweet and fine flavor which is compatible with many styles of beer, lower protein and polyphenol contents of beer, thereby enhancing superior chill-proof qualities and reducing haze potential (Peterson, 1996), the taste may be apparent making it more generally suited for the sweet dark beer. Embashu and Nantanga (2019) noticed the potential of red sorghum for industrial malting for brewing non-alcoholic and low alcohol beverages. Sorghum based beverages can be a potential vector of phenolics compounds with antioxidant activity (Abdoul-latif *et al*., 2012).

This review examines the potential of sorghum in malt and beer production, the progress made so far and discusses factors affecting sorghum malt quality. For this purpose, pertinent published articles mainly from Web of Science and Scopus indexed journal articles were reviewed using the key words of this review article.

Sorghum grain composition and physical properties

Sorghum grain is composed of three main components namely, the pericarp (3 to 6%), endosperm (84 to 90%), and germ (5 to 10%) (Rooney and Serna-Saldivar, 2000; Evers and Millar, 2002) and the grain is unique in that it is the only cereal to have starch granules present in the pericarp (Evers and Millar, 2002). Figure 1 shows the overall structure of sorghum grain with its function in brewing technology. The sorghum grain can vary in physical attributes, including shape, size, color, and hardness (Evers and Millar, 2002) due to its genetic diversity. The color of the grain is influenced by pericarp color and thickness, the color the endosperm, and the presence of a testa layer. A range of 30 to 80 g was reported for the thousand-kernel-weight sorghum (Rooney and Serna-Saldivar, 2000; Chiremba *et al*., 2012) and for individual grain weight 3 to 80 mg (Bean *et al*., 2006).

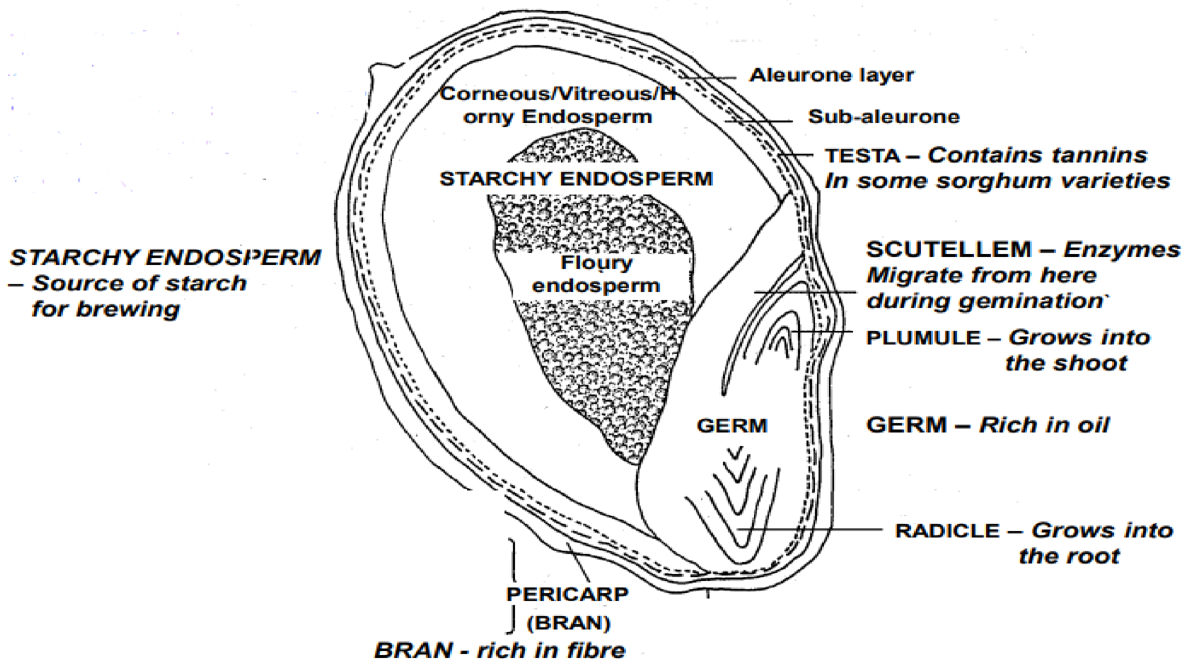

Figure 1. The structure of sorghum grain (Taylor, 2010)

