academicJournals

Vol. 9(5), pp. 326-333, May, 2015
DOI: 10.5897/AJFS2015.1288
Article Number: F31181253093
ISSN 1996-0794

http://www.academicjournals.org/AJFS

African Journal of Food Science

Full Length Research Paper

Nutritional suitability of bred sorghum (*Sorghum bicolor*) accessions from East Africa

Kiprotich Felix[1]*, Mwendia M. Charles[1], Cheruiyot K. Erick[3] and Wachira N. Francis[2]

[1]Biochemistry and Molecular Biology Department, Egerton University, P.O. Box 563-20115, Egerton, Kenya.
[2]Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) P.O. Box 765, Entebbe, Uganda.
[3]Department of Crops, Horticulture and Soil, Egerton University, P.O. Box 536-20115, Egerton, Kenya.

Received 18 February, 2015; Accepted 13 March, 2015

In many semi-arid and tropical areas of the world especially in sub Saharan Africa, sorghum is a staple food grain and has great potential to be used in various industries. Thirty sorghum highland and open pollinated varieties were analysed for their biochemical and physiological characteristic to determine their industrial suitability and breeding impacts. The results show that sorghum varieties have the capability to be used for different industries and can be good alternatives to other cereal varieties. Majority of the varieties like *Ainamoi #1, Siaya # 24-2, Kipkelion # 2, Kipkelion # 1, Nyangezi, Uasin Gishu #1* and *Uasin Gishu #2* with high starch and amylopectin contents also recorded high tannin contents and vice versa. Hybrids are bred to give low tannins, but unfortunately this also affects their starch amounts and in the long run, decreases the suitability of sorghum for industrial and domestic use. In addition, there was a significant correlation between yielding ability and plant height.

Key words: Breeding, industrial suitability, biochemical characteristics.

INTRODUCTION

Sorghum, *Sorghum bicolour,* is the fifth most important cereal crop after rice, wheat, maize and barley (Smith and Frederiksen, 2000; FAO, 2005), and it contributes significantly to the protein and energy requirements of millions of people, especially the poor in Africa and Asia (Elkhier and Hamid, 2008). Sorghum has the potential to drive economic development in Africa. In developing countries, the commercial processing of these locally grown sorghum grains into value-added food and beverage products is an important driver for economic development (Taylor, 2004). Subsistence farmers in Africa cultivate sorghum widely as a staple food for home consumption. In particular, sorghum is mainly important for people in sub-Saharan Africa as a food crop because it is adapted to a wide range of ecological conditions and can tolerate adverse conditions such as hot, dry, wet and water logged conditions. It can also adapt to poor fertility and high salinity soils (FAO, 2012).

Sorghum grain is an important staple food in developing countries of the semi-arid tropics and is also used as an animal feed in both developed and developing countries. The use of sorghum not only

*Corresponding author. E-mail: kiprotichfelix@yahoo.com.

provides farmers with incomes after marketing their products but also saves foreign exchange, which would otherwise be required to import cereals. More than 35% of sorghum is grown primarily for human consumption, while the rest is used for feeding animals, brewing alcohol among other uses (Amir et al., 2009). Cereal grains like sorghum can constitute major energy sources and starch as raw materials for several end uses such as in baking, brewing, poultry and livestock industries. Despite this, maize, wheat and barley still remains the primary energy source in these industries. Ajaja et al. (2002) stated that maize is still the main energy source in compounded diets and constitutes about 50% of poultry ration. Like other cereals, starch is the principal storage form of carbohydrate and sorghum has an average starch content of 69.5% (Jambunathan and Subramanian, 1987). High fiber content and poor digestibility of nutrients are characteristic features of sorghum grains, which severely influences its consumer acceptability. Proteins form the second major component of sorghum grains. The protein content of sorghum is affected by both genetic and environmental factors (Arun et al., 2009).

Phenolic compounds in cereal grains encompass a diverse group of secondary plant metabolites. They can be conveniently divided broadly into phenolic acids, flavanols, polymeric flavanols and condensed tannins. Tannins bind proteins, carbohydrates and minerals, thereby affecting the nutritional and functional value of the bound constituents. Sorghum varieties rich in tannins are recommended for obese individuals and diabetic patients. Animal studies observed a 50% weight loss when fed with sorghum containing high tannin levels (Ambula et al., 2001). This is because they have a longer emptying time in the stomach (Awika and Rooney, 2004). The low digestibility of high tannin sorghums is due to the inhibition of hydrolytic enzymes and their potent antioxidant activities (Dicko et al., 2005) may be interesting from a nutritional standpoint for obese persons.

