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# Biochemical quality indices of sorghum genotypes from east Africa for malting and brewing

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**There is a gradual shift to substitute barley with sorghum in brewing industry to reduce the cost of doing business and make beer products more competitive. This study evaluates the sorghum genotypes for desirable malting and brewing characteristics. Biochemical characteristics assayed for 131 sorghum [*Sorghum bicolor* (L) Moench] accessions included total starch, amylopectin, amylose, proteins, tannins contents, germination energy and germination capacity. Results indicate that starch contents ranged from 22.8 - 81.2%, amylose from 11.5 - 30.2% while the amylopectin content ranged from 6.6 - 59.8%. Generally, amylose contents of sorghum genotypes were lower than their amylopectin contents, with a ratio of 1:2. The mean protein content for the sorghum accessions was 9.4% with a range of 3 - 18%, while that of barley was from 7.7 - 9.8%. Germination energy and germination capacity for sorghum ranged from 82.9 - 99.8% and 74.0 to 99.5%, respectively. Barley varieties showed germination energy and capacity greater than 98%. Sorghum tannin contents ranged from 2.55 mg/100 ml to as high as 100 mg/100 ml while barley varieties had tannin contents of 8.9 to 10.3 mg/100 ml. Two genotypes, SDSA 1x ICSR 43 and SP 993520-1 were the most favorable for brewing.**

**Key words:** Sorghum, starch, protein, tannin, germination energy, malting and brewing.

## INTRODUCTION

The principal raw material used in the brewing industry in Kenya is barley (*Hordeum vulgare* L.). However, there has been a gradual shift to replace barley with sorghum [*Sorghum bicolor* (L.) Moench] so as to reduce the cost of production and make beer products more competitive in the market. Sorghum belongs to the *Poaceae* family and is ranked fifth in importance after wheat, rice, maize and barley (Buchanan et al*.,* 2005). Sorghum is believed to have originated from Ethiopia, where it was cultivated some 5000 and 7000 years ago (ICRISAT, 2005). The crop offers a better alternative for the brewing industry, owing to its adaptability to wide environmental conditions. It is among the few crops that can survive and produce under low soil moisture and relatively high temperatures (Dicko et al., 2005). Significant research for the utilization of sorghum as malt in brewing industries has been done in South Africa since the mid 20$^{th}$ century and in Nigeria during the 1970s (Palmer, 1992). Some of the desirable attributes to be considered in sorghum grain for brewing include total starch, amylopectin, amylose, proteins, tannins contents, germination energy and germination capacity. These quality characteristics play considerable role in malting and brewing.

Starch is the raw material which is broken down to

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simple sugars for alcohol production after fermentation. Malting is part of the brewing process that involves controlled germination of cereal grain to activate biochemical and physical changes followed by stabilization through kilning at specific temperatures (Gupta et al., 2010). Structurally, starch is composed of two high molecular weight homopolysaccharides known as amylose and amylopectin (Dicko et al., 2006a). Their content and quantity, especially the amylose to amylopectin ratio, affects the rate of starch digestibility (Tester et al., 2006; Sharma et al., 2008). During the brewing process, proteins are degraded by proteolytic enzymes to peptides and amino acids (Jones, 2005a, b) which provide energy for the yeasts during fermentation process leading to production of alcohol as the end product. The quantity of protein in sorghum has a significant effect on brewing (FAO, 1995; Beta et al., 1995). There is need for a balance between proteins and other biochemical parameters in sorghum grain for quality beer. Tannins are considered undesirable due to their capacity to bind to proteins, making them less digestible and also producing undesirable astringent taste (Ambula et al., 2003). Sorghum accessions naturally have high tannin contents and this poses a challenge when using sorghum as a raw material.

The brewing industry in Kenya contributes to the economy through job creation. Despite this benefit of sorghum, its adoption, production and utilization as a staple and commercial crop in Kenya remains low. This is largely due to low yields, lack of specific genotypes for malting and brewing, inadequate product promotion, poor marketing linkages and unfavorable policy environment. The aim of this study was to evaluate and identify suitable sorghum genotypes for malting and brewing as one of the means of enhancing sorghum production.

## MATERIALS AND METHODS

The sorghum materials used in the study were collections consisting of 31 hybrids and 60 open pollinated genotypes bred for the mid-lowlands, and 40 open pollinated genotypes bred for the highlands. The mid lowland sorghum were grown in Kampi Ya Moto (00° 05' S, 35° 56'E) at an altitude 1660 m above sea level (asl) while the highland sorghum was grown at Egerton University (00° 22' S, 35° 35'E) placed at 2,250 m asl. Both of the sorghum materials were grown in a randomized complete blocking design and replicated three times during the April - August season. The grain from two middle rows in each experimental unit was harvested, dried, threshed and used for subsequent laboratory and industrial tests. During the laboratory evaluation, commercial barley varieties were obtained and used as control.

### Determination of protein content

One tenth gram finely milled sorghum grain were weighed and transferred into a digestion tube. Selenium catalyst mixture weighing 1 g was mixed with the samples and 5 ml of sulphuric acid (96%) was added into the tube. The tubes were then heated cautiously in the digester at the fume cupboard until the digest was clear. The sample was transferred to a 100 ml volumetric flask, and distilled water was added into 100 ml graduated flask up to the mark. Boric acid indicator solution of 5 ml was then transferred to 100 ml conical flask containing 5 drops of mixed indicator and was placed under the condenser of the distillation apparatus. 10 ml of the clear supernatant liquid of the digest was then transferred into the apparatus, and 10 ml of 46% sodium hydroxide added and then rinsed again with distilled water. Distillation was then commenced. After the first distillation, drops reached the boric acid indicator solution, and colour changed from pink to green. A total of 150 ml of the distillate was collected. The solution was titrated with 0.0174 N sulphuric acids until the colour changed from green to pink.

### Determination of starch content

0.25 g of milled grain sample was homogenized in 80% hot ethanol to remove sugars. The residue was then centrifuged and retained. The residue was dried well over a water bath. To the residue, 5.0 ml of distilled water and 6.5 ml of 52% perchloric acid was added, and then extracted at 0°C for 20 min. The supernatants were centrifuged, pooled and made up to 100 ml. 0.1 ml of the supernatant was pipetted out and made up to the volume to 1 ml with distilled water. The standards were prepared by taking 0.2, 0.4, 0.6, 0.8 and 1 ml of the working standard and the volume made up to 1 ml in each tube with water. 4 ml of anthrone reagent was then added to each tube and sample heated for 8 min in a boiling water bath. Each sample was cooled rapidly and the intensity of green to dark green colour was read using a spectrophotometer at 630 nm. The glucose content in the sample was determined using the standard calibration graph, and then the value was multiplied by a factor of 0.9 to arrive at the starch content.

