

Effects of Grist Particle Size Distribution on the Wort Quality of Improved Sorghum Varieties (CSR01, CSR02, And SK5912) Under a Single-Infusion Mashing Regime

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DOI: <https://doi.org/10.62154/ajasfr.2026.023.01023>

Abstract

This study evaluated the effects of particle size distribution and single-infusion mashing regime on the wort quality of three improved sorghum varieties (CSR01, CSR02, and SK5912). The sorghum varieties were malted and assessed for their malting and brewing characteristics. Malted sorghum varieties were milled into different particle size fractions (coarse, medium, fine, and flour) and mashed at 60°C using a single-infusion mashing regime. Sorghum grist particle size distribution was analyzed using sieve analysis, and the resulting worts were analyzed for selected physicochemical properties. CSR01, CSR02, and SK5912 exhibited germinative capacities, germinative energy, water sensitivity, malting loss and a thousand-corn weight of 99%, 99%, 1.33%, 5.30%, and 0.24 g for CSR01 and 98%, 97%, 1.66 %, 12.12% and 0.32 g for CSR02 and 97%, 86%, 1.66%, 9.88% and 0.38g for SK5912, respectively. The values obtained in this study showed significant differences ($P < 0.05$). The proximate composition analysis showed that CSR01, CSR02 and SK5912 exhibited moisture content, protein, lipid, ash, fibre and carbohydrate content of 7.60%, 8.55%, 5.30% 2.00%, 2.46% and 74.07% for CSR01; 8.54%, 8.19%, 5.74% 1.77%, 2.06% and 73.69% for CSR02; 11.34%, 7.69%, 6.37% 2.10%, 1.82% and 70.67% for SK5912 respectively. The values showed significant differences ($P < 0.05$) across the varieties. Analysis of the CSR01 variety of sorghum ranged from 0.63 – 0.87 mg/ml, 4.86 – 5.66, 1.00 – 1.02, 2.26 – 2.37 and 1.04 – 2.81 ml/min for lipid concentration, pH, specific gravity, specific viscosity and filtration rate, respectively. The CSR02 variety of sorghum ranged from 0.45 – 0.66 mg/ml, 4.66 – 4.98, 1.00 – 1.02, 2.80 – 2.88 and 1.15 – 2.66 ml/min for lipid concentration, pH, specific gravity, specific viscosity and filtration rate, respectively. While the SK5912 variety ranged from 0.69 – 0.97 mg/ml, 3.87 – 4.45, 1.00 – 1.02, 2.07 – 2.17 and 1.16 – 2.29 ml/min for lipid concentration, pH, specific gravity, specific viscosity and filtration rate, respectively. There was no significant difference ($P > 0.05$) in the specific gravity of the samples across the sorghum varieties. These results demonstrate that both sorghum variety and grist particle size influence wort quality parameters and processing performance during mashing. The findings highlight the importance of optimizing particle size distribution during sorghum malt processing to improve wort quality and support the utilization of improved sorghum varieties in brewing applications.

Keywords: Particle Size Distribution, Sorghum Varieties, Sorghum Malt Mashing, Wort Quality, Brewing.

Introduction

Barley is the primary raw material used in breweries for beer production. It is typically imported from Europe by the Nigerian government, leading to high import costs, which can negatively affect the nation's economy. According to Orji-Udezuka *et al.* (2020), there is a need for grains with similar agronomic properties to barley that can be grown domestically in Nigeria to support the brewing industry. During the malting process, barley undergoes biochemical changes that produce the essential enzymes, carbohydrates, and proteins needed to create wort. While barley malt is the main raw material for beer production, it is common in the brewing industry to partially replace barley with cereal adjuncts like wheat, maize, or sorghum (Hernández-Becerra *et al.*, 2020). Climate change is predicted to have significant impacts on barley production, with crop and economic models suggesting that extreme weather events could lead to a 17% reduction in global barley production under the most severe conditions. This potential decline in barley supply could cause beer prices to increase by 193% by 2099 (Hernández-Becerra *et al.*, 2020). Therefore, incorporating a broader range of adjuncts could help maintain the supply of raw materials for brewing amid anticipated climate change (Palombi *et al.*, 2023).

Sorghum is the world's fifth most important cereal after wheat, rice, maize, and barley (Correia *et al.*, 2008). It is produced in large quantities, with approximately 65 million tons harvested annually. (Palmer, 1989). It belongs to the grass family, *Graminae*, and the tribe *Andropogonae* (Ogbonna, 2011). Sorghum is considered a potential substitute for barley and can serve as an alternative substrate (Ogu *et al.*, 2006). It is locally grown in the semi-arid savannah and grassland regions of northern Nigeria, where it is a key staple food rich in carbohydrates. Nigeria is the largest producer of sorghum in the West African sub-region, contributing about 71% of the total regional output. Nigeria is the world's third-largest producer of sorghum overall (after the USA and India). Unlike the USA, where most sorghum is used as animal feed, a large proportion of Nigeria's sorghum is produced for human consumption. In Nigeria, sorghum is considered a dual-purpose crop: 35% is consumed as food, while the remainder is used for livestock feed, alcohol production, and various industrial purposes (Awika & Rooney, 2004). Over 10,000 varieties of sorghum exist, and ongoing plant breeding efforts continue to develop new varieties with improved traits (Ogu *et al.*, 2006). These sorghum varieties differ in colour, size, texture, and biochemical properties (Owuama, 1997). Research has shown that these varieties can be used for various food and non-food purposes (Dicko *et al.*, 2006). Of particular importance is the evaluation of the malting and brewing qualities of the sorghum varieties (Ogbonna, 2011). Extensive pioneering and follow-up research studies have led to the successful use of sorghum malt in brewing continental beers in Nigeria and other countries, including Mexico, Cuba, Israel, the USA, and South Africa (Ijasan *et al.*, 2011). Various sorghum varieties were used in the earlier studies; these represent only a small portion of the total number of improved sorghum grain varieties presently in existence.

