

## REVIEW ARTICLE

# The Factors That Made Barley the Most Preferred Cereal for Base Brewing Malt and the Potential of Malting and Brewing with Other Cereal Grains – A Review

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DOI: [https://doi.org/10.70851/jfines.2025.2\(3\).182.190](https://doi.org/10.70851/jfines.2025.2(3).182.190)

### ABSTRACT

Barley (*Hordeum vulgure*) is the main cereal grain used for producing base brewing malt. Besides, there is growing interest in brewing with other cereal crops. This stems from a desire to produce unique beer types and to ensure continuous brewing in regions unfavorable for barley production or in countries where barley grain importation is restricted. To understand the potential of brewing with other cereal crops, a review of factors that made barley the most preferred, and other cereal species less so, was undertaken. Grain structure, grain chemistry, maltability, processibility, enzyme potential and development during malting and the ability to impart desirable beer characteristics, were found to be the major factors. However, acceptable base brewing malts were produced from the grain of some of these other cereal species when the malting procedure was modified to suit their characteristics. Moreover, acceptable beer was produced from base brewing malts produced from some of these other cereal species when the general brewing method was modified. It was, therefore, concluded that brewing with other cereal species could be made possible by modifying the malting procedure to suit their characteristics and modifying the brewing procedure to suit their malt quality attributes.

### Article history

Received;

18 July, 2025

Revised;

02 August, 2025

Accepted;

03 August, 2025

### Keywords

Malting,

Barley,

Other cereal species,

Brewing,

Base malt,

Barley grain structure

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Peer review under responsibility of Journal of Food Innovations, Nutrition, and Environmental Sciences.

A Publication of EcoScribe Publishers company Limited,  
Uganda.

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## 1. INTRODUCTION

Barley (*Hordeum vulgare*) is the preferred cereal grain for the production of base brewing malt. Base brewing malt is produced by curing the grain that has been steeped, germinated and withered, at lower temperatures (e.g., 70-85°C) (Briggs et al., 2004; Plamer, 2018) as opposed to speciality malts that are cured at higher temperatures, sometimes reaching 230°C for roasted malts such as chocolate or black malt (Table 1). High curing temperatures lead to starch modification and denaturation of enzymes whereas low curing temperatures preserve starch and enzymes (Briggs et al., 2004). Base malt contributes high extract (material dissolved in water after mashing and filtering ground malt) and enzyme compliment (Kunze, 2004). It is for these reasons that base malts form the bulk of the grain bill in brewing recipes. Specialty malts contribute unique characteristics to beer, e.g. colour, flavour, foam stability or body, but, have little or no enzymes and contribute insignificant levels of extract, therefore, small quantities of speciality malts are added in the brewing recipes. Enzymes are important for breaking down cell walls and starch encasing proteins during malting, softening the grain for milling and exposing starch for subsequent digestion by amylase enzymes during the mashing stage of the brewing process (Kuntz & Bamforth, 2007; Zanamwe, 2021).

The grain of any cereal species can be used for the production of malt. However, certain cereal species or some varieties of certain cereal species are more suitable for the production of base brewing malts (Arendt & Zannini, 2013; Reeds, 2016; Stewart, 2018). Although barley is the most preferred cereal grain for the production of base brewing malt, other temperate cereal grains such as oat (*Avena sativa*), rye (*Secale cereale*) and wheat (*Triticum aestivum*) and tropical cereal grains such as maize (*Zea mays*), sorghum (*Sorghum bicolor*), rice (*Oryza sativa*) and millets are malted. Although malts produced from some of these other cereal species (wheat, sorghum, oat and rice) are used as base brewing malts, their malts are used in making distilled products, foodstuffs and confectionary (Briggs et al., 2004). Moreover, the base brewing malts produced from wheat, sorghum, oat and rice are not widely used as compared to that from barley (Ceppi & Brenna, 2010; Klose et al., 2011; Stewart 2018). However, the desire to make beer with unique characteristic such as unique flavour, low gluten level, improved mouth feel etc., is increasing the demand for base malts produced from other cereal species. Moreover, use of grain of other cereal species for brewing was suggested as a way of ensuring continuous brewing in regions where climates are not favourable for the production of barley as well as in countries where importation of either barley grain or barley malts is expensive or illegal (Ofoedu, 2021). However, information on how grain of these other species can be malted to produce highly preferred base brewing malt is scarce as compared to that of barley.