### Determination of amylose content

0.1 g of milled sorghum grain was weighed, and 1 ml of distilled ethanol added followed by 10 ml of 1 N NaOH. The sample was heated for 10 min in a boiling water bath. The volume was made up to 100 ml. The extract taken was 2.5 ml and 20 ml of distilled water was added followed by three drops of 0.1% phenolphthalein. Dropwise HCl 0.1N was then added until the pink colour just disappeared. 1 ml iodine reagent was added till the volume was 50 ml and the colour read at 590 nm using a spectrophotometer. Standard amylose solution 0.2, 0.4, 0.6, 0.8 and 1 ml was taken and the colour developed as in the case of the test samples. The amount of amylose present in the sample was calculated using the standard graph.

### Determination of tannin content

0.5 g of the powdered flour was weighed and transferred to a 250 ml conical flask, and then 75 ml of water added. The flask was heated gently and boiled for 30 min, then centrifuged at 2000 rpm for 20 min. The supernatant was collected in a 100 ml volumetric flask. 1 ml of the sample extract was transferred to a 100 ml volumetric flask containing 75 ml water. 5 ml of folin regent, 10 ml of 35% sodium carbonate solution were added, and then diluted to 100 ml with water. The sample was shaken and the absorbance read at 700 nm after 30 min. A graph was prepared using 0 - 100 mg tannic acid, where 1 ml contained 100 mg tannic acid. The tannin content of the sample was calculated as tannic acid equivalent from the standard curve.

### Determination of germination energy

200 uniform sized and clean grains were picked and steeped in a

500 ml beaker containing 200 ml of distilled water for 24 h. At the end of the 24 h, the grains were strained and left to germinate at 21°C. The germinated grains were then counted and the germinative capacity calculated using the formula:

Germination capacity = (200-N)/2

Where, N = grains that did not show radicle.

**Determination of germination capacity**

Three lots of cleaned 500 sorghum grains were obtained. Each lot of the 500 grains was transferred into a funnel standing in tap water to ensure complete flooding of the grains at 20°C. The water was removed after steeping for 3 h. The grains were covered with Whatmans No. 4 filter papers and the funnel itself covered with a glass plate. The steeping was repeated for 2 h after 20 h from the beginning of the test. The grains were again covered with filter paper in the funnel with a glass plate. After 72 h from the beginning of the test, the funnels were emptied and the number of non-germinated grains counted. The percent Germination energy was determined as:

Germination energy (GE) = (500-N)/5

**Statistical analysis**

Data obtained from this study was statistically analyzed using one way analysis of variance (ANOVA) ($Y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij}$) and the means were separated using Duncan's multiple range test using the Statistical Analysis Software (SAS). Multiple correlation analysis was also carried out to determine the relationship between biochemical parameters. The level of significance used was ≤ 0.05.

## RESULTS

Most of the hybrids had starch contents of < 60% except SDSA 1 X ICSR 43 which had starch content of 62.21% (Table 1). Among the barley varieties, Sabini had the highest starch content while Karne had the lowest. All the barley accessions in this study are commercially used for brewing. Comparing starch content in barley and sorghum, it is evident that barley had higher starch than sorghum. The amylopectin was relatively higher than amylose in both sorghum and barley varieties. Most of the mid lowland and highland genotypes (Tables 2 and 3) with red pericarp had high starch and amylopectin contents. Out of the 60 mid-lowland genotypes and 40 highland accessions, 18 and 16 sorghum genotypes, respectively, had starch contents greater than 60% (Tables 2 and 3). Amylose content greater than 20% was registered with Sabini a barley variety, while the amylopectin amounts were higher than amylose both in commercial barley and sorghum genotypes. Like the lowlands genotypes, most of the highland accessions with high starch contents had red pericarp. Amylopectin contents were higher than the amylose contents in most of the genotypes (Table 3). As the starch contents increased, the amylopectin content also increased, while the amylose content generally decreased.

The protein content, tannin content, germination energy and germination capacity of SDSA 1 X ICSR 43 (Table 1) and SP 993520-1 (Table 2) was found to be within the same range with the commercial barley. Most of the protein contents were within the range of the barley controls except some with ≥ 10% among all sorghum accessions. With regards to sorghum tannin content, the hybrids (Table 1) seem to have higher levels than barley. Tannin contents varied among the genotypes with as high as 79.89 mg/100 ml for the mid lowlands (Table 2). Some cream colored genotypes like Nyondok, Nyangjang, IESV 92036 SH (Table 2) had high tannin levels of 52.2, 40.0 and 29.5 mg/100 ml respectively which were not different from the red pericarp genotypes. Genotypes Ainamoi #1 and #2, Kipkelion #1 and #2, Kabamba,, IESV 94121 SH, Nyangezi, IS 8884, Nyondok, IESV 94079, Cyhure, Abaleshya, Londiani, Ndamoga, IS 25562 and E 1291, had high tannin contents (Table 3). Tannins were the most limiting factor on the selection criteria. The other genotypes (Table 3) had lower than 40 mg/100 ml tannic acid equivalent.

Commercial barley genotypes showed good germination qualities compared to sorghum accessions. The sorghum genotypes Kipkelion # 1 and 2, Ainamoi #1 and 2, Busia #3-3, Nyangezi, Kabamba, Nyondok, IS 11909, and E1291 had germination energies less than 95% and these genotypes have red or brown pericarp (Table 3). Most accessions with less germination properties were red/brown in colour. Barley controls had low tannin contents between 9 - 12%. The genotypes were selected in reference to the commercial barley quality characteristics. The values of the other accessions are as shown in Tables 1, 2 and 3. Starch contents had a positive significant association with amylopectin and the tannins, while it was negatively correlated with proteins and germination capacity (Table 4). Tannin content was negatively correlated with protins and amylose contents.