Statement of the Problem

Beer brewing from sorghum malt proved very difficult due to physical and biochemical problems, including low extract yield, which leads to low diastatic power (Ogbonna, 2011). This problem can be attributed to the differences in particle size distribution of the malt. The particle size determines the extent to which the surface area of the malt endosperm is exposed during mashing to convert the starch to sugars. According to several studies on sorghum grain, no detailed research has been conducted on the particle size distribution and mashing regime of improved sorghum varieties on wort quality with regard to CSR 01, CSR 02, and SK5912. It is of interest to compare the particle size distribution and mashing regime of these improved sorghum varieties, as these parameters are the determinants of a successful brewing process in the bid to replace barley malt with sorghum malt to optimize the brewing process concerning extract yield and wort run-off rate.

Objectives and Research Questions

The general objective of this study is to evaluate and compare the impact of particle size distribution and mashing regime on wort quality from improved sorghum varieties (CSR01, CSR02, and SK5912). The following are the specific research questions

- How does particle size distribution modify extract recovery and starch hydrolysis during single-infusion mashing of improved sorghum malts?
- Does particle size distribution interact with sorghum genotype to determine key wort quality attributes?
- Which particle size distribution provides the optimal balance between extract yield, filtration performance, and fermentable sugar production?
- Can optimized milling improve the brewing suitability of improved sorghum varieties under a single-infusion mashing regime?

General Hypotheses

Null Hypothesis

There is no significant effect of particle size distribution, sorghum variety, or their interaction on the wort quality obtained under a single-infusion mashing regime.

Alternative Hypothesis

Particle size distribution, sorghum variety, and their interaction significantly affect the wort quality obtained under a single-infusion mashing regime.

Materials and Methods

Sources of Materials

Three improved sorghum varieties (CSR01, CSR02, SK5912) were obtained from the Institute of Agricultural Research, Ahmadu Bello University, Zaria. The processing of samples and experiments was carried out using the facilities available at the laboratory of

the Department of Food Science and Technology, University of Uyo, Uyo. All chemicals and reagents were procured from certified sources and were of an analytical grade standard.

Sample Preparation

The three varieties of Sorghum obtained were carefully and individually sorted manually to remove broken kernels and foreign materials before being surface-sterilized by immersion in 1% (v/v) hypochlorite solution (Ogbonna *et al.*, 2003) and allowed to stand for a few minutes. After thoroughly rinsing with tap and distilled water, the grains were spread on a clean surface layered with soft absorbent paper and allowed to dry at room temperature overnight.

Malting process

The malting processing was carried out according to the method described by Ogbonna *et al.* (2004). The process includes steeping, germination, kilning, and deculming.

Steeping

One (1) kg of each of the three sorghum grain varieties was weighed out and washed twice in tap water to remove dust. A 24-hour steeping regime was used: 12 hours water steep, 2 hours air rest, and 10 hours water steep. Steeping was done with a 1:2 grain/water ratio. 0.1% of hypochlorite was added to the steep water to reduce microbial load on the grains.

Germination

Germination was done at 30 °C for five (5) days in a dark germinating cupboard, with twelve 10 -hourly sprays of about 10ml of distilled water to prevent drying out, and was turned intermittently to prevent matting of the grains.



Plate 1: Germination Process of the Improved Sorghum Varieties

A = CSR01 Variety

B = CSR02 Variety

C = SK5912 Variety

Kilning

The germinating grains were kilned in an attempered oven at 50 °C for 24 hours.

De-culming

After kilning, the malts were detached from the rootlets and stored for use.

Milling Process

500g of malted sorghum grains were milled using the manual grinder (Beltone Minshune Model) for 30 minutes.

Particle Size Analysis of Milled Sample

The particle size analysis of the milled sample was conducted using the standardized mechanical sieve analysis recommended by Houghton *et al.* (2024). The weighed grist was placed on the top sieve in the stack of different sieves and shaken mechanically for 5 minutes on a Ro-Top Shaker. The fraction retained on or passing through each sieve was weighed and reported as a percent of the total grist.

Table 1 Grist formulation for mashing (%)

Grist samples	M ₁₀ (coarse)	M ₁₆ (medium)	M ₄₀ (fine)	M ₂₀₀ (flour)
A	10	40	30	20
B	10	30	30	30
C	-	50	40	10
D	10	40	40	10
E	10	50	30	10

Keys

M₁₀ = 2.36mm; 0.937 in

M₁₆ = 2.00mm; 0.781 in

M₄₀ = 1.118mm, 0.469 in

M₂₀₀ = 0.75mm; 0.0029 in

Proximate Composition Analysis of the Three Varieties of Sorghum Grains

Moisture Content Determination

The standard method of AOAC (2023) was followed to determine the moisture content of sorghum grains. Cleaned crucibles were dried in a hot air oven at 100°C for 1 hour to reach a constant weight, then cooled in a desiccator. 1g of each sample was weighed into the crucibles and dried at 100 °C until a constant weight.

$$\% \text{ Moisture content} = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

Where: W₁ = Initial weight of the empty crucible in grams

W₂ = weight of crucible + sample before drying

W₃ = weight of crucible + sample after drying.