Starch represents the major reserve carbohydrate in the endosperm of cereal seeds. Sorghum kernels contain both a vitreous and a floury endosperm fraction (Schober and Bean, 2008). However, the relative proportions of vitreous and floury endosperm vary greatly between different sorghum cultivars (Schnitzenbaumer *et al.*, 2013). Starch of the vitreous endosperm is more resistant to gelatinization than starch of the floury endosperm (Chandrashekar and Kirleis, 1988). Beta *et al.* (2000) found a significant negative correlation between amylose content of normal, non-waxy sorghum starch and the floury endosperm proportion, the pericarp thickness and the polyphenol content of the grain; they also reported a significant positive correlation between starch amylose content and gelatinization temperature, probably owing to the amylose–lipid complexes. The floury endosperm starch granules in the center of the kernel are packed loosely in a protein matrix; whereas vitreous or glassy endosperm is characterized by more compact embedding of starch granules into a protein matrix. This might affect the water and enzyme distribution in the endosperm, which is a principal prerequisite for homogeneous modification of endosperm in the course of malting. Glassy endosperm is degraded more slowly than mealy endosperm (Chandra *et al.*, 1999) and thus the distribution and activity of key enzymes is affected and this leads to lower modification during malting. The relative proportions of corneous to floury endosperm can vary widely in sorghum, with overall grain hardness in sorghum correlated to the percent vitreosity of the grain (Hallgren and Murty, 1983).

Sorghum proteins appear to play an integral role in the relationship of endosperm type and grain hardness. A range of 5.4 to 12.9% crude protein content of sorghum grains was reported (Eburuche *et al*., 2019), and the main storage proteins are mostly kafirins. Previous researches reported the total protein content of sorghum grain in the range of 7 to 15%, with the majority of the protein approximately (80–85%) found in the endosperm (Rooney and Serna-Saldivar, 2000). The germ, which is composed of the embryonic axis and scutellum and contains lipid, protein, and minerals and the majority of lipid found in sorghum grain is located in the germ (Rooney and Waniska, 2000).

However, the presence of non-starchy substances such as proteins over the starch granule surface, the amylose to amylopectin ratio, and the endosperm texture are some of the factors that may affect the rate of enzymatic hydrolysis of starch granules (Singh *et al.*, 2010). Sorghum vitreous endosperms are less digestible compared to floury endosperm counterparts. This is apparently due to the lower accessibility of amylases to the starch resulting from the complex and restrictive prolamin protein network present in the vitreous endosperm area (Ezeogu *et al.*, 2005). Yan *et al.* (2011) found holes in waxy starch granules, which they assume make them more susceptible to enzymatic digestion because water and enzymes can more easily enter through these apertures.