Anthocyanins are nowadays regarded as an important nutraceuticals mainly due to their possible antioxidant effects. They have a potential therapeutic role related to some cardiovascular diseases, cancer treatment, inhibition of certain types of virus including human immunodeficiency virus type 1 (HIV-1) and improvement of visual acuity (Stintzing et al., 2002; Sandvik, 2004; Talavera et al., 2006; Beattie et al., 2005). Mild levels of reactive oxygen species (ROS) in food have been shown to induce proliferation of cancer cells (Arora et al., 1999; Del Bello et al., 1999). Therefore, foods rich in antioxidant phytochemicals are important for the prevention of diseases related to oxidative stress such as heart disease and cancer.

Sorghum hybrids have contributed significantly to increased grain and forage yields in several countries. A large number of hybrids have been developed and released for commercial cultivation in East Africa. Achievements in sorghum breeding in Africa have mainly been in the development and release of improved varieties based on higher grain yield and resistance to diseases, insect pests and Striga (Obilana, 2004). Little focus has been put on improving the nutritional aspects of cereal grains.

In plant breeding traits such as yielding ability and quality should be the fundamental objectives. However before a new cultivar is released to farmers, it is important that its nutritional quality is properly evaluated for their biochemical characteristics. Therefore, to screen varieties for consumer acceptability, simplified laboratory tests, applicable to a very large number of samples are required. The objective of this study was to determine biochemical and physiological characteristics of sorghum grain that lead to food and nutritional security.

MATERIALS AND METHODS

Sample preparation

Thirty (30) sorghum materials used in the study were obtained from the East African region. The mid lowland sorghum were grown in Kampi Ya Moto (035°. 56' E and 00°. 05' S) at an altitude of 1660 m a s l while the highland sorghum were grown at Egerton University at an altitude of 2,250 m a s l . Both sorghum materials were sown in a randomized complete blocking design and replicated 3 times during the April – August season 2013. The grain from two middle rows in each experimental unit was harvested, dried, threshed and used for subsequent laboratory and industrial tests (Table 1).

Determination of protein content

Total nitrogen and protein was determined using Kjeldahl method (AOAC, 1999). Sorghum grain was finely milled after which 0.1 g was weighed and transferred into a digestion tube. Selenium catalyst mixture weighing 1 g was mixed with the sample and 5 ml of sulphuric acid (96%) was added into the tube. The tubes were then heated cautiously in the digestion apparatus, 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 upto 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 was then transferred into the apparatus; 10 ml of 46% sodium hydroxide was added and then rinsed again with distilled water. Colour changed from pink to green when the first distillation drops reached the boric acid indicator solution. A total of 150 ml of the distillate was collected and was titrated with 0.0174 N sulphuric acids. Total nitrogen (N) was then determined as follows:

$$N\ (\%) = \left\{ \frac{a \times N \times M_w \times 100}{b \times c} \right\} \times 100\%$$

Where a = ml of sulphuric acid used for titration of the sample; N = normality of sulphuric acid (0.0174); a = titer volume (10 ml); Mw = molecular weight of N_2 (0.014); c = ml digest taken for distillation (10 ml); b = g sample taken for analysis (0.1 g); % crude protein = 6.25 × % N.

Table 1. A list of the selected sorghum varieties used in the study.

Code	Variety	Code	Variety	Code	Variety
1	Ainamoi #1	11	IS 25547	21	ICSA 276 X ICSR 162
2	Siaya # 24-2	12	SDSH 90003	22	1S 25546
3	Kipkelion # 2	13	Uasin Gishu #1	23	IESH 22012
4	Nyiragikori	14	1S 25561	24	ICSA 12 X WAHI
5	Kipkelion # 1	15	Uasin Gishu #2	25	SDSA 29 X KARI MTAMA 1
6	MB 27	16	IESH 22006	26	IESV 92033 SH
7	Kabamba	17	Gadam Hamam	27	IESV 91104 DL
8	Nyangezi	18	ICSA 276 X ICSR 38	28	ICSA 371 X ICSR 108
9	BM 32	19	Kisanana	29	Busia # 21
10	1S 11162	20	Siaya # 2-3	30	IESV 92043 DL

Determination of starch content

Percent starch content was estimated by the Anthrone method (Hodge and Hofreiter, 1962). A powdered sample (0.25 g) was homogenized in hot 80% 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. Of this supernatant, 0.1 ml was pipetted out and topped to the 1 ml mark 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. To this, 4 ml of anthrone reagent was then added to each tube and sample heated for eight minutes in a boiling water bath. 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