Determination of Crude Lipid Content

Fat content was determined using the Soxhlet extraction method described by AOAC (2023). A Soxhlet extractor with a reflux condenser and a round-bottom flask was fixed. 1g of each of the sorghum varieties was weighed into a labeled thimble. Petroleum ether was filled into the round-bottom flask and the extractor thimble was sealed. The Soxhlet apparatus was refluxed for several hours before removing the thimble. Petroleum ether collected from the flask was dried at 105°C for an hour in an oven, cooled in a desiccator, and weighed. This procedure was carried out for all the sorghum samples.

$$\% \text{ Fat} = \frac{\text{weight of fat}}{\text{weight of sample}} \times 100$$

weight of sample

Where the weight of fat = (weight of thimble with sample – the weight of empty thimble).

Determination of Crude Protein

Crude protein was determined using the Kjeldahl method described by AOAC (2023). Exactly 1 g of each sorghum variety was weighed into a 100 ml Kjeldahl flask. 1grams of anhydrous Na₂SO₄, 1g of CuSO₄ and 5ml of concentrated H₂SO₄ was added and allowed. The flask was heated in a flame chamber till the solution was clear. This process is called digestion. After cooling, the content was transferred into a 100ml volumetric flask and made up to the mark with repeated washing using distilled water. Distillation was done by mixing the digest with 5 mL of boric acid and 3 drops of methyl red indicator in an 100ml conical flask. 100 mL of 60% NaOH was added to neutralize it. Distillation was done for a few minutes until there was a colour change. Titration was done using 5ml distillate against 0.01N HCl until a purple-pink endpoint was observed

The percentage protein was calculated using the expressions below:

$$\% \text{ Protein} = \% \text{ Nitrogen} \times 6.25 \text{ (where 6.25 = Conversion factor of protein).}$$

$$\% \text{ Nitrogen} = \frac{T \times A \times N \times 20}{W \times 100} \times 100$$

$$W \times 100$$

Where T = Titre value

W = Weight of the sample (1g)

20 = Dilution factor

N= Normality of HCl = 0.01

A = Atomic mass of nitrogen.

Determination of Total Ash

Determination of the ash content was done using the procedure stated by AOAC (2023). Exactly 1g of each sorghum variety sample was weighed into four different crucibles. The crucibles were ignited, cooled, and weighed to get the initial weight of the crucible without the content. The crucibles and their contents were transferred into a muffle furnace ignited at 550°C. Ashing was done for 7-8 hours. The un-ashed samples were exposed by adding a few drops of water to the crucible. It was dried in the oven for 2 hours and re-ashed at 550°C. After ashing, the sample was removed from the furnace, cooled in a desiccator, and weighed. Percentage ash was calculated using this expression below:

$$\% \text{ Ash} = \frac{(\text{Weight of crucible and ash}) - (\text{weight of crucible})}{(\text{Weight of crucible and sample}) - (\text{weight of crucible})} \times 100\%$$

Determination of Crude Fiber

Crude fibre was determined using the method described by AOAC (2023). Exactly 1g of each sorghum variety was weighed, put in a boiling 200ml of 1.25% H₂SO₄, and allowed to boil for 30 minutes. When cooled, the solution was filtered using a muslin cloth fixed to a funnel; it was washed with boiling water until it was completely free from acid. Filtration was done in less than 10 minutes. The residue was returned to 200ml boiling NaOH and allowed to boil for 30 minutes. This is to analyze the nitrogen part in protein and perform saponification with the fat. It was then pre-heated with boiling water, and the hydrolyzed mixture was carefully filtered before letting it rest for 1 minute. The residue was washed with boiling water and HCl acid solution and then washed again with boiling water. The final residue was placed in a crucible, and an oven was set at 105 °C for 12 hours and then cooled. The final weight of the crucible was taken. The percentage crude fibre was calculated thus:

$$\% \text{ Crude fibre} = \frac{(\text{weight of crucible with dry residue}) - \text{weight of crucible with ash}}{\text{Weight of sample}} \times 100$$

Determination of Carbohydrate Content

The total carbohydrate content was estimated as 100 minus the sum of moisture, fat, protein, crude fibre, and ash, as described by AOAC (2023). It was calculated thus;

$$\% \text{ Total carbohydrate} = 100 - (\text{moisture} + \text{crude protein} + \text{fat} + \text{ash} + \text{crude fibre})$$

Grain and Malt Analysis

Determination of Germinative Energy (GE)

Germinative energy was determined using the standardized procedure described by the Mitteleuropäische Brautechnische Analysenkommission (MEBAK, 2016). One hundred (100) randomly selected grains were placed in Petri dishes lined with moistened filter paper. Two moisture regimes (4 mL and 8 mL of distilled water) were applied to assess water sensitivity. The dishes were incubated at 20 ± 1°C for 72 hours. Germinated grains (with visible rootlet emergence ≥ 2 mm) were counted after 72 hours, and germinative energy was expressed as the percentage of grains that germinated during this period.