**Table 1:** The malting and brewing steps and the products of some of the steps.

Process	Stages	Products
Malting	Cereal grain	Grain
	First steeping	
	Air rest	
	Second steeping	
	Second air rest	
	Germination	Green malt
	Withering (40 - 50 °C)	Malt with 10-20 % moisture content
	Curing (70 - 85 °C)	Base malt (3-6 % moisture content.
	High kilning temperature (90-140°C for lighter malts and up to 225°C for chocolate and black malts)	Roasted speciality malt
	Germ removal/cleaning	Cleaned malt
Brewing	Milling	Gist
	Mashing	
	Lautering/filtering	Wort
	Boiling (addition of hops)	
	Cooling	
	Filtration	Clear wort
	Fermentation	Beer
	Carbonification	Carbonated beer
	Bottling	Bottled beer

The use of barley for production of base brewing malt has been extensively studied (Gupta et al., 2010; Wang, 2017). It was, therefore, hypothesised that understanding the factors that made barley a preferred cereal species for making base brewing malt may help in understanding how grain of other cereal species can be malted to produce acceptable base brewing malt. The aim of the study was to assess the potential of using other cereal species as the base brewing malt. This study, therefore, reviewed literature on factors that made barley the preferred cereal species for the production of base brewing malt and the potential of brewing with base malts from other cereals.

## 2. MATERIALS AND METHODS

A comprehensive literature review to understand the factors that made barley the preferred cereal for brewing and the potential of using other cereal species was carried out. The search engines used include, Google scholar, Research4life, Wiley and Science

Direct. The search phrases used were use of other cereals for base malt, malting for base malt, factors that made barley popular in brewing, brewing with other cereals and other cereals used in brewing. Relevant and peer reviewed literature addressing base brewing malt, attributes of malting barley, other cereals used for brewing and properties of brewing malt were considered. Articles were excluded for not addressing brewing malt, base brewing malt, not involving cereal species and not used for brewing. Articles were screened by title, followed by abstract and finally by full text. The results were grouped into thematic areas according to factors that made barley the most preferred cereal for base brewing malt. These thematic areas include; grain structure, grain chemistry, maltability, enzyme formation, processibility and product characteristics.

### 3. RESULTS AND DISCUSSION

#### 3.1 Grain structure

Barley grain is oval in shape, tapering at each end, with a shallow groove running along its ventral axis and in most malting types, the glumes (husks/hulls) adhere to the grain (Bell, 2012; Zanamwe, 2021). The husks are important during malting for they offer protection against damage during regular turning that is done to avoid matting during the germination stage (Briggs et al., 2004; Palmer 2018). Husks of the malting barley types adhere to the grain even after processing to malt (Briggs et al., 2004; Gupta et al., 2010; Serna-Saldivar, 2012). Moreover, the husks aid in the formation of wort filtration bed and hence facilitates easy wort filtration during the lautering (filtering) brewing stage (Table 1; Kunze, 2004; Serna-Saldivar, 2012). Apart from these advantages, barley husks are generally known to reduce oxygen uptake and hence reduce the rate of germination during the steeping stage of malting (Hamidi et al., 2010). Fast and uniform germination are desirable characteristics in malting (Gupta et al., 2010; Woonton et al., 2005). However, barley varieties with thin husks are considered as suitable malting barley types (Palmer, 2018). Although naked/hull-less varieties are known, these are not used in malting (Kunze, 2004; Palmer, 2018).