Malting processes and conditions

The malting of sorghum is similar to that of other grains. The purpose of malting is to produce some physical and biochemical changes to obtain fermentable products via changing the microstructure of cell walls, proteins, and starch granules (Gupta *et al.*, 2010). During malting, the endosperm of the grain is degraded by enzymes mobilized during steeping (Ratnavathi *et al.*, 2016). The process of malting could break proteins and carbohydrates and can be utilized by germination shoots and roots; results in the reduction of malt barley protein content (Galano *et al.*, 2008). Malting consists of three major stages, namely steeping, germination, and kilning. Steeping increases the moisture of the grains to around 45% and activates ß-glucanase, endo-proteases, α-amylase and pentosanase enzymes (Vinje *et al.,* 2015; Contreras-Jim´enez *et al.*, 2019). The duration of germination and watering rate had the highest effect on enzyme activity and malting losses respectively (Abdulraheem *et al.,* 2013). Increase in moisture content is important during the malting process since the grain needs to absorb enough water for activation of enzymes and initiation of germination which ultimately affects the quality of beer produced from the malt (Usai *et al.*, 2013). To keep the metabolism very active, and enzymes such as hemicellulases, amylases, proteases, oxidases, maintaining moisture and temperature with frequent rotation of the grain is important. Depending on the malting conditions and grain, the germination stage may take 4 to 5 days. The enzymes produced during germination lead to the hydrolysis of starch and protein which release sugar and amino acids, directly making them easily available (Deepika, 2017). Finally, the germination process stopped by kilning when the root of the grain has the same size of the grain (Contreras-Jim´enez *et al.,* 2019). Kilning has two stages with the initial drying where the grain is exposed to 50 ^{0}C, and enzymatic activity decreases and the second drying stage at 85–90 ^{0}C to reduce the moisture content to 4–5%. The highest extract yield was noticed at 40 ^{0}C compared with drying at 30 and 50 ^{0}C (Clement *et al.*, 2015). It is a key stage to stop the metabolic activity and maintaining the quality characteristic of malt like enhancing flavor, aroma, and obtaining a malt with a long shelf life (Vinje *et al.*, 2015). Malting conditions such as time, moisture and temperature affect the quality of final malt. Malt quality can be maximized by maintaining of steeping temperature and steep out moisture of the grain (Ahmed *et al.*, 2016). Pelembe *et al.* (2002) revealed that the optimum malting conditions for high diastatic power, α- and β- amylase activity, good free amino nitrogen, and moderate malting loss in pearl millet were 25-30 ^{0}C and 3-5 days germination. In order to produce acceptable quality of malts for the brewing industry in Nigeria, Abuajah *et al.* (2016) recommended a germination period of 5 days for malting sorghum varieties. Simona *et al.*, (2015) noticed a direct correlation between germination temperature and the number of days needed for seed germination. Optimized the malting conditions of sorghum to obtain an alcoholic beverage called *Pito* and found that 12.0–12.5 hr steeping, 5 days of germination at 30 ^{0}C, and drying at 40 ^{0}C were the best conditions to obtain better malt quality (Djameh *et al.*, 2015). The general overview of malting process is indicated in Figure 2.

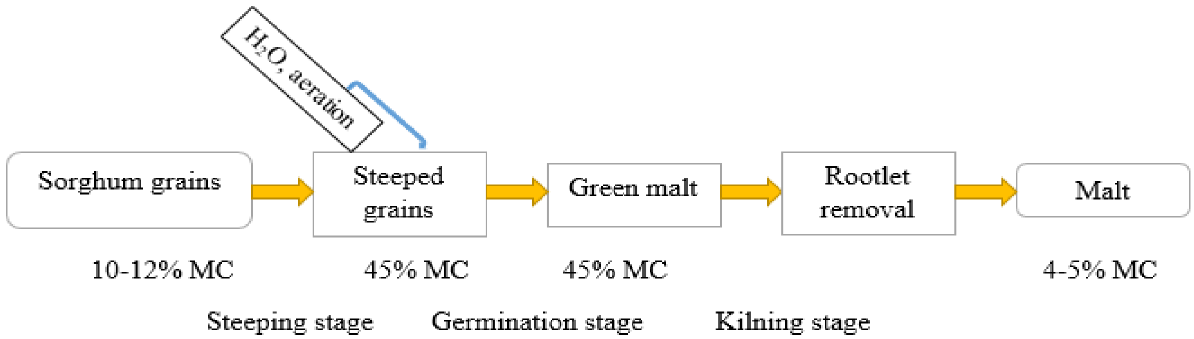

Figure 2. Malting process flowchart (MC, moisture content)

Malting characteristics of sorghum grain

A sorghum malt characteristic is highly dependent on variety, endosperm structure, malting conditions and methods. For instance, in Southern Africa, sorghum is commercially processed by pneumatic and floor malting methods. Malting conditions such as moisture, temperature, and time are better controlled during pneumatic malting as a result the malt obtained is more uniform and better quality than that obtained from floor malting (Beta *et al.*, 1995). Malts of some sorghum varieties display α-amylase and ß-amylase activities comparable to those of barley, making them useful for various agro-industrial foods (Dicko *et al.*, 2006). However, there is much less ß-amylase in sorghum malt than in barley malt. Taylor, (2010) described the term diastatic power as the joint activity of the α- and ß-amylase enzymes. The temperature of gelatinization of sorghum starch is higher than that of barley, and malt has lower extract yield and diastatic power than barley malt (Ratnavathi *et al.*, 2016). The total enzymes produced, α- and β-amylases are needed to hydrolyze starch and produce fermentable sugars in these processes.