$$GE(\%) = \frac{\text{Number of grains germinated at 72 h}}{\text{Total number of grains tested}} \times 100$$

Determination of Germinative Capacity (GC)

Germinative capacity was determined using the method described by ICC Standard No. 174 (ICC, 2018). One hundred sorghum grains were incubated under controlled conditions (20 ± 1°C) on moist filter paper for 5 days. At the end of the incubation period, all normally germinated grains were counted. Germinative capacity was calculated as the percentage of total viable grains capable of germination.

$$GC(\%) = \frac{\text{Total number of normally germinated grains}}{\text{Total number of grains tested}} \times 100$$

Determination of Water Sensitivity

Water sensitivity was evaluated following the MEBAK (2016) procedure. Parallel germination tests were conducted using 4 mL and 8 mL of distilled water. Water sensitivity was calculated as the difference in germination percentage between the lower and higher moisture treatments:

$$\text{Water sensitivity (\%)} = GE_{4mL} - GE_{8mL}$$

Higher differences indicate greater sensitivity to excess moisture during steeping.

Determination of One Thousand (1000) Corn Weight

The thousand kernel weight (TKW) was determined according to the procedure described by Okonkwo *et al.* (2021). One thousand (1000) clean, sound grains were counted manually and weighed using an analytical balance (± 0.001 g accuracy). The weight was recorded in grams and reported as the average of duplicate determinations.

$$TKW(g) = \text{Weight of 1000 grains}$$

Determination of Malting Loss

Malting loss was determined following the procedure described by Nocente *et al.* (2024). The weight of 1000 grains were measured before malting and after kilning. Malting loss was calculated as the percentage reduction in grain weight due to respiration losses, rootlet removal, and moisture changes during malting.

$$\text{Malting loss (\%)} = \frac{\text{initial weight} - \text{final weight}}{\text{Initial weight}} \times 100$$

Mashing Process

The three sorghum varieties (CSRO₁, CSRO₂, and SK5912) were subjected to a single-infusion mashing regime at 60°C for each particle size. After mashing, the mash was filtered using Whatman No. 1 filter paper to produce wort, which was boiled for 10 minutes and cooled in a refrigerator at 40 °C before analysis.

Mashing Test; Iodine Test (Saccharifying Test)

Saccharification was performed with 0.02 N tincture of iodine solution on cold mash samples

Wort analysis

Following mashing, lautering, and wort boiling, the clarified sorghum wort was cooled to $20 \pm 1^\circ\text{C}$ before analysis. According to the newest editions of Analytica EBC by the European Brewery Convention (2010), the wort qualities of the sorghum varieties were determined.

Determination of Lipid Concentration in Wort

Lipid concentration in the wort was determined using a solvent extraction method adapted from the procedures described by the American Society of Brewing Chemists (ASBC, 2011) and standard lipid extraction methods used in cereal-based beverages. 100 mL of wort was transferred into a separatory funnel and extracted with a chloroform–methanol mixture (2:1 v/v). The mixture was shaken vigorously and allowed to separate into phases. The lower organic layer containing lipids was collected, filtered, and evaporated to dryness using a rotary evaporator. The residue was dried at 105 °C to constant weight, cooled in a desiccator, and weighed.

Lipid concentration was calculated as:

$$\text{Lipid (\% w/v)} = \frac{\text{Weight of extracted lipid (g)}}{\text{Volume of wort (mL)}} \times 100$$

Determination of Filtration Rate of Wort

Wort filtration rate was determined using the small-scale wort filtration procedure described in Analytica-EBC by the European Brewery Convention (EBC, 2010). A 100 mL portion of wort was filtered through Whatman No. 1 filter paper under gravity at room temperature (20 °C). The time required to collect 50 mL of filtrate was recorded using a stopwatch.

Filtration rate was expressed as:

$$\text{Filtration Rate (mL/min)} = \frac{\text{Volume filtered (mL)}}{\text{Time (min)}}$$

Determination of Wort pH

The pH of the cooled wort was measured according to the ASBC Wort-pH Method (ASBC, 2011). The pH meter was calibrated using standard buffer solutions (pH 4.00 and 7.00). The electrode was rinsed with distilled water and immersed directly into the wort sample maintained at 20 °C. The reading was recorded once stabilization occurred.

Determination of Specific Viscosity

Specific viscosity of the wort was determined with a capillary (Ostwald) viscometer according to EBC Method 8.4 (EBC, 2010). The viscometer was placed in a constant temperature water bath maintained at 20 ± 0.5 °C. The flow times of distilled water (t_0) and the wort sample (t_s) between two calibration marks were recorded.

Specific viscosity (η_{sp}) was calculated as:

$$\eta_{sp} = \frac{t_s - t_0}{t_0}$$

Determination of Specific Gravity (SG)

Specific gravity of the wort was determined according to ASBC Wort-Specific Gravity Method (ASBC, 2011). The cooled wort (20 °C) was transferred into a 250 mL graduated

cylinder. A calibrated brewing hydrometer was carefully inserted, and the reading at the lower meniscus was recorded. Temperature corrections were applied where necessary.