## DISCUSSION

Among the essential grain quality indices for malting and brewing are starch, proteins, germination energy, germination capacity and tannins. Using the four commercial barley varieties as standard checks, 18 sorghum genotypes were identified as potential suitable material for malting and brewing. Half of these were submitted for industrial confirmation by the East African Breweries Ltd (EABL), where SDSA 1 X ICSR 43 and SP 993520-1 genotypes emerged as most suitable. In analyzing the attributes of these two among the 131 sorghum collections, some quality indices are salient; among them is the starch content. The two selected sorghum genotypes had relatively high starch contents of 62.20 and 62.27%, respectively. Although there were several sorghum accessions with starch contents above

**Table 1.** Starch, amylose, amylopectin, and pericarp colour of selected hybrid sorghum and commercial barley varieties.

| Genotype | Starch (%) | Amylose (%) | Amylopectin (%) | Protein (%) | Tannins (mg/100ml) | Germination energy (%) | Germination capacity (%) | Pericarp colour |
|---|---|---|---|---|---|---|---|---|
| Sabini (barley) | 88.90$^{a}$ | 20.73$^{fed}$ | 68.17$^{a}$ | 7.17$^{op}$ | 10.63$^{mkl}$ | 99.60$^{a}$ | 99.60$^{a}$ | Cream |
| Nguzo (barley) | 77.98$^{b}$ | 16.80$^{ifjlgkh}$ | 61.17$^{a}$ | 7.78$^{on}$ | 12.36$^{ikj}$ | 99.40$^{a}$ | 99.40$^{a}$ | Cream |
| Hkbl (barley) | 69.48$^{c}$ | 19.69$^{fegdh}$ | 49.79$^{b}$ | 9.15$^{jmkonl}$ | 12.36$^{ikj}$ | 99.60$^{a}$ | 99.00$^{ab}$ | Cream |
| SDSA 1 X ICSR 43 | 62.20$^{d}$ | 15.36$^{ijlk}$ | 46.83$^{bc}$ | 7.57$^{on}$ | 14.09$^{ighfj}$ | 97.20$^{cedfg}$ | 96.50$^{fcadbe}$ | Cream |
| ICSA 90001 X ICSR 160 | 58.88$^{de}$ | 20.06$^{fegd}$ | 38.81$^{dfec}$ | 9.10$^{jmkonl}$ | 13.22$^{ihj}$ | 97.47$^{cedf}$ | 95.00$^{fcgde}$ | Cream |
| IESH 22002 | 58.45$^{de}$ | 19.02$^{ifjegdh}$ | 39.42$^{dfec}$ | 12.76$^{fde}$ | 12.65$^{ikj}$ | 94.20$^{mkl}$ | 90.67$^{ikj}$ | Cream |
| SDSH 90003 | 57.01$^{fde}$ | 18.62$^{ifjegdh}$ | 38.38$^{dfeg}$ | 7.93$^{mno}$ | 24.47$^{a}$ | 93.47$^{ml}$ | 92.83$^{figh}$ | Red |
| IESH 22019 | 56.67$^{fde}$ | 13.52$^{l}$ | 43.15$^{dbc}$ | 11.19$^{jfkhgei}$ | 7.46$^{qpo}$ | 96.80$^{hcedgf}$ | 95.67$^{fcgdbe}$ | Cream |
| ICSA 376 X ICSR 160 | 56.60$^{fde}$ | 29.89$^{a}$ | 26.71$^{ikjlm}$ | 8.80$^{mnol}$ | 15.53$^{egf}$ | 95.60$^{hjikg}$ | 93.83$^{fighe}$ | Brown |
| ICSA 276 C ICSR 160 | 56.49$^{fde}$ | 13.92$^{lk}$ | 42.57$^{dbec}$ | 9.61$^{jmkhnil}$ | 12.07$^{klj}$ | 96.80$^{hcedfg}$ | 92.17$^{igjh}$ | Cream |
| ICSA 276 X ICSR 93001 | 54.63$^{fge}$ | 29.12$^{ab}$ | 25.51$^{nkjlm}$ | 13.07$^{fde}$ | 16.11$^{edf}$ | 98.13$^{cab}$ | 94.83$^{fcgde}$ | Cream |
| ICSA 9 X ICSR 93001 | 54.56$^{fge}$ | 18.41$^{ifjegdh}$ | 36.15$^{dfegh}$ | 9.30$^{jmkonil}$ | 14.38$^{ighf}$ | 97.33$^{cedf}$ | 94.83$^{fcgde}$ | Cream |
| ICSA 89003 X ICSR 24008 | 50.38$^{fgh}$ | 21.40$^{ed}$ | 28.98$^{ikjlh}$ | 9.15$^{jmkonl}$ | 12.94$^{ij}$ | 95.93$^{hjiefg}$ | 96.17$^{fcadbe}$ | Cream |
| Karne (barley) | 49.93$^{fgih}$ | 15.52$^{ijlk}$ | 34.40$^{ifegh}$ | 9.76$^{jmkhnil}$ | 12.36$^{ikj}$ | 99.20$^{ab}$ | 99.20$^{ab}$ | Cream |