The hot water extract, viscosity, Kolbach index, wort β-glucan, fermentability, diastatic power, α-amylase, β-amylase, free amino nitrogen, friability, and β-glucanase are the critical quality attributes for malt barley. Evans *et al.* (2009) revealed that the sum of individual starch degrading enzymes and the thermo-stability of the enzymes as well was a better indicator of diastatic power and that these enzymes also correlated better to ferment ability. Beta *et al.* (1995) investigated the changes that occur in nutrient composition, enzymatic activities of α and β-amylase, and viscosity of sixteen sorghum cultivars at the end of the malting process and found excellent correlations between some study variables. According to this author, diastatic power was correlated to α-amylase and the reduction in pasting viscosity; and β-amylase was negatively correlated with α-amylase. Malts with higher dry matter losses were correlated with high germination energy, high α-amylase activity, and low starch content. A study reported that white and red sorghum, using the micro-malting method and found that the varieties have high diastatic activities between 55 and 68% of the commercial barley malt, sustainable amounts of free nitrogen (Demuyakor and Ohta, 1992). Moreover, Djameh *et al.* (2015) optimized the malting conditions of sorghum to obtain an alcoholic beverage called *Pito* and found that 12.0–12.5 h steeping time, 5 days of germination at 30 ^{0}C, and drying at 40 ^{0}C were the best conditions to obtain malt to produce *Pito* evaluating diastatic power, extract yield, attenuation limit and free amino nitrogen were determined.

Compared to malt barley, sorghum showed a logistic curve in its germination power which attained 91% on the second day (Oseguera-Toledo *et al.*, 2020). This indicates it takes less time to achieve total germination, making it an interesting grain for malting due processing time and economically attractive to the industry (Contreras-Jim´enez *et al.*, 2019). Brewing with sorghum (high starch gelatinization temperature) necessitates the use of a double infusion mashing procedure, where the sorghum starch is pre-gelatinized by cooking before its enzymatic conversion into fermentable sugars. Sorghum kernels have no husks but exhibit a high starch gelatinization temperature (Beta *et al.*, 2000).

Sorghum has very low β-glucan content in comparison to malting barley (Zhang *et al.*, 2002). Its cell walls and water-unextractable solids account for around 5% of the total grain dry weight, and these consist predominantly of arabinoxylans and non-starch polysaccharides called cellulose. The major part of these cell wall components is located in the pericarp of the sorghum kernel (Verbruggen *et al.*, 1993). Arabinoxylans present in sorghum are more complex than those present in barley; the former are highly substituted and contain considerable amounts of uronic acids, as well as acetyl groups (glucuronoarabinoxylans) (Izydorczyk and Dexter, 2008). Malt barley arabinoxylans have been positively correlated with wort/beer viscosity (Li *et al.*, 2005) and negatively correlated with beer filtration efficiency, whereas glucuronoarabinoxylans from sorghum appear to have little or no impact on brewing performance (Verbruggen, 1996).

Sorghum tannins can inhibit enzyme activities and adversely affect beer quality (Taylor and Belton, 2002). Use of darker skinned, high tannin cultivars in brewing is thought to result in inhibition of mash enzymes and an objectionable increase in product bitterness (Kobue-Lekalake *et al.*, 2007). However, most sorghum cultivars do not contain non-pigmented testa (Dykes and Rooney, 2006). In fact the seed colour and its intensity are not reliable indicators of the presence or content of tannins in sorghum. As Mikyška *et al.* (2002) revealed, polyphenols can improve the flavour stability of beer, but they also contribute to colour, astringency and haze. The impact of polyphenols on saccharification has also been disputed in mashing using sorghum malts. It has been suggested that the reduced saccharification of some sorghum malts is due not to polyphenols, but to starch characteristics and poor diastatic potential (Dufour *et al.*, 1992).