Amylose was determined using the Mc Cready et al., (1950) method where a sample (0.1 g) of the powdered flour 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. To a 2.5 ml extract, 20 ml of distilled water was added followed by three drops of 0.1% phenolphthalein. Dropwise HCl 0.1 N was then added until the pink colour disappeared. To this solution, 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. The blank was obtained by diluting 1 ml of iodine reagent to 50 ml with distilled water. Amylose content was obtained thus:

$$\text{Amylose (\%)} = \left(\frac{x}{2.5} \right) \times 100 \text{ mg amylose}$$

Where, x is the absorbance obtained. The amylopectin content was obtained thus: Starch (%) - amylose (%).

Determination of tannin content

A sample of (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. A measure of 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. Tannins content was determined by the Folin-Denis method (Schanderl, 1970).

Determination of height and yielding ability

The height of the mature sorghum varieties was determined in centimeters by getting the average of three plants in each plot of each variety in every treatment, then the average of each plot in the three treatments.

The yielding ability of sorghum varieties was determined in grams by getting the average yielding ability of three plants in each plot of each variety in every treatment, then the average yield of each plot in the three treatments.

Data analysis

Data obtained from this study was statistically analyzed using one way analysis of variance (ANOVA) with JMP 10.0.0 Software, 2012 SAS Institute Inc. Turkey's test was used to find the difference among the means. Pearson's correlation analysis was also carried out to determine the relationship between biochemical parameters at $p \leq 0.05$ and 0.001

RESULTS

The starch content of dry seed weight of the genotypes ranged from 25.5 to 81.1% with a mean of 52.2% while amylose and amylopectin ranged from was 12.3 to 26.7%

and 6.6 to 59.8% with means of 12.3 and 6.7%, respectively. Proteins ranged from 3.1 to 18.1% with a mean of 9.8%. The tannin content ranged from 2.5 to 100.0 mg/100 g with a mean of 35.5 mg/100 g. Yield values were 8570 to 863.6 kg/ha with a mean of 3879.0 kg/ha while height ranged from 341.5 to 97.0 cm with a mean of 198.4 cm.

There was a statistically significant correlation between starch and amylopectin (0.97, $p \leq 0.001$) while starch and protein had a negative significant correlation (-0.55, $p \leq 0.001$). The correlation between starch and tannins was 0.49, $p \leq 0.05$, whilst starch and height had a correlation of 0.47, $p \leq 0.05$. Other significant correlation includes amylopectin and proteins (- 0.58, $p \leq 0.001$), tannins and height (0.47, $p \leq 0.05$); 0.52, $p \leq 0.05$. Protein and tannin contents had a negative correlation of – 0.52, $p \leq 0.05$ whereas protein and height had a correlation of –0.46, $p \leq 0.05$. The yielding ability and height has a positive significant correlation of 0.64, ≤ 0.001.

Hierarchical clustering (method = ward)

Cluster 4 varieties had high starch and high tannins contents and also had high amylopectin as compared to their respective amylose amounts (Figure 2). They also had medium height, yield and good protein amounts. On the other hand, cluster 3 varieties had medium starch, height and good protein amounts. They exhibited high amylopectin as compared to their respective amylose high yields and tannins.

Cluster 2 varieties had high amylopectin as compared to their respective amylose amounts, medium starch, height and average protein contents lower than cluster 1 and 2. They possess the highest yields and height as compared to the rest of the clusters. Cluster 1 varieties had the lowest starch, tannins and height as compared to other clusters. Most varieties with lower amylopectin to amylose ratio are in this cluster. They registered highest proteins and are mostly the hybrids while the yields of the varieties varied. These clusters are useful when identifying the varieties that are favourable for different end uses.

DISCUSSION

The varieties used in this study were both hybrids and open pollinated and they portrayed a wide range of nutritive contents (Table 2). Starch is the main component of sorghum grains (BSTID-NRC, 1996) as evident, thus this makes it favorable to be explored for different industries. This study has demonstrated that sorghum varieties possess biochemical characteristics that can match up to other cereals thus should be considered as alternative to these industries. Sorghum with starch as high as 70% *Ainamoi, kipkelion, Siaya* 24-2 (Figure 1 and Figure 2, Cluster 4) is a reliable source of energy that can be explored by many industries. In terms of nutritive value, cost and availability sorghum grains are probably the next best alternative to maize in poultry feed as reported by Lepleaideur (2004). As per this study, most of the varieties with good starch contents are open pollinated while the hybrids showed moderate to low levels of starch (Table 2). Normally, hybrids are improved varieties thus expected to have good starch amounts but this was not the case as shown in Table 2. More needs to be done to improve the starch contents of these hybrids if they are to be accepted in these industries.