| ATX 623 X IESV 91131 DL | 49.34$^{gih}$ | 20.09$^{fegd}$ | 29.25$^{ikjlh}$ | 8.95$^{mkonl}$ | 10.05$^{ml}$ | 97.67$^{cdb}$ | 96.33$^{fcadbe}$ | Cream |
| IESH 22005 | 49.23$^{gih}$ | 19.77$^{fegdh}$ | 29.46$^{ikjlh}$ | 8.24$^{mno}$ | 12.65$^{ikj}$ | 97.53$^{ced}$ | 98.33$^{cab}$ | Cream |
| IESH 22006 | 48.76$^{igih}$ | 18.49$^{ifjegdh}$ | 30.27$^{ikjgh}$ | 13.42$^{de}$ | 9.48$^{mno}$ | 95.80$^{hjifg}$ | 95.33$^{fcgdbe}$ | White |
| SDSH 94011 | 48.67$^{jgih}$ | 16.30$^{ijlgkh}$ | 32.37$^{ifjgh}$ | 14.09$^{cd}$ | 18.42$^{bc}$ | 96.80$^{hcedfg}$ | 94.67$^{fcgde}$ | Cream |
| SDSA 29 X ICSR 196 | 48.09$^{jgihk}$ | 15.63$^{ijlk}$ | 32.45$^{ifjgh}$ | 10.22$^{jmkhgli}$ | 16.69$^{edc}$ | 96.33$^{hiedfg}$ | 96.00$^{fcadbe}$ | Cream |
| ICSA 371 X ICSR 160 | 48.02$^{jgihk}$ | 27.22$^{ab}$ | 20.79$^{noplm}$ | 10.93$^{jfkhgli}$ | 16.96$^{edc}$ | 96.33$^{hiedfg}$ | 93.17$^{figh}$ | Brown |
| ICSA 276 X ICSR 38 | 44.60$^{jlihk}$ | 25.59$^{cd}$ | 19.01$^{nopqm}$ | 15.66$^{cb}$ | 13.80$^{ighj}$ | 97.33$^{cedf}$ | 96.50$^{fcadbe}$ | Cream |
| ICSA 11 X ICSR 160 | 44.00$^{jlihk}$ | 22.04$^{cd}$ | 21.95$^{noklm}$ | 10.27$^{jmkhgli}$ | 7.46$^{qpo}$ | 96.93$^{hcedfg}$ | 94.83$^{fcgde}$ | Cream |
| ICSA 276 X ICSR 162 | 43.43$^{jlihk}$ | 18.59$^{ifjegdh}$ | 24.84$^{nokjlm}$ | 11.80$^{fhge}$ | 6.30$^{qr}$ | 97.47$^{cedf}$ | 97.33$^{cadbe}$ | Cream |
| ICSA 90001 X SP 74279 | 42.67$^{jllk}$ | 30.24$^{a}$ | 12.43$^{rq}$ | 10.93$^{jfkhgli}$ | 18.13$^{dc}$ | 92.87$^{m}$ | 91.00$^{ikjh}$ | Brown |
| ICSA 371 X ICSR 56 | 41.75$^{jlk}$ | 22.25$^{cd}$ | 19.49$^{nopqm}$ | 5.44$^{p}$ | 8.90$^{mnpo}$ | 98.13$^{cab}$ | 97.67$^{cadb}$ | Brown |
| IESH 22012 | 41.66$^{jlk}$ | 15.74$^{ijlkh}$ | 25.92$^{nlkjlm}$ | 16.88$^{ab}$ | 9.77$^{mn}$ | 97.53$^{ced}$ | 96.33$^{fcadbe}$ | Cream |
| ICSA 88006 X ICSR 196 | 41.07$^{lk}$ | 19.15$^{ifegdh}$ | 21.91$^{noklm}$ | 11.24$^{jfkhgei}$ | 6.88$^{qp}$ | 96.53$^{hceidfg}$ | 95.00$^{fcgde}$ | Cream |
| IESH 22010 | 40.47$^{l}$ | 27.03$^{ab}$ | 13.43$^{rpq}$ | 12.46$^{fdge}$ | 13.51$^{ighj}$ | 98.00$^{cadb}$ | 94.50$^{fgdhe}$ | Cream |
| ICSA 12 X WAHI | 40.13$^{l}$ | 17.63$^{ifjegkh}$ | 22.49$^{noklm}$ | 18.15$^{a}$ | 7.75$^{qnpo}$ | 95.28$^{hjik}$ | 93.67$^{fighe}$ | Cream |
| SDSH 409 | 39.68$^{l}$ | 14.99$^{jlk}$ | 24.69$^{nokjlm}$ | 11.34$^{jfhgei}$ | 20.15$^{b}$ | 90.33$^{n}$ | 88.17$^{l}$ | Red |
| IESH 22011 | 39.66$^{l}$ | 13.65$^{lk}$ | 26.00$^{nikjlm}$ | 9.46$^{jmkonil}$ | 15.25$^{eghf}$ | 98.13$^{cab}$ | 96.33$^{fcadbe}$ | Cream |
| IESH 22009 | 39.50$^{l}$ | 15.55$^{ijkl}$ | 23.95$^{nokjlm}$ | 11.54$^{fhgei}$ | 8.90$^{mnpo}$ | 97.60$^{cedb}$ | 98.17$^{cadb}$ | Cream |
| SDSA 29 X KARI MTAMA 1 | 38.40$^{l}$ | 21.74$^{d}$ | 16.65$^{opq}$ | 18.00$^{a}$ | 2.55$^{s}$ | 95.00$^{jik}$ | 88.17$^{k}$ | Cream |
| ATX 623 X IESV 91104 DL | 37.93$^{l}$ | 20.41$^{fed}$ | 17.51$^{nopq}$ | 14.59$^{cd}$ | 10.05$^{ml}$ | 96.60$^{hciedfg}$ | 94.50$^{fgdhe}$ | Cream |
| ICSA 371 X ICSR 108 | 27.09$^{m}$ | 20.49$^{fed}$ | 6.60$^{r}$ | 16.07$^{cab}$ | 4.57$^{r}$ | 94.60$^{jkl}$ | 89.33$^{kj}$ | Brown |