Enzymes are a large group of proteins that have evolved into highly active and specific catalysts for virtually all physiological reactions. Researches revealed that un-malted sorghum exhibit very low levels of enzyme activities like cytolytic, proteolytic or amylolytic in comparison to malt barley (Schnitzenbaumer and Arendt, 2013; Schnitzenbaumer *et al.,* 2013), as hydrolytic pre-existing enzymes are activated and new enzymes are synthesized during the malting process (Briggs, 1998). Barley has proved to be more suitable for malting/brewing purposes than sorghum or oats owing to the development of higher hydrolytic enzyme activities like β-amylase) during germination (Beta *et al.*, 1995). The synthesis of endosperm degrading enzymes such as endo-β-glucanases, endopeptidases and α-amylase in the aleurone layer of germinating barley grains is induced by gibberellins (phytohormones), which are primarily produced in the embryo (An and Lin, 2011) and are secreted into the starchy endosperm, where β-amylase is released and activated by cysteine endopeptidase activity for partial proteolysis (Schmitt and Marinac, 2008; An and Lin, 2011).

Factors affecting sorghum malt quality

Malting is the keystone of the brewing and distilling industries. As a result of the malting process, there is an increase in enzyme activity which results in formation of higher amount of soluble protein and small peptides (Hoseney, 1994). Zhang and Jones (1995) observed that at least 42 different active proteases were found within the grain during germination. Cysteine class proteases play a key role in the degradation of storage proteins, making them very important to the production of high quality malt (Jones, 2005). Bhatty (1996) found that germination resulted in extensive hydrolysis of protein, leading to high soluble to total protein ratio (Kolbach index) in barley malt.

The quality of malt depends upon various grain parameters such as kernel shape, size, boldness, hectolitre weight, grain protein content. Factors such as temperature and time of steeping and germinating of grains with their intrinsic enzymic activities, and kilning temperature determine the quality of malt (Owuama, 1999). These affects the malt quality parameters like malt yield, friability, homogeneity, diastatic power, wort viscosity, saccharification rate, Kolbach index, filtration rate and others. Most of these attributes could be affected by both the genetic makeup of the grain and the environmental conditions in which the grain is grown, stored and malted. The production of lager beer from barley malt along with sorghum as a cereal adjunct poses no problem; however, lager beer brewing from 100% sorghum is confronted with problems relating to equipment, sorghum malting, mash gelatinization (Espinosa-Ramírez *et al.*, 2014), saccharification, lautering, wort fermentability, body fullness, and acceptability. The higher gelatinization temperature (>70°C), and the lower diastatic power which is especially deficient in β-amylase activity (Ogbonna, 2011; Serna-Saldívar, 2010) are the main problems in brewing with malt sorghum. In addition, the absence of husk for filtration, development of non-biological haze caused by polyphones and insoluble proteins present in sorghum malt and the presence of high lipid content are other unfavorable aspects encountered during sorghum brewing. The use of exogenous amylolytic enzymes, such as β-amylase or amyloglucosidase to counteract this low amylolytic activity, or to increase ethanol yields in beers, has been extensively studied (Bamforth, 2009; Ogu *et al.*, 2006).

Diastatic power is an important indicator of good quality malt and is defined by the total concentration of starch degrading enzymes present in the malt (Arends *et al.*, 1995). The activity of α-amylase, β-amylase, limit dextrinase and α-glucosidase is important during malting and mashing, which hydrolyzes the starch into simple sugars (Tester *et al.*, 2006). Variation in diastatic power of malt is affected by complex interaction of genetic variation and environmental factors (Arends *et al.*, 1995). According to this study, the variation in diastatic power of barley affected by complex interaction between the different amylases enzymes and other malting and brewing parameters. β-amylase is considered as the main principal enzyme responsible for diastatic power and is synthesized during grain development and appears in mature grain both in the free and the bound forms (Arends *et al.*, 1995; Mccleary *et al.*, 1997; Georg-Kraemer *et al.*, 2001). There is an increase in diastatic power of malted grain due to the conversion of the bound form of β-amylase to the active free-state through proteolytic cleavage which occurred during grain germination (Georg-Kraemer *et al.,* 2001). Very strong correlation was found between protein content of grain and β-amylase activity (Bera *et al.,* 2018). Nitrogen application on soil during barley grain development results in increasing protein content of barley and increased the diastatic power value, but reduced malt extract (Wang *et al.,* 2007), which may have led to higher β-amylase after germination (Yin *et al.,* 2002). Arends *et al.* (1995) explained that the strong correlation between grain protein and β-amylase content was because the same factors influence the production of β-amylase during grain filling and the synthesis of others proteins in endosperm of barley. Similarly, α-amylase is important during grain germination, as it is one of the only known enzymes to be present in germinating barley grains that can initiate native starch hydrolysis (Georg-Kraemer *et al.,* 2001).