The grains of other cereal species, e.g., oat, rice, and some old wheat varieties such as Spelt (*T. spelta*) and Emmer (*T. monococcum*) (Table 2), also have husks, however, the husks of these cereal species are generally less adherent than barley husks and can be easily removed during malting (Serna-Saldivar, 2012). Oat and rice have high husk content compared to barley (Table 2). High husk content was reported to correlate with low extract yield during the mashing stage of brewing and low oxygen uptake during the steeping stage of malting (Serna-Saldivar, 2012).

Besides, these other husked cereal species (rice, wheat and oats) can be used as adjunct (un-malted grain) or speciality malt where barley malt is used as base brewing malt (Kunze, 2004). However, experimental brewing with oat and rice malt only,

respectively, to produce gluten free beers was studied (Ceppi & Brenna, 2010; Klose et al., 2011). A 100% oat base brewing malt beer that was comparable to barley base malt beer was produced using a mathematically modelled mashing regime (Klose et al., 2011). However, although the lautering performance improved due to the high husk content of oat grain, the extract content was low compared to that of barley (Klose et al., 2011). Extract content can be increased by use of other sources of sugar. However, these sources should be studied to find out if they do not affect the attributes of beer. Again, by using mashing procedures different from those commonly used when mashing barley malts, 100% rice beer was produced and its quality was found to be acceptable (Ceppi & Brenna, 2010).

**Table 2:** Species of cereal crops with and without husks adhering on the grain after threshing.

Species without husks on the grain	Species with husks on the grain	% husk content
Wheat*	Barley^	10-13
Maize	Oat	20-36
Sorghum	Rice	20
Rye		
Millet		

\* Some old varieties have husks attached on the grain after threshing.

^Some varieties have no husks attached on the grain after threshing.

Malting of husk-less cereals (rye, sorghum, maize, wheat and millets) for the production of base brewing malts is traditionally not favoured (Wang, 2017). However, sorghum and wheat are sometimes used in the production of base brewing malts. Wheat malt may comprise more than 50% of the grist bill in some beer styles such as German Weizens and Belgian Wit or white beers and sorghum base brewing malts are used in the production of clear beers as well as opaque Bantu beers in Africa (Arendt & Zannini, 2013; Taylor et al., 2013; Stewart, 2018). However, the malting and brewing procedures different from those used with barley grain or barley base brewing malt are used (Ratnavathi & Chavan, 2016). To avoid filtration problems, barley malt and or husks may be used together with the gist of these malts, especially where clear beer is intended. The absence of generally extract-poor husks may mean high extract yield during mashing and quick water absorption during malting (Stewart, 2018). Quick water uptake reduces the malting time and hence reduce malting cost.

In addition to husks, barley grain has thick aleurone layer cells. The presence of thick cells in the aleurone layer increases the ability of the grain to produce large number of enzymes which are desirable in base brewing malts (Kuntz & Bamforth 2007; Nateghi et al., 2014). Again, although the barley grain aleurone layer has one cell layer on the embryo, it generally comprises of two to three cell layers around the endosperm (Holopainen-

Mantila, 2015). Maize, sorghum, wheat, rye, rice and millet grains comprise of a single layer of aleurone cells (Oliver & Colicchio, 2011; Stewart, 2018). Number of layers of aleurone cells were found to correlate with enzyme levels (Cook, 2013). It is therefore important to supplement enzymes when brewing with malt from these other cereals.

Moreover, though smaller than maize (350 mg), barley grain is sufficiently large (45 mg) and hence does not pack during steeping and germination stages of malting (Table 3; Briggs et al., 2004). Rye (30 mg) and finger millet (5 mg) grains are relatively small and thin making them inconvenient to handle using conventional malting equipment due to packing (Table 3; Briggs et al., 2004). Malting of these species, therefore, may require redesigning of the malting equipment.