Means with the same letter in the column are not significantly different.

**Table 2.** Contents of starch, amylose, amylopectin, protein, tannin, germination energy, germination capacity and pericarp colour contents of mid - lowland sorghum accessions.

| Genotype | Starch (%) | Amylose (%) | Amylopectin (%) | Protein (%) | Tannins (mg/100ml) | Germinationenergy (%) | Germinationcapacity (%) | Pericarp colour |
|---|---|---|---|---|---|---|---|---|
| SABINI (barley) | 88.90$^{a}$ | 20.73$^{fed}$ | 68.17$^{a}$ | 7.17$^{op}$ | 10.63$^{mkl}$ | 99.60$^{a}$ | 99.60$^{a}$ | Cream |
| Ainamoi #1 | 81.19$^{b}$ | 22.20$^{b}$ | 59.00$^{cb}$ | 7.83$^{tsrmnopqu}$ | 79.85$^{b}$ | 95.67$^{qmrsnpo}$ | 96.33$^{fcgjhdibke}$ | Brown |
| NGUZO (barley) | 77.98$^{b}$ | 16.80$^{ifjlgkh}$ | 61.17$^{a}$ | 7.78$^{on}$ | 12.36$^{ikj}$ | 99.40$^{a}$ | 99.40$^{a}$ | Cream |
| Siaya # 24-2 | 76.41$^{dbc}$ | 19.43$^{gdhbecf}$ | 56.99$^{dcb}$ | 9.56$^{jilhmkfg}$ | 41.78$^{pno}$ | 96.33$^{qmrihnjklpo}$ | 96.33$^{fcgjhdibke}$ | Brown |
| Kipkelion # 2 | 76.10$^{dbc}$ | 16.28$^{pqorhkisjnltm}$ | 59.82$^{cb}$ | 7.43$^{tsrvopqu}$ | 58.80$^{ljh}$ | 99.13$^{cadbe}$ | 99.50$^{a}$ | Brown |
| Nyiragikori | 75.22$^{dbec}$ | 18.28$^{gdhkiejclfm}$ | 56.94$^{dcb}$ | 8.19$^{tslrmknopqu}$ | 15.53$^{yx}$ | 93.33$^{u}$ | 91.67$^{rqsp}$ | White |
| Kipkelion# 1 | 71.67$^{dfec}$ | 19.16$^{gdhbiecf}$ | 52.51$^{dce}$ | 5.19$^{zyx}$ | 59.95$^{igh}$ | 96.60$^{qmgihnjklpo}$ | 93.33$^{nqompl}$ | Brown |
| HKBL (barley) | 69.48$^{c}$ | 19.69$^{fegdh}$ | 49.79$^{b}$ | 9.15$^{jmkonl}$ | 12.36$^{ikj}$ | 99.60$^{a}$ | 99.00$^{ab}$ | Cream |
| Kabamba | 68.93$^{dfeg}$ | 12.38$^{uvw}$ | 56.55$^{dcb}$ | 6.97$^{tsrvwqu}$ | 100.00$^{a}$ | 95.87$^{qmrsnklpo}$ | 94.50$^{ngjhoimkpl}$ | Brown |
| Muhimpundu | 68.57$^{feg}$ | 21.35$^{dbc}$ | 47.22$^{igfeh}$ | 10.94$^{dcef}$ | 56.78$^{ij}$ | 96.87$^{fmgihnjklpo}$ | 92.17$^{rqop}$ | Red |
| Ainamoi #2 | 68.25$^{hfeg}$ | 19.45$^{gdhbecf}$ | 48.80$^{dgfeh}$ | 7.38$^{tsrvopqu}$ | 48.99$^{m}$ | 96.87$^{fmgihnjklpo}$ | 94.67$^{ngjhoimkl}$ | Red |
| IESV 94121 SH | 68.21$^{hfeg}$ | 21.64$^{bc}$ | 46.57$^{jigfeh}$ | 7.53$^{tsropqu}$ | 48.70$^{m}$ | 97.73$^{fcgihdjkle}$ | 97.33$^{fcgadbe}$ | Brown |
| Busia # 3-3 | 68.01$^{hfeg}$ | 17.66$^{gohkiejnlfm}$ | 50.34$^{dgfe}$ | 7.58$^{tsrnopqu}$ | 28.51$^{rs}$ | 96.13$^{qmrinjklpo}$ | 93.67$^{njomkpl}$ | Brown |
| Teso # 11-2 | 66.39$^{hfig}$ | 14.67$^{puqorvwsnt}$ | 51.71$^{dcfe}$ | 6.51$^{tyvwxu}$ | 17.26$^{wx}$ | 95.93$^{qmrnjklpo}$ | 94.17$^{njoimkpl}$ | White |
| IESV 91111 DL | 65.60$^{hfigj}$ | 16.80$^{pgqorhkisjnlm}$ | 48.85$^{dgfeh}$ | 12.56$^{ab}$ | 9.47$^{edc}$ | 95.20$^{qrstp}$ | 89.17$^{s}$ | Cream |
| Nyangezi | 64.48$^{khfigj}$ | 17.18$^{pgqorhkiejnlfm}$ | 47.30$^{igfeh}$ | 8.80$^{jilhmknopg}$ | 69.18$^{d}$ | 97.87$^{fcgihdjbe}$ | 96.00$^{fcgjhdikel}$ | Brown |
| IS 8884 | 63.40$^{khigj}$ | 18.92$^{gdhbiejcf}$ | 44.48$^{jikgfeh}$ | 5.50$^{zywx}$ | 49.86$^{lm}$ | 96.53$^{qmgihnjklpo}$ | 95.33$^{fgjhdimkel}$ | Red |
| SP 993520-1 | 62.27$^{khligj}$ | 13.52$^{uvwst}$ | 48.75$^{dgfeh}$ | 5.80$^{zyvwx}$ | 18.13$^{wx}$ | 97.80$^{fcgihdjke}$ | 96.17$^{fcgjhdibkel}$ | Cream |
| Siaya # 6-1 | 62.12$^{khligj}$ | 18.46$^{gdhkiejclf}$ | 43.65$^{jikgfeh}$ | 9.56$^{jilhmkfg}$ | 30.24$^{r}$ | 96.53$^{qmgihnjklpo}$ | 96.33$^{fcgjhdibke}$ | Brown |
| Nyondok | 61.71$^{khligj}$ | 15.50$^{puqorvksjnltm}$ | 46.21$^{jikgfeh}$ | 7.53$^{tsropqu}$ | 52.16l$^{m}$ | 94.87$^{qurst}$ | 92.33$^{rnqop}$ | Cream |
| IESV 94079 SH | 60.61$^{khlimj}$ | 18.60$^{gdhkiejcf}$ | 42.01$^{jikglh}$ | 9.97$^{jihefg}$ | 42.93$^{no}$ | 98.27$^{fcgahdbe}$ | 96.33$^{fcgjhdibke}$ | Brown |
| Siaya # 50-3 | 59.01$^{knlimj}$ | 16.09$^{pqorhkisjnltm}$ | 42.93$^{jikgfh}$ | 10.28$^{dhefg}$ | 42.93$^{no}$ | 97.00$^{fmgihnjklpo}$ | 95.17$^{fngjhimkel}$ | Red |
| Londiani | 58.09$^{knlomj}$ | 18.44$^{gdhkiejclf}$ | 39.65$^{jikmnl}$ | 6.46$^{yvwxu}$ | 51.59$^{lm}$ | 96.80$^{fmgihnjklpo}$ | 95.17$^{fngjhimkel}$ | Red |
| IESV 92041 SH | 57.42$^{knlom}$ | 17.50$^{gohkiejnlfm}$ | 39.92$^{jikmnlh}$ | 4.83$^{z}$ | 42.07$^{pno}$ | 98.47$^{fcgadbe}$ | 92.17$^{rqop}$ | Brown |
| Uasin Gishu #1 | 55.28$^{nlomp}$ | 21.59$^{bc}$ | 33.70$^{qomnlp}$ | 5.09$^{zy}$ | 65.14$^{fe}$ | 95.53$^{qrsnpo}$ | 92.50$^{rnqomp}$ | Red |
| Siaya # 42 | 54.95$^{nlomp}$ | 14.57$^{puqorvwsnt}$ | 40.38$^{jikmlh}$ | 5.40$^{zywx}$ | 43.51$^{n}$ | 95.67$^{qmrsnpo}$ | 96.00$^{fcgjhdikel}$ | Red |
| Imbundi | 53.26$^{nqomp}$ | 15.42$^{puqorvksjnltm}$ | 37.84$^{jokmnl}$ | 9.77$^{jihkfg}$ | 40.05$^{pno}$ | 97.60$^{fmgihdjkle}$ | 97.17$^{fcgahdbe}$ | Red |
| Teso # 5 | 52.97$^{rnqomp}$ | 15.61$^{puqorksjnltm}$ | 37.36$^{okmnlp}$ | 7.88$^{tsrmnopqu}$ | 63.12$^{fg}$ | 97.87$^{fcgihdjbe}$ | 94.33$^{njhoimkpl}$ | Brown |
| IESV 92036 SH | 52.41$^{rnqosp}$ | 22.23$^{b}$ | 30.18$^{qortsp}$ | 7.94$^{tsrmnopqu}$ | 29.95$^{r}$ | 95.47$^{qrspo}$ | 96.00$^{fcgjhdikel}$ | Cream |
| Uasin Gishu #2 | 51.62$^{rnqosp}$ | 18.33$^{gdhkiejclfm}$ | 33.29$^{qomnlp}$ | 8.75$^{jilhmknop}$ | 73.80$^{c}$ | 97.27$^{fmgihnjkleo}$ | 97.33$^{fcgadbe}$ | Red |
| Siaya # 93-1 | 50.92$^{rtqosp}$ | 19.53$^{gdhbecf}$ | 31.39$^{qornp}$ | 10.38$^{dhefg}$ | 57.93$^{ijh}$ | 95.80$^{qmrsnlpo}$ | 80.33$^{t}$ | Red |
| KARNE (barley) | 49.93$^{fgih}$ | 15.52$^{ijlk}$ | 34.40$^{ifegh}$ | 9.76$^{jmkhnil}$ | 12.36$^{ikj}$ | 99.20$^{ab}$ | 99.20$^{ab}$ | Cream |
| Cyihure 55 | 49.53$^{rtqusp}$ | 16.30$^{pqorhkisjnltm}$ | 33.23$^{qomnlp}$ | 9.67$^{jilhkfg}$ | 36.01$^{q}$ | 97.60$^{fmgihdjkle}$ | 97.00$^{fcgahdibe}$ | Red |
| Busia # 30-2 | 49.40$^{rtqusp}$ | 15.53$^{puqorvksjnltm}$ | 33.87$^{qomnlp}$ | 6.77$^{tsrvwxu}$ | 52.74$^{lk}$ | 94.87$^{qurst}$ | 79.83$^{t}$ | Red |