Specific gravity was expressed as:

$$SG = \frac{\text{Density of wort}}{\text{Density of water at 20 } ^\circ\text{C}}$$

Extract preparation and analysis

The experimental wort was prepared from the sorghum grist using the step/single infusion method. Exactly 10g of the grist was mashed at different temperatures using 625.5ml of distilled water. The pH was adjusted from 6.5 to 7.0 using calcium hydroxide, and neutrase was added to induce proteolysis. The mash was held for 30 minutes, after which glucanase and cellulase were added, and the mash temperature was raised and maintained for 60 minutes to maximize gelatinization of the sorghum starch. The mash was subsequently cooled to the appropriate temperature, after which amyloglucosidase (AMG) and fungal amylase were added to facilitate starch hydrolysis. The mash was held at this temperature for 30 min to allow enzymatic activity. Thereafter, the temperature was increased and maintained for an additional 20 min to ensure complete starch conversion (saccharification). The extent of saccharification was verified using the saccharification test. Upon completion of saccharification, the mash was mashed off and prepared for wort recovery and subsequent physicochemical analyses, following the method of Etuk (2003).

Statistical analysis

All the data were subjected to statistical analysis using Analysis of Variance (ANOVA). The means were then separated using the Duncan New Multiple Range Test (DMRT) using the Statistical Package for the Social Sciences (SPSS) 23.0 software.

Results and Discussion

Table 2 Proximate Composition of Three Sorghum Varieties (CSR01, CSR02 and SK5912) (%)

Samples	Moisture	Protein	Lipid	Ash	Fiber	Carbohydrate
CSR 01	7.60 ^c ±0.30	8.55 ^a ±0.25	5.30 ^b ±0.17	2.00 ^{ab} ±0.04	2.46 ^a ±0.20	74.07 ^a ±0.32
CSR 02	8.54 ^b ±0.10	8.19 ^{ab} ±0.13	5.74 ^b ±0.21	1.77 ^b ±0.16	2.06 ^b ±0.08	73.69 ^a ±0.26
SK 5912	11.34 ^a ±0.43	7.69 ^b ±0.19	6.37 ^a ±0.20	2.10 ^a ±0.03	1.82 ^b ±0.10	70.67 ^b ±0.19
Barley (Castillo <i>et al.</i> , 2019)	10.34	12.47	2.67	2.36	5.67	76.84

Values are means of triplicate determinations ± standard deviation. Means with different superscripts in the same column are significantly (p<0.05) different

Proximate Composition of Three Sorghum Varieties (CSR01, CSR02 and SK5912)

The proximate composition of the three sorghum varieties is presented in Table 2. All varieties exhibited relatively high moisture contents, ranging from 7.60% to 11.34%. The higher moisture content observed in SK 5912 suggests a shorter shelf life, as high moisture promotes microbial growth and grain deterioration. The values obtained in this study fall within the range of 6.77–12.84% reported for sorghum varieties by Gebreyes (2017). Similarly, Htet *et al.* (2022) reported moisture contents ranging from 8.04% to 9.66% across different sorghum genotypes. The slight variation observed may be attributed to varietal differences and post-harvest handling conditions.

Similarly, the protein content was appreciable across the samples, varying from 7.69% in SK5912 to 8.55% in CSR01. The protein content obtained in this study is slightly lower than that reported by Aliyu *et al.* (2024), who recorded protein values of 10.13–10.68% in selected Nigerian sorghum varieties. However, they fall within the 6–12% range reported for sorghum (Htet *et al.*, 2022). The lower protein content observed in this study may be due to differences in soil fertility, climatic conditions, or genetic makeup. Protein variability in sorghum has been widely reported, with compositional differences occurring among cultivars and grain fractions (Adebo and Kesa, 2023).

The endosperm nutrient reserves were notably substantial in all three varieties, particularly with respect to lipid content (5.30–6.37%). The lipid content (5.30–6.37%) observed in this study is higher than the range of 2.22–3.41% reported by Aliyu *et al.* (2024) and 2.74–3.32% reported in other sorghum studies (Mawouma *et al.*, 2022). This suggests that the studied varieties, particularly SK 5912, may have higher energy density. Variations in lipid content are often attributed to genetic factors and processing conditions, as well as the presence of germ fractions, which are typically rich in fats. Higher lipid content enhances caloric value but may predispose the grains to oxidative rancidity during storage (Aliyu *et al.*, 2024).

Ash content ranged from 1.77% to 2.10%, indicating moderate mineral composition. These values are comparable to those reported by Aliyu *et al.* (2024), who obtained ash values between 1.85% and 2.01%. However, slightly higher values (up to 1.59%–1.91%) have also been reported in other studies (Htet *et al.*, 2022; Mawouma *et al.*, 2022). The relatively higher ash content in SK 5912 suggests it may be richer in minerals, which is nutritionally advantageous (Lakurbe *et al.*, 2020).

Crude fibre content ranged from 1.82% to 2.46%, with CSR 01 having the highest value. These results are consistent with the range reported by Aliyu *et al.* (2024) (2.00–2.52%) and Htet *et al.* (2022) (1.58–2.49%). Fibre plays an important role in digestion and metabolic health, and the relatively higher fibre content in CSR01 suggests better functional properties for dietary applications.