**Table 3:** The average weight of the grains of different cereal species.

Crop	Average weight (mg)
Barley	45
Maize	350
Sorghum	30
Oat	45
Rice	40
Wheat	45
Rye	30
Pearl millets	10
Finger millets	5

### 3.2 Grain chemistry

In addition to the grain structure, the chemistry of the barley grain also makes it suitable for production of the base brewing malt. The barley grain contains 60-65% starch (dry weight), which is sufficient to give adequate levels of fermentable sugars (Kunze, 2004). In addition to provision of sufficient fermentable sugars, barley starch is gelatinised at temperatures (61-62 °C) lower than the temperatures that denature diastatic (starch hydrolysing) enzymes (65 °C for  $\beta$ -amylase and 72 °C for  $\alpha$ -amylase; Kuntz & Bamforth 2007). Sorghum, maize and rice starches gelatinises at temperatures (70-80 °C, 70-80°C, 70-85 °C, respectively) beyond the thermo-resistance of  $\alpha$ -amylase (Table 4; Marconi et al., 2017). Gelatinization is described as the irreversible disruption of the molecular order within the starch granule when heated in excess water (Marconi et al., 2017). Gelatinisation is desirable because it renders starch hydrolysable during mashing.

The main constituent of the endosperm cell wall of a cereal grain is hemicelluloses which consist of  $\beta$ -glucans and pentosans (Kunze, 2004). The barley grain consists of 80-90%  $\beta$ -glucans and 10-20% pentosans; which together form the rigid cell wall framework. Insufficient breakdown of  $\beta$ -glucan and pentosans during malting cause poor wort filtration during brewing. This is because  $\beta$ -glucan and pentosans form gums during mashing.

However, the barley grain was found to produce enough cell wall hydrolysing enzymes during malting (Briggs et al., 2004; Kunze, 2004; Sungurtas et al., 2004). In experimental brewing, pentosan gums were reported to be less in barley worts compared to rye, triticale and wheat and this was attributed to cell wall hydrolysis as barley produces enough cell wall hydrolysing enzymes during malting (Briggs 1998). Oat and sorghum were found to have high concentrations of high molecular weight  $\alpha$ - and  $\beta$ -glucans which was not broken down sufficiently during malting and hence caused filtration problems (Klose et al., 2011; Stewart, 2018). To brew with these other cereals, the malting regimes have to be modified to promote the formation of high levels of cell wall degrading enzymes. Moreover, varieties that form sufficient enzymes during malting should be selected and or bred.

**Table 4:** Grain starch gelatinization temperature for different cereal species.

Cereal crop	Starch gelatinisation temperature (°C)
Barley	61-62
Maize	70-80
Oat	55-60*
Rice	70-80
Rye	60-65
Sorghum	70-80
Wheat	52-54
Finger millet	62.5-74
Pearl millet	56.5-72
Foxtail millet	56-67

\* The starch gelatinisation temperature of oat is lower than that of barley and most other cereal species. This can be taken advantage of in brewing with oat base brewing malt.

In addition to carbohydrates, barley grain was reported to have a favorable protein content (11.1 %) compared to rice (7.7 %), maize (8.8%), millets (10.6%), sorghum (9.9%) and rye (9.4%), respectively (Table 5; Vég, 2009; Koehler & Wieser, 2013; Marconi et al., 2017). If the protein content is too low, inadequate amounts will be solubilized into the wort during mashing, leading to insufficient free amino nitrogen (FAN) essential for yeast nutrition. Experimental beer produced with rice base brewing malt as the only grist material was found to have poor free amino nitrogen (FAN) and low total soluble nitrogen (Marconi et al., 2017). On the other hand, high protein content cause low extract yield and beer haze (Palmer, 2018; Poreda et al., 2014). In experimental brewing with rye base brewing malt, the proportion of grain nitrogen that became soluble in mashed malt was very high (Briggs et al., 2004). Some barley types (six row barleys) have high protein content and base brewing malts produced from these barleys are traditionally used in conjunction with stabilising adjuncts such as un-malted maize (Briggs, 1998). Brewing with other cereal grains could, therefore be possible, if high protein containing cereals are mashed in conjunction with stabilising adjuncts. Moreover, breeding should

be aimed at breeding varieties with protein levels sufficient for brewing purposes.