**Table 2.** Contd.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IESV 93042 SH | 47.62$^{rtvqusp}$ | 20.07$^{gdbecf}$ | 27.55$^{qurtsv}$ | 9.66$^{jilhkfg}$ | 23.89$^{u}$ | 96.20$^{qmrinjklpo}$ | 96.50$^{fcgjhdibe}$ | Cream |
| Gadam Hamam | 47.48$^{rtvqusp}$ | 16.52$^{pqorhkisjnlm}$ | 30.97$^{qornp}$ | 10.93$^{dcef}$ | 26.21$^{tus}$ | 97.93$^{fcgihdbe}$ | 93.33$^{nqompl}$ | White |
| Tegemeo | 46.88$^{rtvqusw}$ | 21.67$^{bc}$ | 25.21$^{quwrtsv}$ | 11.55$^{dceb}$ | 12.07$^{zyabc}$ | 95.47$^{qrspo}$ | 93.50$^{nomkpl}$ | Cream |
| Siaya # 6-2 | 46.65$^{rtvqusw}$ | 18.06$^{gdhkiejnlfm}$ | 28.59$^{qurtsp}$ | 7.43$^{tsrvopqu}$ | 39.47$^{pqo}$ | 94.53$^{urst}$ | 89.83$^{rs}$ | Brown |
| Siaya # 46-1 | 46.11$^{rtvqxusw}$ | 18.60$^{gdhkiejcf}$ | 27.52$^{qurtsv}$ | 8.24$^{tslrmknopq}$ | 38.89$^{pq}$ | 97.67$^{fcgihdjkle}$ | 96.17$^{fcgjhdibkel}$ | Red |
| SP 993515 | 45.25$^{zvyxuaw}$ | 11.60$^{w}$ | 30.65$^{qorsp}$ | 10.12$^{ihefg}$ | 11.78$^{zabc}$ | 88.60$^{vw}$ | 74.00$^{u}$ | Red |
| Siaya # 81-2 | 45.15$^{rtvyxusw}$ | 12.38$^{uvw}$ | 32.77$^{qomnp}$ | 10.07$^{ihefg}$ | 42.65$^{pno}$ | 97.00$^{fmgihnjklpo}$ | 90.67$^{rqs}$ | Brown |
| Siaya # 29-1 | 44.99$^{rtvyxusw}$ | 16.86$^{pgqorhkisjnlm}$ | 28.13$^{qurts}$ | 8.44$^{jilrmknopq}$ | 22.74$^{uv}$ | 98.32$^{fcgadbe}$ | 98.83$^{cab}$ | Red |
| Kisanana | 44.54$^{ztvyxusw}$ | 26.77$^{a}$ | 17.77$^{xwyz}$ | 7.22t$^{srvpqu}$ | 68.32$^{de}$ | 93.20$^{u}$ | 91.67$^{rqsp}$ | White |
| Siaya # 2-3 | 43.46$^{ztvyxuaw}$ | 13.82$^{urvwst}$ | 29.64$^{qortsp}$ | 5.19$^{zyx}$ | 19.57$^{wv}$ | 82.93$^{x}$ | 76.00$^{u}$ | Cream |
| Siaya # 62-1 | 41.77$^{zbvyxuaw}$ | 18.62$^{gdhkiejcf}$ | 23.15$^{xuwrtsv}$ | 8.65$^{jilhmknopq}$ | 39.47$^{pqo}$ | 98.73$^{fcadbe}$ | 97.33$^{fcgadbe}$ | Brown |
| Sima | 41.12$^{zbvyxcaw}$ | 14.91$^{puqorvwsntm}$ | 26.21$^{quwrtsv}$ | 10.94$^{dcef}$ | 15.25$^{zyx}$ | 96.60$^{qmgihnjklpo}$ | 93.33$^{nqompl}$ | Cream |
| ZSV 3 | 40.85$^{zbvyxcaw}$ | 16.01$^{pqorhkisjnltm}$ | 24.85$^{quwrtsv}$ | 10.12$^{ihefg}$ | 24.19$^{tu}$ | 98.40$^{fcgadbe}$ | 97.83$^{cadbe}$ | Brown |
| Macia | 40.58$^{zbvyxcaw}$ | 12.99$^{uvwt}$ | 27.59$^{qurtsv}$ | 9.46$^{jilhmkfg}$ | 7.75$^{ed}$ | 98.67$^{fcadbe}$ | 97.83$^{cadbe}$ | Cream |
| Nyan-Jang | 40.52$^{zbvyxcaw}$ | 15.80$^{puqorkisjnltm}$ | 24.72$^{quwrtsv}$ | 9.11$^{jilhmknog}$ | 40.05$^{pno}$ | 94.00$^{ust}$ | 93.67$^{njomkpl}$ | Cream |
| Siaya #81-4 | 38.90$^{zbdyxcaw}$ | 17.37$^{pgqohkiejnlfm}$ | 21.53$^{xuwtsv}$ | 8.04$^{tslrmnopqu}$ | 60.53$^{gh}$ | 97.27$^{fmgihnjkleo}$ | 93.33$^{nqompl}$ | Red |
| SP 993532 | 38.58$^{zbdyxcae}$ | 13.87$^{uqrvwst}$ | 24.71$^{quwrtsv}$ | 6.82$^{tsrvwxu}$ | 9.47$^{edc}$ | 99.87$^{a}$ | 98.17$^{cadb}$ | Cream |
| IESV 91131 DL | 37.66$^{zbdycae}$ | 20.52$^{dbecf}$ | 17.14$^{xwyz}$ | 9.46$^{jilhmkfg}$ | 11.20$^{dabc}$ | 97.47$^{fmgihnjkle}$ | 97.67$^{fcadbe}$ | Cream |
| Siaya # 41-2 | 37.55$^{zbdycae}$ | 12.08$^{vw}$ | 25.47$^{quwrtsv}$ | 7.02$^{tsrvwqu}$ | 43.22$^{no}$ | 88.93$^{vw}$ | 90.$^{17rs}$ | Red |
| IS 8193 | 37.35$^{zbdycae}$ | 17.10$^{pgqorhkijnlfm}$ | 20.24$^{xuwyv}$ | 10.53$^{dcefg}$ | 55.91$^{jk}$ | 93.53$^{ut}$ | 94.83$^{fngjhoimkl}$ | Red |
| IESV 92033 SH | 36.81$^{zbdcae}$ | 18.09$^{gdhkiejnlfm}$ | 18.72$^{xwyv}$ | 9.11$^{jilhmknog}$ | 8.61$^{edc}$ | 97.13$^{fmgihnjklpo}$ | 96.17$^{fcgjhdibkel}$ | White |
| IESV 92037 SH | 36.09$^{bdcae}$ | 14.83$^{puqorvwsntm}$ | 21.26$^{xuwtv}$ | 6.61$^{tsyvwxu}$ | 24.48$^{tu}$ | 90.13$^{v}$ | 93.33$^{nqompl}$ | Brown |
| IESV 92001 DL | 35.82$^{bdcae}$ | 21.27$^{dbc}$ | 14.55$^{xyz}$ | 13.89$^{a}$ | 13.51$^{zyab}$ | 87.73$^{w}$ | 76.33$^{u}$ | White |
| SP 993442-1 | 34.04$^{bdfce}$ | 14.57$^{puqorvwsnt}$ | 19.48$^{xuw}$ | 9.26$^{jilhmknfg}$ | 6.88$^{e}$ | 95.20$^{qrstp}$ | 94.50$^{ngjhoimkpl}$ | Cream |
| Siaya #27-3 | 33.67$^{dfce}$ | 14.22$^{puqorvwst}$ | 19.44$^{xuwyv}$ | 9.05$^{jilhmknog}$ | 39.47$^{pqo}$ | 97.60$^{fmgihdjkle}$ | 96.33$^{fcgjhdibke}$ | Red |
| IESV 91104 DL | 32.20$^{dfge}$ | 13.95$^{puqrvwst}$ | 18.25$^{xwy}$ | 10.88$^{dcef}$ | 9.19$^{edc}$ | 96.93$^{fmgihnjklpo}$ | 92.17$^{rqop}$ | White |
| IESV 94025 SH | 30.87$^{fge}$ | 21.27$^{dbc}$ | 9.61$^{z}$ | 12.05$^{cb}$ | 27.65$^{trs}$ | 97.00$^{fmgihnjklpo}$ | 94.83$^{fngjhoimkl}$ | Brown |
| IESV 92041/1 SH | 27.05$^{fg}$ | 15.23$^{puqorvksnltm}$ | 11.82$^{yz}$ | 8.29$^{jslrmknopq}$ | 38.90$^{pq}$ | 96.60$^{qmgihnjklpo}$ | 93.67$^{njomkpl}$ | Brown |
| Busia # 21 | 26.92$^{fg}$ | 17.61$^{gohkiejnlfm}$ | 9.31$^{z}$ | 11.80$^{dcb}$ | 66.30$^{fde}$ | 97.33$^{fmgihnjkleo}$ | 94.50$^{ngjhoimkpl}$ | Brown |
| IESV 92043 DL | 25.55$^{g}$ | 13.36$^{uvwst}$ | 12.18$^{yz}$ | 10.83$^{dcef}$ | 14.66$^{zyax}$ | 97.87$^{fcgihdjbe}$ | 93.83$^{njomkpl}$ | White |