The carbohydrate content constituted the largest proportion of the proximate composition, with values ranging from 70.67% to 74.07% across the three sorghum varieties. Carbohydrate content was highest in CSR 01 (74.07%) and lowest in SK 5912 (70.67%). These values fall within the typical range of 66.83–78.74% reported for sorghum grains (Gebreyes, 2017). Similarly, other studies have reported carbohydrate values

between approximately 67% and 72% (Mawouma *et al.*, 2022). The high carbohydrate content confirms that sorghum is predominantly an energy-giving cereal. The relatively lower carbohydrate content in SK 5912 may be due to its higher lipid and moisture content, reflecting the inverse relationship among proximate components. Compared with barley (Castillo *et al.*, 2019), the sorghum varieties in this study exhibited lower protein and fibre contents but relatively higher lipid content. This aligns with general cereal composition trends, where barley is known to be richer in fibre and protein, while sorghum provides more readily available energy through carbohydrates. Therefore, sorghum and barley can be considered nutritionally complementary depending on dietary needs.

Grain and Malt Analysis of Three Sorghum Varieties (CSR01, CSR02 and SK5912).

Table 3. Grain and Malt Analysis of Three Sorghum Varieties (CSR01, CSR02 and SK5912).

Samples	Germinative Energy (%)	Water sensitivity (%)	Malting loss	A thousand corn-weight	Germinative capacity (%)
CSR 01	99.00 ^a ±1.73	1.33 ^a ±0.57	5.30 ^c ±0.31	0.24 ^b ±0.03	99.00 ^a ±1.00
CSR 02	97.00 ^a ±1.73	1.66 ^a ±0.57	12.12 ^a ±0.33	0.32 ^a ±0.02	98.66 ^a ±0.76
SK 5912	86.33 ^b ±5.50	1.66 ^a ±1.15	9.88 ^b ±0.68	0.38 ^a ±0.25	97.66 ^a ±0.57

Values are means of triplicate determinations ± standard deviation. Means with different superscripts in the same column are significantly ($p < 0.05$) different

The results of the grain and malt analysis of the three sorghum varieties (CSR01, CSR02 and SK5912) are shown in Table 3. CSR 01 and CSR 02 exhibited significantly higher germinative energy compared to SK 5912. High germinative energy is desirable in malting because it indicates rapid and uniform germination, which is essential for efficient enzyme development. The values obtained for CSR 01 and CSR 02 are comparable to the 95–100% range reported for good malting sorghum varieties (Taylor and Duodu, 2015). The lower value observed in SK 5912 suggests reduced malting efficiency, possibly due to dormancy issues or grain viability differences. Water sensitivity values ranged from 1.33 to 1.66, with no significant ($p > 0.05$) difference among the varieties. Low water sensitivity is desirable, as it indicates that germination is not adversely affected by excess moisture during steeping. The results suggest that all three varieties have good tolerance to water uptake during malting. Similar findings have been reported by Ogbonna (2011) in sorghum malting studies, where low water sensitivity is associated with improved germination performance. Malting loss represents the loss of dry matter due to respiration and rootlet formation during germination (Kleinwächter *et al.*, 2012). Lower malting loss is desirable as it indicates better retention of extractable materials (Deme *et al.*, 2020). The relatively low malting loss observed in CSR 01 suggests higher malting efficiency, while the high loss in CSR 02 may indicate excessive metabolic activity during germination. These findings agree with reports that malting losses in sorghum typically range between 5% and 12%, depending on variety and malting conditions (Taylor and Duodu, 2015).

The thousand-grain weight ranged from 0.24 g (CSR 01) to 0.38 g (SK 5912), with SK 5912 and CSR 02 showing significantly higher values than CSR 01. Grain weight is an important physical parameter that influences malting quality, as larger grains generally contain more endosperm and thus higher extract potential. The higher grain weight observed in SK 5912 suggests a potential advantage in terms of malt yield. However, grain size alone does not guarantee superior malting quality, as enzymatic activity and germination capacity are also critical (Fox and Bettenhausen 2023).

Germinative capacity was high in all samples, ranging from 97.66% to 99.00%, with no significant ($p > 0.05$) differences among the varieties. High germinative capacity indicates that most of the grains are viable and capable of germination under optimal conditions. The values obtained in this study fall within the acceptable range for malting sorghum (above 95%) as reported in previous studies (Ogbonna, 2011). This suggests that all three varieties are suitable for malting in terms of viability.

Particle Size Analysis of Three Sorghum Varieties (CSR01, CSR02 and SK5912).

Figure 1 presents the particle size distribution of sorghum malt grist from varieties CSR01, CSR02 and SK5912. It illustrates a steady decline in the proportions of both fine and flour grist, alongside a corresponding increase in medium grist from samples A through E. These variations may be due to an increase in the milling efficiency of the systems used.