Furthermore, barley contains relatively low levels of lipids compared to other cereals (Table 5). High grain lipid content may cause quality problems in beer by affecting flavour. e.g., oxidative off-flavors and damaging beer foam by negatively impacting foam stability. (Reed, 2016). The lipid contents of sorghum (2-6 %), oat (3-12 %) and maize (4-5 %) are high compared to that of barley (1-3 %) (Table 5; Arendt & Zannini, 2013; Klose et al., 2011; Ratnavathi & Chavan, 2016; Stewart, 2018). The embryos of maize and sorghum are large (approximately 10 % of the grain's dry weight), and most of the lipids are contained therein (Stewart, 2018). Cereals used for base brewing malts should have high starch content, enough proteins to provide sufficient amino acids needed for yeast growth and enough nitrogenous material important for beer foam as well as low lipid content to ensure beer foam stability. Malting varieties of other cereals with low lipids should be bred as a way of promoting brewing with other cereal grains.

**Table 5:** The average starch, protein and lipid contents of some cereals used as adjuncts or brewing malts.

Crop	Starch (g/100g)	Protein (g/100g)	Lipids (g/100g)
Barley	73.5	11.1	2.1
Maize	79.5	8.8	3.8
Oat	55.5	10.8	7.2
Rice	75.8	7.7	2.2
Rye	58.9	9.4	1.7
Sorghum	69	9.9	4
Wheat	71.9	11.3	1.8
Millets*	71.9	10.6	3.9

\*The percentage given are averages; however, the starch, protein and lipid contents of millets vary with the type.

### 3.3 Maltability

Malting is the limited germination of grain under carefully controlled conditions; ensuring that the grain is germinated at the same rate, a good level of enzymes is produced and the cell wall components of the endosperm are degraded (Palmer, 2018; Zanamwe, 2021). The process involves germinating cereal grain after initial soaking and kiln-drying the germinated grain as key steps (Woonton et al., 2005; Frank et al., 2010). During soaking (steeping), the moisture content of the grain is raised to levels that ensure adequate wetting of the grain without causing anaerobic conditions within the seed (Reed, 2016). Furthermore, steeping temperatures must be in the ranges that promote formation of cell wall degrading and storage reserves hydrolysing enzymes (Woonton et al., 2005). Preferably, the malting process aims for rapid and uniform grain germination while ensuring limited embryo growth and respiration (Briggs et al., 2004). High respiration and embryo/seedling growth reduce malt extract yield. During kilning, care must be taken to preserve

enzymes whilst allowing the required biochemical reaction and moisture reduction to take place (Kleinwachter et al., 2011; Muller & Methner, 2015).

Cereal species such as wheat, maize, sorghum and rye are difficult to malt compared to barley. Because of their huskless nature, care must be taken not to damage the grain during malting (Stewart, 2018; Wang et al., 2018). The coleoptile (acrosipire) of huskless grains grow free and are easily damaged, impairing malting and increasing chances of mould growth (Briggs, 1998). Again, lack of husks allows tight packing of the grain in steeping chamber/ tank, in the germination compartment and in the kiln requiring more turning that may increase damage (Arendt & Zannini, 2013).