Means with the same letter in the column are not significantly different.

62%, their suitability could have been limited by other quality parameters. It appears that though a high level of starch is desirable, other attributes have to be considered. For instance, starch showed a positive significant relationship with tannins (Table 4). This means that the higher the starch content the higher the undesirable tannins contents in most of the sorghum accessions, and this is one of the limiting factors. However hybrids had less starch contents and also exhibited low tannin contents compared to open pollinated sorghums. Industrial brewing involves the diges-

**Table 4.** Pearson's correlation coefficient results for 131 sorghum accessions.

| Parameter | Starch | Amylose | Amylopectin | Protein | Tannin | Germination energy | Germination capacity |
|---|---|---|---|---|---|---|---|
| Starch | 1.00 | 0.03$^{ns}$ | 0.96* | - 0.37* | 0.26* | - 0.12$^{ns}$ | - 0.15* |
| Amylose | | 1.00 | - 0.24* | 0.17 * | - 0.10* | - 0.05$^{ns}$ | - 0.06* |
| Amylopectin | | | 1.00 | - 0.41* | 0.28* | - 0.10* | - 0.12$^{ns}$ |
| Protein | | | | 1.00 | - 0.37* | - 0.01$^{ns}$ | 0.01$^{ns}$ |
| Tannins | | | | | 1.00 | - 0.15 $^{ns}$ | - 0.19* |
| Germination energy | | | | | | 1.00 | 0.78 * |
| Germination capacity | | | | | | | 1.00 |

*Significant at $P_{0.05}$; N, 135; NS, non-significant at $P_{0.05}$

tion of starch by amylase enzymes to glucose units followed by fermentation to produce alcohol. The amount and ratio of amylose and amylopectin influence the digestibility of starch. Generally, amylopectin contents of sorghum are higher than their amylose amounts with a few exceptions. The hydrolysis of starch is influenced by the amylose chain length (Copeland et al., 2009; Putseys et al., 2010). The higher the amylose content the better the hydrolysis. This is because unlike amylopectin, amylose is broken down completely to glucose molecules by the α amylase enzyme, because it is not branched with α - 1 - 6 glycosidic bond like amylopectin. However, the mashing process could retard starch hydrolysis since glucose molecules re-associate immediately when the mash is allowed to cool (Dicko et al., 2006a). The degree of re-association after mashing is related to the quantity of amylase; amylose re-associates faster hence will negatively affect the intended starch hydrolysis. Besides amylase enzymes, breakdown temperature referred to as gelatinization temperature hastens starch digestion and ideal range differ with source of starch. Barley starch has low breakdown temperature of 60 to 65°C compared to sorghum starch which is 80°C and above (Palmer, 1989). Hence high temperatures are needed to breakdown sorghum starch to its disaccharides. Sorghum accessions SDSA 1X ICSR 43 and SP 993520-1 were considered good for brewing as they had less amylose (15.36 and 13.52%) and more amylopectin (46.83 and 48.75%). The barley accessions had an amylopectin mean of 54.4%, which was generally higher than that of sorghum collections, though some open pollinated accessions had amylopectin levels comparable to barley. There was a weak negative correlation (r = -0.24, p≤ 0.05) between amylose and amylopectin. Correlation studies between starch and amylopectin had strong positive relationship (r = 0.96, p≤ 0.05) compared to that of starch and amylase (r = 0.03, p≥ 0.05). This suggests that there is a genetic association between the two parameters, as starch increase, the amylopectin content of the genotypes also increases.