Apart from the high starch content, the ratio of amylose to amylopectin is vital for the baking and brewing industries because it affects the quality of the end products. Generally, the amylopectin are higher than their respective amylose contents in sorghum. This study demonstrated some exceptions (Table 2 and Figure 2, Cluster 1) like *IESV 92033 SH, SDSA 29 X KARI MTAMA 1, ICSR 276 X ICSR 38* and *Kisanana*. These exceptions are favourable for the baking industry because high amylose gives stabilization to bread quality as stated by Taylor et al. (2006). Sorghum alone cannot be used for baking due to its lack of gluten, but addition of 20 to 50% sorghum flour to wheat flour results to good quality bread (Hugo et al., 2003). Sorghum is a good candidate for the brewing industry and has been adopted by the East African industry to some extent. This is because of lack of specific varieties that are tailored for this industry. The amylose to amylopectin ratio in this study was 1:2, and this is lower than the 1:3 ratio reported by Taylor et al. (2006). On the other hand, varieties favourable for brewing ought to have more amylopectin than amylose contents because Sharma et al. (2008) reported that high amylose affects starch digestibility. As per this study, most varieties suitable for brewing were mostly the hybrids.

The protein contents of sorghum varieties ranged from 3 - 18% and this was similar to 6 – 18% reported by Lasztity (1999). Varieties *ICSA 12 X WAHI* and *SDSA 29 X KARI MTAMA 1* had notably high protein contents (Table 2). These varieties would be good for animal and human foods, thus boost food security. The wide variety of sorghum protein gives it an advantage to be utilized for different uses depending on the protein requirements of that industry. The brewing and baking industry needs varieties with moderate proteins while animal and human feeds needs maximum proteins, and sorghum offer a wide choice. All the hybrids recorded high protein value unlike the open pollinated varieties. This can be attributed to sorghum breeding efforts as originally sorghum was more subsistence than industrial. Sorghum protein is gluten free and this is safe to be used by celiac patients (Ciacci et al., 2007) and high proteins means high food quality. This gives a good alternative to wheat flour due to their neutral flavor and the hybrids with white pericarp (Normell et al., 2010).

Table 2. ANOVA output of biochemical and physiological traits of sorghum accessions.