In addition to damage and tight packing, the huskless cereal grains have other malting difficulties (Reed, 2016). Wheat forms clumps during germination and hence have to be turned more often during malting. Although this can be avoided by germinating wheat at low temperatures than normal; germination at low temperature was found to cause poor cell wall breakdown (Reed, 2016). Sorghum's rootlet growth is rapid causing entanglement and hence requires that the grain bed be increased markedly during the germination stage of malting (Briggs, 1998). Again, there is massive migration of nitrogen into the seedling causing very variable and high malting losses e.g. 9.5-35% with roots and shoots and 18.5-60.5% if the seedling parts are removed (Ratnavathi & Chavan, 2016). Moreover, the best conditions for malting sorghum were reported to differ substantially from those appropriate for barley (Ratnavathi & Chavan, 2016). For example, because of their low enzyme complements, sorghum malts are kilned using low air-on temperatures and with high airflows to maximize enzyme survival (Ratnavathi & Chavan, 2016; Taylor et al., 2013). In addition, sorghum is warm germinated, i.e., in-bed temperatures of 24-28 °C as opposed to cool germination of 16-20 °C for barley (Ratnavathi & Chavan, 2016). In millets, significant increase of diastatic power over germination time were found when the grain of *Pennisetum maiwa* and *P. Sossat* were steeped and germinated at high temperatures (30°C) and kilned at low temperature (50°C) (Eneje et al., 2012). Millets are, therefore, malted at different temperatures compared to barley which is steeped and germinated at low temperatures (Muller & Methner, 2015). Rye is very difficult to malt because of its high cell wall pentosan content (Wang et al., 2018). Unless it is accelerated by applications of gibberellic acid, rye need 7 days of germination to modify completely (Briggs, 1998).

Maize cannot be malted successfully using the regimes used for barley. The roots and shoots had to be well grown before modification is adequate (Briggs, 1998). Again, maize grains are comparatively large and generate large seedlings during germination (Reeds, 2016). Like in sorghum malting, the volume of the grain bed should be increased markedly to accommodate this growth. Moreover, the seedling of maize is prone to damage

during malting, consequently, maize is extremely likely to develop mould infestations (Chaudhary et al., 2013). Furthermore, the green (wet) maize malt should be kilned using low air-on temperatures and with high airflows to maximize enzyme survival (Chaudhary et al., 2013).

Oat can also not be malted well using the regimes used for barley. Kilning of oat malt is slow. This has been attributed to the high proportion of husks which may affect water exchange (Kordialik-Bogacka et al., 2014). These findings suggest that malting the grain of these other cereal species using the procedures developed for barley is problematic.

### 3.4 Enzyme formation

One of the primary reasons for the production of base brewing malt is to develop and activate latent enzymes in the cereal grain (Milala & Addy, 2014; Marconi et al., 2017). Some of these enzymes break down cell walls and protein matrix during malting and some hydrolyse starch during mashing (Kuntz & Bamforth, 2007). The enzymes that catalyse important changes that occur during mashing are chiefly hydrolases, which catalyse the breakdown of starch, proteins, phytate and other substances (Briggs et al., 2004). As highlighted above, barley grain produces sufficient enzymes during germination/ malting compared to other cereal species (Ceppi & Brenna, 2010). Enzyme potential of sorghum is lower compared to that of barley (Ciocan et al., 2023; Ratnavathi & Chavan, 2016). Relative to barley malt, sorghum malt is poor in  $\beta$ -amylases, hence, most of the sorghum diastatic power comes from  $\alpha$ -amylase activity (Ratnavathi & Chavan, 2016). In a comparative study where, experimental beers brewed from millet, sorghum and barley were compared, millets and sorghum malts derived wort were found to have low extract (10.0 °P and 10.5 °P, respectively) and low attenuation limit (66.8% and 71.2%, respectively) compared to barley derived malts (11 °P extract and 88% attenuation limit) due to low levels of hydrolysing enzymes (Agu, 1994). Like sorghum, maize malt also showed low diastatic power compared to barley malt (Milala & Addy, 2014). Again, endo- $\beta$ -glucanase activity of sorghum, maize and rice is low compared to barley malt (Taylor et al., 2013).