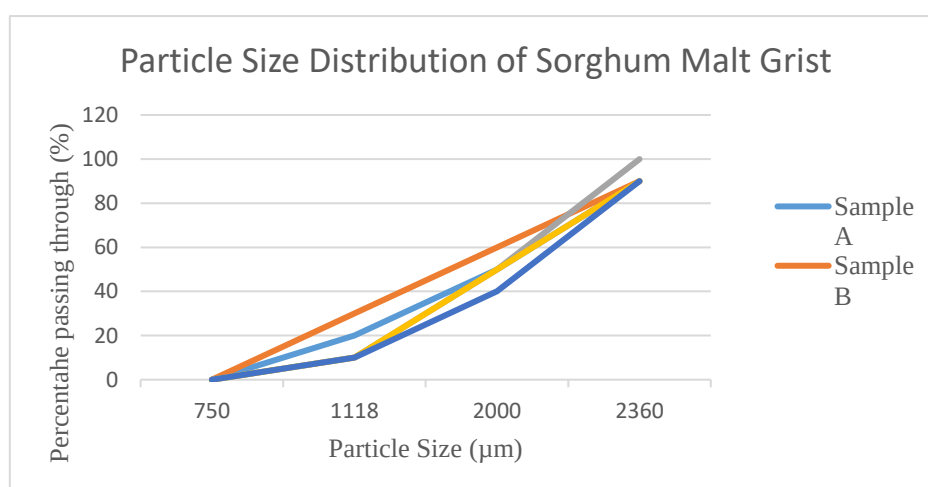


Fig. 1: Particle size distribution of sorghum malt grist (Varieties CSR01, CSR02 and SK5912).

Comparative Wort Analysis of Three Sorghum Varieties (CSR01, CSR02 and SK5912) Based on the Particle Size

Table 4 Wort Analysis of Sorghum Variety CSR 01

Samples	Lipid concentration	pH	Specific gravity	Specific viscosity	Filtration rate	Extract AS-1S (%)
A	0.81 ^{ab} ±0.02	4.86 ^d ±0.00	1.01 ^a ±0.01	2.26 ^b ±0.02	1.20 ^c ±0.04	76

Samples	Lipid concentration	pH	Specific gravity	Specific viscosity	Filtration rate	Extract AS-1S (%)
B	0.87 ^a ±0.01	5.10 ^c ±0.02	1.02 ^a ±0.01	2.37 ^a ±0.01	2.81 ^a ±0.07	78
C	0.80 ^{ab} ±0.00	5.17 ^{bc} ±0.01	1.02 ^a ±0.00	2.31 ^{ab} ±0.01	1.12 ^d ±0.06	75
D	0.75 ^b ±0.03	5.22 ^b ±0.01	1.01 ^a ±0.00	2.28 ^{ab} ±0.02	1.49 ^b ±0.57	76
E	0.63 ^c ±0.02	5.66 ^a ±0.02	1.00 ^a ±0.01	2.27 ^b ±0.02	1.04 ^e ±0.03	75

Values are means of triplicate determination ± standard deviation. Means with different superscripts in the same column are significantly (p<0.05) different

Sample A= 10:40:30:20 of M10, M16, M40, M200

Sample B= 10:30:30:30 of M10, M16, M40, M200

Sample C= 50:40:10 of M16, M40, M200

Sample D= 10:40:40:10 of M10, M16, M40, M200

Sample E= 10:50:30:10 of M10, M16, M40, M200

Mashing ratio = 5:50w/v

Table 5 Wort Analysis of Sorghum Variety CSRo2

SAMPLES	Lipid concentration	pH	Specific gravity	Specific viscosity	Filtration rate	Extract AS-1S (%)
A	0.55 ^b ±0.07	4.66 ^b ±0.01	1.00 ^a ±0.01	2.80 ^c ±0.01	2.66 ^a ±0.05	78
B	0.66 ^a ±0.04	4.92 ^{ab} ±0.03	1.00 ^a ±0.00	2.80 ^c ±0.00	2.47 ^b ±0.05	80
C	0.45 ^c ±0.07	4.77 ^c ±0.02	1.00 ^a ±0.01	2.86 ^b ±0.02	1.22 ^d ±0.03	77
D	0.48 ^c ±0.02	4.82 ^{bc} ±0.03	1.02 ^a ±0.00	2.88 ^a ±0.02	2.29 ^c ±0.05	79
E	0.53 ^b ±0.04	4.98 ^a ±0.01	1.01 ^a ±0.01	2.87 ^{ab} ±0.010	1.15 ^e ±0.02	76

Values are means of triplicate determination ± standard deviation. Means with different superscripts in the same column are significantly (p<0.05) different

Sample A= 10:40:30:20 of M10, M16, M40, M200

Sample B= 10:30:30:30 of M10, M16, M40, M200

Sample C= 50:40:10 of M16, M40, M200

Sample D= 10:40:40:10 of M10, M16, M40, M200 (Flour)

Sample E= 10:50:30:10 of M10, M16, M40, M200

Mashing ratio = 5:50w/v

Table 6 Wort Analysis of Sorghum Variety SK 5912

Samples	Lipid concentration	pH	Specific gravity	Specific viscosity	Filtration rate	Extract AS-1S (%)
A	0.83 ^{ab} ±0.02	3.92 ^c ±0.02	1.00 ^a ±0.01	2.07 ^a ±0.04	1.56 ^b ±0.02	74
B	0.96 ^a ±0.04	3.87 ^c ±0.02	1.02 ^a ±0.01	2.17 ^a ±0.01	2.29 ^a ±0.05	77
C	0.69 ^b ±0.08	4.45 ^a ±0.02	1.01 ^a ±0.01	2.12 ^a ±0.02	1.31 ^c ±0.02	74
D	0.97 ^a ±0.02	4.24 ^b ±0.03	1.02 ^a ±0.00	2.14 ^a ±0.02	1.60 ^b ±0.03	75
E	0.89 ^a ±0.01	4.18 ^b ±0.02	1.01 ^a ±0.01	2.11 ^a ±0.02	1.16 ^d ±0.04	73

Values are means of triplicate determinations $\pm$ standard deviation. Means with different superscripts in the same column are significantly ($p < 0.05$) different

Sample A= 10:40:30:20 of M10, M16, M40, M200

Sample B= 10:30:30:30 of M10, M16, M40, M200

Sample C= 50:40:10 of M16, M40, M200

Sample D= 10:40:40:10 of M10, M16, M40, M200

Sample E= 10:50:30:10 of M10, M16, M40, M200

Mashing ratio = 5:50w/v

The results of the Wort analysis of sorghum varieties CSR01, CSR02 and SK5912 are shown in Tables 4, 5 and 6, respectively.