Genotype	Starch (%)	Amylose (%)	Amylopectin (%)	Protein (%)	Tannins mg/100 (g)	Yielding ability (kg/ha)	Height (cm)
Ainamoi #1	81.1^{a}	22.2^{abc}	58.9^{a}	7.8^{efgh}	79.8^{b}	3362.2^{cdef}	241.5^{de}
Siaya # 24-2	76.4^{ab}	19.4^{bcde}	56.9^{ab}	9.5^{def}	41.7^{g}	3245.5^{cdef}	125.0^{jk}
Kipkelion # 2	76.0^{ab}	16.2^{cdef}	59.8^{a}	7.4^{fgh}	58.7^{f}	3617.9^{bcdef}	209.2^{efg}
Nyiragikori	75.2^{ab}	18.2^{cdef}	56.9^{ab}	8.2^{efgh}	15.5^{kl}	3014.5^{def}	260.4^{cd}
Kipkelion # 1	71.6^{abc}	19.1^{bcdef}	52.5^{abc}	5.2^{hi}	59.9^{ef}	2263.1^{ef}	233.5^{de}
MB 27	68.9^{abcd}	14.0^{def}	54.9^{abc}	3.1^{i}	18.9^{kl}	6975.4^{abcd}	218.0^{def}
Kabamba	68.9^{abcd}	12.3^{f}	56.5^{ab}	6.9^{fgh}	100.0^{a}	1591.3^{f}	226.2^{de}
Nyangezi	64.4^{bdce}	17.1^{cdef}	47.2^{abcde}	8.7^{defg}	69.1^{cd}	3045.5^{def}	290.1^{bc}
BM 32	62.7^{bcdef}	18.1^{cdef}	44.5^{abcdef}	8.1^{efgh}	33.1^{h}	7460.9^{abc}	306.7^{abc}
1S 11162	61.7^{bcdefg}	13.4^{ef}	48.2^{abcd}	8.6^{defg}	35.1^{h}	7909.5^{ab}	341.5^{a}
IS 25547	57.4^{cdefgh}	16.1^{cdef}	41.3^{bcdefg}	5.9^{ghi}	42.3^{g}	6459.3^{abcde}	317.7^{ab}
SDSH 90003 (H)	57.0^{cdefgh}	18.6^{cdef}	38.3^{cdefgh}	7.9^{efgh}	24.4^{ij}	4777.3^{abcdef}	124.8^{ijk}
Uasin Gishu #1	55.2^{defghi}	21.5^{abc}	33.6^{defghi}	5.8^{hi}	65.1^{de}	3253.8^{cdef}	173.1^{fghi}
1S 25561	54.5^{defghij}	15.4^{cdef}	39.0^{cdefgh}	11.8^{cd}	44.6^{g}	4972.6^{abcdef}	305.8^{abc}
Uasin Gishu #2	51.6^{efghijk}	18.3^{cdef}	33.2^{defghi}	8.7^{defg}	73.7^{g}	3382.1^{cdef}	204.3^{efg}
IESH 22006 (H)	48.7^{fghijk}	18.4^{cdef}	30.2^{efghi}	13.4^{bc}	9.4^{mno}	5020.7^{abcdef}	139.0^{hijk}
Gadam Hamam	47.4^{ghijk}	16.5^{cdef}	30.9^{efghi}	10.9^{cde}	26.2^{i}	863.6^{f}	97.0^{k}
ICSA 276 X ICSR 38 (H)	44.6^{hijkl}	25.5^{ab}	19.0^{ijkl}	15.6^{ab}	13.8^{lmn}	2872.3^{def}	131.2^{hijk}
Kisanana	44.5^{hijkl}	26.7^{a}	17.7^{ijkl}	7.2^{fgh}	68.3^{d}	3186.2^{cdef}	155.6^{hij}
Siaya # 2-3	43.4^{hijkl}	13.8^{def}	29.6^{fghi}	5.1^{hi}	19.5^{jk}	4151.4^{bcdef}	203.8^{efg}
ICSA 276 X ICSR 162 (H)	43.4^{hijkl}	18.5^{cdef}	24.8^{ghijk}	11.8^{cd}	6.3^{op}	4323.2^{abcdef}	176.6^{fgh}
1S 25546	41.9^{ijklm}	14.2^{def}	27.6^{fghij}	7.1^{fgh}	36.0^{h}	8570.1^{a}	300.7^{abc}
IESH 22012 (H)	41.6^{ijklm}	15.7^{cdef}	25.9^{ghijk}	16.8^{a}	9.7^{mno}	2738.1^{def}	127.4^{ijk}
ICSA 12 X WAHI (H)	40.1^{jklmn}	17.6^{cdef}	22.4^{hijkl}	18.1^{a}	7.7^{op}	1245.4^{f}	134.7^{hijk}
SDSA 29 X KARI MTAMA 1(H)	38.4^{klmn}	21.7^{abc}	16.6^{ijkl}	18.0^{a}	2.5^{p}	3888.2^{bcdef}	173.6^{fghi}
IESV 92033 SH	36.8^{klmn}	18.0^{cdef}	18.7^{ijkl}	9.1d^{efg}	8.6^{no}	3448.2^{cdef}	163.4^{ghij}
IESV 91104 DL	32.1^{lmn}	13.9^{def}	18.2^{ijkl}	10.8^{cde}	9.1^{no}	2095.3^{ef}	154.0^{hij}
ICSA 371 X ICSR 108 (H)	27.0^{mn}	20.4^{abcd}	6.6^{l}	16.0^{ab}	4.5^{op}	2915.8^{def}	147.2^{hij}
Busia # 21	26.9^{mn}	17.6^{cdef}	9.3^{jkl}	11.8^{cd}	66.2^{d}	2869.8^{def}	121.0^{jk}
IESV 92043 DL	25.5^{n}	13.3^{ef}	12.1^{jkl}	10.8^{cde}	14.6^{klm}	2849.5^{def}	146.5^{hij}
Standard Error (SE)	2.69	1.22	3.08	0.58	0.96	785.5	8.42

Means with the same letter are not significantly different, H– hybrids.