Oat malt is poor in both  $\alpha$ -amylase and  $\beta$ -amylase (Briggs et al., 2004). In a comparative study, oat malt was found to be considerably low in dextrinising units (23 DU for the laboratory micro-malted malt and 25 DU for the commercial malted malt) compared to barley malt (57 DU) (Klose et al., 2011).  $\beta$ -glucanase activity of oat malt is also low compared to barley malt (Klose et al., 2011; Kordialik-Bogacka et al., 2014).

Rice malt was found to have low diastatic power compared to barley (Marconi et al., 2017). Again, rice malt developed low lipase enzyme compared to barley malt (Marconi et al., 2017). Lipase is important for degradation of the lipid vesicles that envelops starch grains of most cereal grains. Optimum lipase

levels are, therefore, important for improving accessibility to endosperm starch for subsequent conversion by amylases (Milala & Addy, 2014). Conversely, high lipase activity in cereal grains may not be desirable since it may cause the malt to be susceptible to lipid peroxidation (Milala & Addy, 2014). It can be noted that, barley generally develops more levels of important enzymes compared to other cereal species. As suggested above, supplementary enzymes from either microbes or other plant extracts should be added during mashing when brewing with these other cereal species.

### 3.5 Processibility

Cereal grains are malted to make them suitable for use in brewing (Edney et al., 2014). Generally, the ideal base brewing malt is the one which yield high carbohydrate extract, do not require additional processing or treatment, pass through the plant within the required cycle time, produce wort that provide sufficient yeast nutrients to ensure satisfactory fermentation and provide the flavour and process requirements of the brewer and the brewer's customers (O'Rourke, 2002; Frančáková et al., 2012). The barley malting method was optimised to produce base brewing malt that meet these specifications. However, this is not so with other cereal species. Moreover, the brewing procedure developed for barley malt often cannot be directly applied when using malts from other cereal species (Briggs, 1998). As noted above, the gelatinization temperatures of maize, rice and sorghum starches are high that most important enzymes are inactivated (Briggs, 1998). When sorghum base brewing malt was mashed alone, it was generally found that starch conversion was incomplete and the wort obtained was not suitable for making European style clear hopped beer (Reed, 2016). This could be partly because the high starch gelatinization (70-80 °C) temperature denatured the enzymes or that the sorghum grain produced low levels of amylase enzymes during malting (Ciocan et al., 2023). It was reported that unless highly enzymatic barley malt or heat-stable microbial enzymes are incorporated in mashes or mashing procedure different from that used with barley are used, extract levels from mashed sorghum malt are low (Reed, 2016; Taylor et al., 2013). Maize base brewing malt is also mashed using different procedures from those used for mashing barley base brewing malt (Briggs, 1998). This also applies to brewing/mashing with rice base brewing malt which its starch has high gelatinisation temperature (70-85 °C) (Marconi et al., 2017). As for millets, although millet starches differ in their gelatinization temperature range, i.e. finger millet 62.5-74 °C, pearl millet 56.5-72 °C and foxtail millet 56-67 °C; they can be gelatinised at the same gelatinising temperatures as barley starch (Briggs, 1998).

Grains of other cereal species have other processing problems in addition to the gelatinisation temperatures. Nitrogen solubilization, extract development, wort separation, and beer filtration were found to be more limited when beer was produced from sorghum base brewing malt rather than from barley base