Extractable solid in wort from malt during mashing is known as hot water extract (HWE) and it is one of the key parameters for selection of good quality malt. HWE was significantly affected by both germination duration and variety and the interaction. Aychew *et al.* (2012) observed an increment in HWE with increased germination duration regardless of varietal differences. The best and highest extract yields can only be obtained at temperature between 80 to 85^{o}C and the red sorghum meets this criterion (Abdulraheem *et al.,* 2013). Malt Extract is the percentage of dry substance in the malt which is soluble in water when extracted over a standard gradient regime (Usai *et al.,* 2013). It measures the amount of sugars broken down and released during the malting process. The higher extract indicates higher modification (Archibong *et al.,* 2015). According to Abdulraheem *et al.* (2013) the highest extract yield was obtained at temperature between 80 to 85 ^{0}C and the red sorghum meets this criterion. A strong negative correlation was noticed between hot water extract and diastatic power (Bera *et al.,* 2018).

Sorghum has a relatively lower price compared to other brewing cereals, and consequently has potential as an alternative substrate for lager beer brewing and especially represents an excellent option for gluten-free beers (Owuama, 1997). The ethanol level of barley beer was reported to be 50% more compared to sorghum malt beer (Espinosa-Ramírez *et al.,* 2014).

A highly intractable nature and their high protein content might be responsible for the low susceptibility of sorghum endosperm cell walls to enzymatic degradation during malting (Etokakpan & Palmer, 1990). Another important physiological difference between sorghum and barley malts is that the former contains a lower activity of β-amylase, an important diastatic-power enzyme, possibly because of lower amounts of salt-soluble proteins (Aisien & Muts 1987; Etokakpan & Palmer, 1990). Yan *et al.* (2011) found holes in waxy starch granules, which they assume make them more susceptible to enzymatic digestion because water and enzymes can more easily enter through these apertures.

Researches revealed that there is positive correlation between grain milling energy and malt milling energy. The loss in milling energy due to starch granule modification during malting may be responsible for the highly significant correlation between diastatic power and malt milling energy. However, grain milling energy showed non-significant correlation with percentage extract in sorghum (Owuama, 1999).

Physicochemical and morphological changes during sorghum germination

Sorghum is rich in starch (50–60%), proteins (7-15%), and lipids 1.6-6%). Malting generates some physical and biochemical changes which results in fermentable products and then stabilized by drying (Gupta *et al.*, 2010). Malting showed an increment in protein content on the first day of germination from 5.68% to 6.12%, which could be due to de novo protein synthesis (Oseguera-Toledo *et al.*, 2020). The final malt had 5.81 ± 0.02% of crude protein. Other researchers reported an increase of protein during fermentation of two varieties of sorghum when this is added with malt (Wedad *et al.*, 2008). It is possible that since the malting the enzymes could contribute to the increase of protein and this process continues during fermentation, doing in both cases sorghum with higher nutritional value.

Researches revealed that soaking of sorghum grain did not result in significant changes to the grain. However, during the first day of germination, nutrient mobilization starts for the embryo development which occurs through enzymatic hydrolysis of the endosperm. Enzymes such as α-amylase, α-glucosidase, dextrinase, and β-amylase are the main enzymes involved in starch degradation during germination. Most of the hydrolytic enzymes present in the aleurone are de Novo synthesized. Enzymes such as hemicellulase, and proteases are activated (Kok *et al.*, 2019).

Conclusion

This review provides comprehensive and up-to-date information on the potential of sorghum grain for malt and beer production. Sorghum is one of the cereal crop grown in drought stricken areas of sub Saharan Africa. Sorghum grain in addition to use for food grain is using to brew traditional opaque beer and traditional alcohol in Africa. In brewing process involves of fermentation of malted grain is important. Malting is a biological process that turns sorghum grain into malt for producing some physical and biochemical changes to obtain fermentable products. The end products should be an appropriate and acceptable quality. The malt quality depends upon several parameters and process. In order to make available malt of proper quality to the various groups of using the proper standard is important. The use of sorghum grain for brewing malt will increase income levels of sorghum producers and cultivators.

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