Sorghum grains are characterized by their high content of condensed tannins which limits their suitability for several end users. Tannins are considered undesirable due to their capacity to bind proteins making them less digestive, and also producing astringent taste (Ambula et al., 2003). Sorghum genotypes with low tannin contents have been produced due to plant breeding efforts and this is evident in the hybrids varieties *ICSA 12 X WAHI, SDSA 29 X KARI MTAMA 1*, *ICSV 92033 SH* and *IESV 91104 DL* (Table 2 and Figure 2, Cluster 1). The open pollinated varieties on the other hand had considerably high tannin contents (Figure 2, Cluster 4). Low tannin content sorghum especially the hybrids are favorable for poultry feeding due to their proteins and carbohydrate contents. This is because high tannic acid varieties are not good for monogastrics feed as reported by Smithhard (2002). He also observed that when monogastrics were fed with high tannic sorghum based diet, there was a general poor performance due to the binding effect of tannins to digestive enzymes. However, when used in conjunction with maize, these effects were minimized. Thus moderate to low tannin sorghum can be used to supplement the poultry industry in an effort to reduce overdependence on maize.

Legumes like lucerne and clovers contain saponins and on fermentation release vast quantities of soluble proteins this is because these legumes lack tannins and this result to bloat in livestock (Jansman, 1993). According to Jones et al. (1973), this can be minimized by using high tannin sorghum that have been shown to posses the ability to control bloat. It has also been reported that after the digestion of tannin foods, the

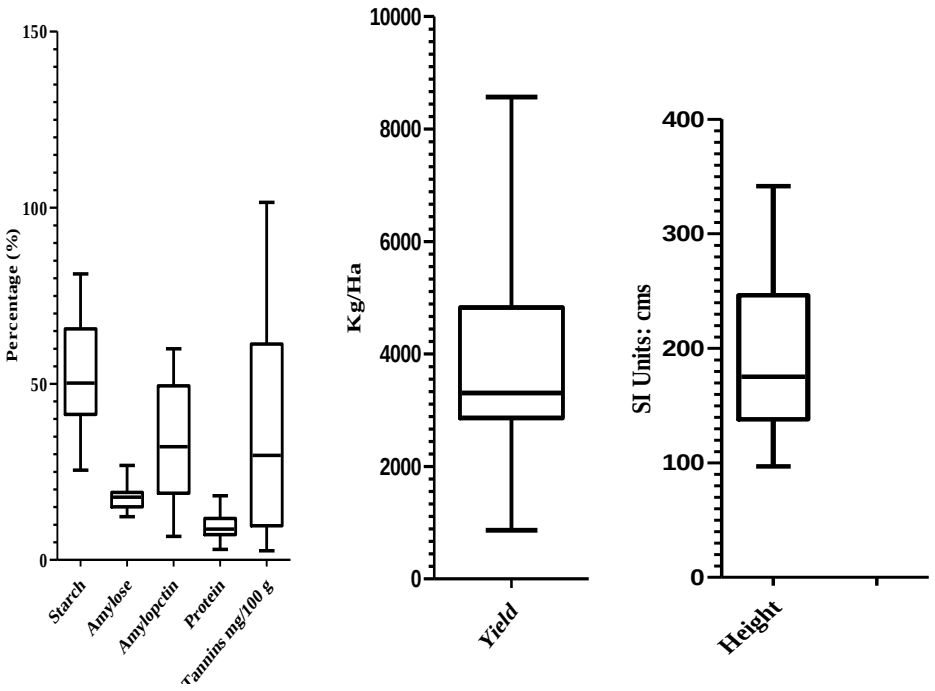

Figure 1. Biochemical and physiological traits of 30 sorghum varieties showing their ranges and means.