Protein content as an attribute influencing the choice of desirable sorghum was evident. Protein is a source of peptides and amino acids following the breakdown by proteolytic enzymes (Jones, 2005a, b). The amino acids are essential because they act as a source of energy for yeasts during fermentation stage of brewing. Despite proteins playing a significant role, they are needed in optimal amounts. High protein content has been related with beer haze (Curioni et al., 1995), and foam formation (Perrocheau et al., 2005). Too much protein has negative effects on the availability of carbohydrates including starch and its derivatives, the amylose and amylopectin (Peltonen et al., 1994; Fox et al., 2002). The unavailability of carbohydrates is attributed to the starch granules being covered by a protein matrix that is rigid (Gupta et al., 2010). Proteins also cause exogenous interaction with polyphenols, phytates, and cell wall components (Duodu et al., 2003).

Proteins can also bond with themselves through disulfide mediated polymeri-zation among beta and gamma kaffirins found on the protein body periphery during cooking (Oria et al., 1995). Hence relatively high amount of protein in sorghum grain is not suitable. The selected accessions SDSA 1X ICSR 43 and SP 993520-1 had proteins amounts of 7.57 and 5.80%, respectively, and this compared favorably well with barley whose range is 7.7 to 9.8%. This suggests that protein content in sorghum grain to be used for malting and brewing would be ideal in a range between 5 to 10%. In this study, correlation studies showed a nega-tive correlation between proteins and starch (r = - 0.374) (p≤ 0.05). Amylopectin also exhibited a negative corre-lation of (r = - 0.41, p≤ 0.05) while amylose had a positive correlation of (r = + 0.41, p≤ 0.05) with the proteins. Most accessions with high proteins exhibited lower levels of amylopectin and high amylose amounts. Genotypes with high starch contents had low protein content and this might be attributed to the negative effects of the proteins on the availability of starch. Further, there was a weak negative correlation (r = -0.37, p = ≤ 0.05) between proteins and tannins contents. This might be attributed to the negative effects of the tannins on proteins as observed by Ambula et al. (2003) and hence the negative correlation observed among the sorghum accessions.

Sorghum grains are largely associated with tannins, which are considered undesirable in the brewing process.

Tannins bind to and thus reduce digestibility of proteins, carbohydrates and mineral nutrients (Dicko et al., 2005). The mechanism by which tannins in sorghum reduce the nutritive value is by binding to food proteins (Hagerman and Butler, 1981) and carbohydrates (Naczk and Shahidi, 1997) leading to insoluble complexes which cannot be broken down by digestive enzymes. The activities of alpha amylase are also inhibited by the presence of tannins (Alonso et al., 2000) and this lowers hydrolysis of starch which is essential for brewing. Unlike the hybrids, the majority of the open pollinated accessions apparently contain moderate to high tannin contents (Tables 3 and 4) and this poses a challenge during brewing. SDSA 1 X ICSR 43 and SP 993520-1 had tannin levels of 14.03 and 18 mg/100 ml, respectively, compared to barley that had tannin contents range of 8.9 to 10.3 mg/100 ml. These tannin levels are low and therefore considered appropriate levels during malting and brewing. This suggests that a good sorghum grain for brewing should have low tannin levels of ≤ 18.13 mg/100 ml. Tannin showed a positive correlation of ($r = + 0.28$, $p \leq 0.05$) and ($r = + 0.26$, $p \leq 0.05$) against amylopectin and starch, while tannins had a weak negative correlation ($r = -0.10$, $p \leq 0.05$) with amylose. The higher the starch and amylopectin content, the higher the tannin contents in most of the genotypes, and the lower the amylose content. Despite most of the sorghums having high starch content, they were limited by their high tannin amounts. During malting, tannins amount are reduced and this may be attributed to their leaching into the sorghum grain (Capanzana and malleshi, 1989). When steeping, seed coat permeability changes may be greater and rapid, hence allowing tannin molecules to penetrate with the imbibed water (Price et al*.,* 1978) reducing the tannin content of the grain. This study has revealed that sorghum hybrids which were mostly white or cream in color had low tannin contents compared to the open pollinated genotypes (mostly red or brown in color). This observation corroborates that of Ochanda et al*.* (2010) who showed that, red sorghums contain higher levels of condensed tannins compared to white sorghums. Most of the genotypes with high tannin contents were either red or brown, with the exceptions of Nyondok, Nyang-jang, IESV 92036 SH which are white/cream coloured accessions. However, some red/brown colored genotypes, had low tannin levels than the white/cream colored grains which may indicate that pericarp color is not a reliable indicator of tannins content in sorghums as stated by Dykes and Rooney (2005).

The selected sorghum accessions had germination energy and capacity of above > 95%. SDSA 1 X ICSR 43 and SP 993520-1 had germination energy and germination capacity of 97.2 and 97.8% and 96.5 and 96.2%, respectively. Germination is induced by the rehydration of the seed grain which increases respiration and metabolic activities. This induces the synthesis of hydrolytic enzymes, proteins and starch degrading enzymes (Limami et al*.,* 2002). To determine whether sorghum genotypes are good for malting and brewing, germination tests have to be conducted. Good germination qualities translate to good quality malt and beer properties. Most of the sorghum accessions with high tannin contents had low germination capacity. This may be due to the negative effects of tannins on the germination enzymes during the germination processes. This is confirmed by the observed negative correlation between germination energy and tannin content ($r = -0.15$, $p \leq 0.05$), germination capacity and tannin content ($r = -0.19$, $p \geq 0.05$) of sorghum accessions. This might explain the general low germination capacity mean range compared to the germination energy.

## Conclusion

Sorghum with desirable attributes for malting and brewing are available. The desirable biochemical qualities in sorghum grain for malting and brewing are starch contents ≥ 60%, protein contents of 5 to 10%, tannin contents of less than 18 mg/100 ml and germination energy and capacity of ≥ 95%.. The sorghum accessions SDSA 1 X ICSR 43 and SP 993520-1 had good biochemical qualities for malting and brewing according to this study.

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