brewing malt (Ciocan et al., 2023). In experimental brewing, wort from wheat base brewing malt tended to separate slowly, possibly because the pentosans that are present in wheat base brewing malt sometimes give rise to viscous wort (Briggs, 1998). Again, the pH values of wort produced by mashing wheat brewing base malt tended to be high compared to barley malts (Briggs, 1998). High pH may affect the activity of some important enzymes. Like wheat malt, wort from mashed rye malt separated slowly (Briggs, 1998). Moreover, the proportion of grain nitrogen that became soluble in mashed rye malt was very high. Although wort soluble nitrogen is important for yeast nutrition and hence fermentation, very high wort soluble nitrogen may cause superfluous yeast growth without adequate fermentation (Taylor et al., 2013). Like sorghum, maize, rye and wheat, wort filtration from mashed finger millet malt is slow (Wang, 2017). Unlike rye, the soluble nitrogen content of wort obtained from mashing finger millet malt is low. Rice base brewing malt also showed processing problems. Great swelling of rice starch during gelatinization led to sticking of the pasta to the hot surfaces of the plant causing burns (Marconi et al., 2017). It can be noted that problems associated with processing or brewing with each cereal species should be studied to suggest solutions. For example, finger millet varieties with sufficient protein content should be bred and use of heat tolerant microbial enzymes can be used to mash sorghum, rice and oat malts.

### 3.6 Product characteristics

The objective of brewing is to produce beer that is acceptable to consumers (Poreda et al., 2014). Beer is defined as a beverage that is obtained from alcoholic fermentation of malted cereal wort to which hops have been added (Ratnavathi & Chavan 2016; Marconi et al., 2017). After fermentation, the beer is usually stored for a period of time for clarification and maturation (Kunze, 2004; Reed, 2016). Generally, beer should be acidic (pH 5.1-5.2), having stable foam, acceptable flavour, body, colour and alcohol level (Agu, 1994). If any variation in ingredients (generally, malts, water, hops and yeast) or production schedules is intended, it is crucial to preserve nearly constant quality to meet the expectations of consumers (Poreda et al., 2014). The popcorn aroma of maize and major aroma compounds in rice were reported to affect beer flavour (Taylor et al., 2013). Beer made from malted rice had harsh flavour and poor body (Ceppi & Brenna, 2010). Moreover, rice malt wort had a sub optimal content of nitrogen that led to low foam stability (Marconi et al., 2017). Again, beer brewed from malted rice was hazy (Ofoedu, 2021). Some types of sorghum contain substantial quantities of condensed tannins which imparts dry and astringency sensation (Taylor et al., 2013). Rye malts were reported to favour high haze instability in beer (Briggs 1998). Although the flour-like flavour from wheat malts have given relatively mild flavour and drinkability to beer, it did not give the toasted flavours found in barley malt beer (Oliver & Colicchio, 2011). Again, due to poor wheat protein hydrolysis, increased high molecular weight protein content from wheat malt

contributed to hazy and beer cloudiness (Depraetere et al., 2004; Oliver & Colicchio, 2011; Reed, 2016). Oat beers had high colour intensity, low wort extract and low alcohol content (Zdaniewicz, 2021). These studies suggest that beer produced from base brewing malt produced from barley grain meets the expected quality whereas the beer produced from base brewing malts from the grain of other cereal species affect one or a few quality attribute/s negatively. It is important to note that, although one of the reasons to produce beer using other cereal species is to produce different types of beer, these beer types should be accepted by consumers.

### CONCLUSIONS

It could, therefore, be concluded that even though other grains can be malted, barley grain's physical and chemical structure, its maltability, enzyme forming ability during malting, processibility of its malt and the ability of its malt to impart desirable characteristics to beer have made it a preferred cereal grain for production of base brewing malt. In a quest to use other cereal crops as base malts, research should be focused on developing varieties that have improved grain structure and chemistry, developing malting methods suitable for each cereal grain type and developing brewing procedures which suit the use of base brewing malts produced from the grain of other cereal species. Moreover, breaking beer quality traditions may increase the use of the grain of other cereal species as base brewing malt.

### ACKNOWLEDGMENTS

The authors are grateful to Mr R. Foti, Department of Horticulture and Crop Production, Gwanda State University for editing the manuscript.

### CONFLICT OF INTEREST

The authors declare no potential conflict of interest from the institutions, persons or any other entities.

### DATA AVAILABILITY

The data used to support the findings of this study are available upon request from the corresponding author.

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