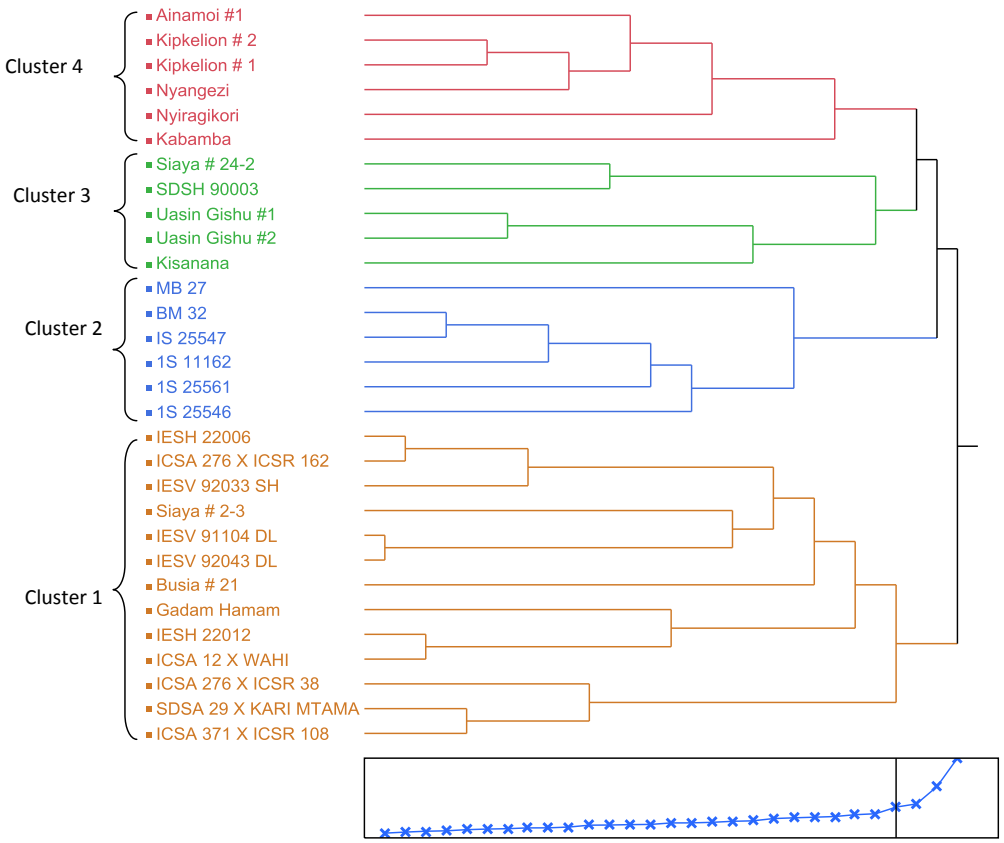

Figure 2. Dendrogram of 30 sorghum varieties shown by ward cluster analysis based on biochemical and morphological data set.

Table 3. Pearson's correlation coefficient results for 30 sorghum accessions.

N = 30;	Starch	Amylose	Amylopectin	Protein	Tannins	Yield	Height
Starch	1.00	0.003 ns	0.97***	- 0.55***	0.49**	0.16 ns	0.47**
Amylose		1.00	- 0.21ns	0.22 ns	0.05 ns	-02.3 ns	- 0.31
Amylopectin			1.00	- 0.58***	0.47**	0.20 ns	0.52**
Protein				1.00	- 0.52**	- 0.34 ns	- 0.46**
Tannins					1.00	- 0.10 ns	0.31ns
Yield						1.00	0.64***
Height							1.00

N = 30; Significant at**- P ≤ 0.05, ***-0.001; NS – non significant at P ≤ 0.05 and 0.001.

tannin-protein complex formed reacts with gut wall proteins and stimulates growth hormones that in turn increases lipid turnover and nitrogen retention (Muir et al., 1983). The significance is that it protects plant protein degradation in the rumen and this is the advantage of sorghum grain in animal feed. Despite sorghum being undesirable in many industries, animal feed industry can take advantage of the availability of sorghum tannins. The varieties that can be explored as per this study include *Ainamoi, Kipkelion # 1, Nyiragikori, Kipkelion # 2, Kabamba* and *Nyaangezi* (Figure 2, Cluster 4).

Sorghum varieties rich in tannins can be recommended for obese individuals and diabetic patients. According to Ambula et al. (2001) animals fed with sorghum containing high level tannins demonstrated 50% weight loss. This was attributed to their long emptying time of the stomach and their low digestibility through the inhibition of hydrolytic enzymes together with their antioxidant activities (Dicko et al., 2005).

In agronomical point of view, tannins are desirable due to their protection against bird, insect and disease damage (Waniska et al., 2001). According to Bullard and Elvis (1980) the astringent taste of tannins is due to tannin-saliva protein complex in the mucous epithelium of the oral cavity thus decreasing its palatability. This largely contributes among other factors to the high yield in tannin sorghum (Table 2).