The wort quality characteristics of the three sorghum varieties (CSR 01, CSR 02, and SK 5912) across different particle sizes (A–E) showed significant ($p < 0.05$) variations in lipid concentration, pH, specific viscosity, filtration rate, and extract yield, while specific gravity remained relatively unchanged. These results indicate that particle size and varietal differences influence wort quality, which is consistent with established reports in sorghum malting and brewing (Krstanović *et al*, 2023). Lipid content varied significantly across particle sizes and among varieties. Particle size influenced lipid extraction, with some finer samples (sample B) showing higher lipid levels. This may be due to increased surface area, which enhances the release of lipids from the germ during mashing. However, high lipid levels in wort are generally undesirable in brewing because they can negatively affect foam stability and beer shelf life (Ogbonna, 2011)

The relatively lower pH observed in SK 5912 suggests higher acidity, which may be due to differences in enzymatic activity or organic acid production during malting. Optimal wort pH is typically between 5.0 and 5.6 for efficient enzyme activity during mashing. CSR 01 samples (particularly D and E) fall within this desirable range, suggesting better enzymatic performance. In contrast, the lower pH values in SK 5912 may limit enzyme efficiency and affect sugar conversion (Ogbonna, 2011). Specific gravity values across all samples were relatively constant (1.00–1.02) and showed no significant differences ($p > 0.05$). This suggests that particle size had minimal influence on wort density in this study. Specific viscosity showed noticeable variation among the samples. Higher viscosity may indicate the presence of more soluble polysaccharides such as β -glucans, which can negatively affect wort separation and filtration. The relatively lower viscosity observed in SK 5912 suggests better flow properties during processing, whereas the higher viscosity in CSR 02 may present challenges in wort handling. Similar observations have been reported in cereal-based wort production, where high viscosity is linked to poor filtration efficiency (Taylor & Duodu, 2015).

Filtration rate varied significantly across particle sizes and varieties. Sample B generally exhibited the highest filtration rates across the sorghum varieties, indicating that this particle size may represent the optimal milling condition for efficient wort filtration. An exception was observed in the CSR02 variety, where Sample A produced a higher filtration

rate than Sample B. Finer particles tend to compact during filtration, reducing the flow rate, while excessively coarse particles reduce extract yield. Therefore, intermediate particle sizes (sample B) often provide the best balance between permeability and extract recovery. This observation agrees with malting and brewing studies, which emphasize the importance of optimal milling size for efficient wort separation (Etuk, 2003)

CSRo2 recorded the highest extract (80% in sample B), indicating superior starch conversion efficiency under optimal particle size conditions. SK 5912 consistently showed lower extract values, likely due to its lower germinative energy, which may have limited enzyme development during malting. The increase in extract at sample B confirms that finer milling improves starch accessibility and enzymatic hydrolysis. However, excessively fine particles may reduce filtration efficiency, highlighting the need for balance (Pérez-Carrillo & Serna-Saldívar, 2007)

Limitations of the Study

This study was conducted under controlled laboratory conditions using a single batch of each improved sorghum variety, which may limit the generalizability of the findings to grains produced under different environmental conditions or from different production batches. Furthermore, the investigation was restricted to the effects of particle size distribution on wort quality and did not extend to pilot-scale brewing, fermentation performance, or sensory evaluation of the resulting beer. Future research should validate the optimized milling conditions under pilot- and industrial-scale brewing systems and assess their effects on fermentation efficiency, beer quality, and consumer acceptability.

Conclusion

The findings demonstrate that both milling characteristics and mashing conditions play critical roles in determining wort quality parameters, including extract yield, filtration rate, viscosity, pH, and lipid content. Particle size distribution significantly influenced wort separation and extract recovery. A higher proportion of flour fractions improved extract yield by increasing surface area and enhancing the solubilization of starch components. However, excessive fine particles contributed to poor filtration performance by increasing wort viscosity and promoting bed compaction during lautering. Conversely, coarser grist fractions improved filtration but were associated with lower extract recovery. The mashing regime also had a pronounced effect on wort quality. Increased mash temperature enhanced extract yield, as reflected by higher specific gravity, primarily due to improved solubility of wort constituents and reduced liquid viscosity. These findings provide useful insights for optimizing sorghum-based brewing processes, particularly in improving wort quality and process efficiency in the production of sorghum malt beverages.

Recommendations

Based on the findings of this study, the particle size distribution represented by Sample B is recommended for milling the improved sorghum varieties prior to single-infusion mashing, as it generally produced superior wort quality and filtration performance. Future

research should validate these findings under pilot- and industrial-scale brewing conditions to determine whether the observed improvements in wort quality translate into enhanced fermentation performance and beer quality. In addition, sensory evaluation of beers produced from the optimized milling conditions should be conducted to establish their consumer acceptability and commercial potential.

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