Yielding ability is a vital parameter when selecting varieties for different end uses because high yielding varieties are economical both to farmers and the industry. The varieties in this study demonstrated a wide range in yielding ability as shown in Figure 1. This study demonstrated yielding ability as high as 8570 kg/ha with some varieties such as *1S 25546* and 7909.5 kg/ha as in *1S 11162*. Industries that focus greatly on yielding ability can adopt these particular varieties. This is vital because due to climate change wheat and maize production have been greatly affected but sorghum is known to be resilient to harsh climatic conditions and give good yield (Dicko et al., 2006). Plant height is also an important parameter especially for large scale farmers because short varieties reduce the cost of production due to the possibility of mechanization. As shown (Table 2), the hybrid varieties were shorter than the open pollinated varieties with less than 176 cm in length while the open pollinated had height as high as 317 cm *1S 25546* and 341 cm *1S 11162* (Figure 2, Cluster 2). These are the same varieties that registered high yields. Thus, it is important to note that yielding ability positively, significantly correlated with plant height in this study. The consequence is that in the event of trying to reduce height via breeding, might lead to reduction of yielding ability.

Correlation analysis

Most of the varieties with high starch and amylopectin contents also recorded high tannin contents with a few exceptions (Table 2). These correlations suggest a genetic association between the parameters both in the hybrids and the open pollinated varieties. The positive significant correlation between tannins and starch of these varieties is a bad characteristic for breeding since starch is desirable in most end uses unlike tannins (Table 2). On the other hand, the negative correlation between tannins and proteins is a good selection indicator for varieties in sorghum breeding (Table 3). The protein was negatively correlated with starch and amylopectin content which is expected, as protein and starch make the major component in grains. This is evident in Table 2 where *SDSA 29 X KARI MTAMA 1* and *ICSA 12 X WAHI* are hybrids with high protein and low starch and tannin amounts. On the other hand, *kabamba, ainamoi # 1, kipkelion* are open pollinated varieties with high tannins and starch but low protein contents (Table 2). Hybrids are bred to give low tannins but unfortunately this also affects their starch content and in the long run decrease the suitability of sorghum for some industrial uses. There was a significant correlation between yielding ability and plant height, as similar to results of Alhassan et al. (2008). This demonstrates the correlation between plant height and yielding ability and it might be attributed to genotypes with good plant height being able to receive more sunlight for photosynthesis, which translates to more photosynthates resulting to increased yield. Plant height also

showed a significant positive correlation with starch and amylopectin contents. This is due to increased photosynthesis due to height which positively affects the yields.

Cluster analysis

Cluster 4 varieties had high starch and high tannins contents and also had high amylopectin as compared to their respective amylose content (Figure 2). They also had medium height, yielding ability and good protein content. On the other hand, cluster 3 varieties have medium starch, height and good protein content. They exhibited high amylopectin as compared to their respective amylose, high yields and tannins. Cluster 2 varieties had high amylopectin as compared to their respective amylose amounts, medium starch, height and average protein contents lower than cluster 1 and 2. They possess the highest yields and height as compared to the rest of the clusters. Cluster 1 varieties had the lowest starch, tannins and height as compared to other clusters. Most varieties with lower amylopectin to amylose ratio are in this cluster. They registered highest proteins and are mostly the hybrids while the yields of the varieties varied. These clusters are useful when identifying the varieties that are favourable for different end uses.

Conclusion

Success of any food grain or its product depends on acceptance by the consumers. In the process of achieving food production targets, agricultural scientists concentrate their efforts on developing high-yielding varieties giving little importance to other quality characteristics. From the study, we find that proteins and tannins were in high contents among the hybrids and the open pollinated varieties (OPVs) respectively. Most of the hybrids had greater amylose than amylopectin and the vice versa was true for the OPVs. It is clear that breeding programmes that aim to reduce tannin contents also result to lower starch as evident in the hybrid varieties. Plant breeders should put into consideration not only agronomical characteristics but also biochemical characteristics. There is need for further research through biotechnological techniques to identify genes responsible for specific biochemical traits if sorghum and other cereals are to be completely adopted by the huge African market.

Conflict of interests

The authors did not declare any conflict of interest.

REFERENCES

Ajaja K, Agbede JO, Aletor VA (2002). Replacement value of sorghum dust for maize in diets for broiler chicks. Proc 27th Ann. Conf. Nig. Soc. for Anim. Prod. March 17-21, Federal University of Technology, Akure. pp. 109-112.

Alhassan U, Yeye MY, Aba DA, Alabi SO 2008. Correlation and path coefficient analyses for agronomic and malting quality traits in some sorghum (Sorghum bicolor (L.) Moench) genotypes. J. Food Agric. Environ. 6 (3&4):285-288.

Ambula MK, Oduh GW, Tuitoek JK (2003). Effects of high tannins sorghum and bentonite on the performance of laying hens. Trop. Anim. Health Prod. J. 35:285-292.

Ambula MK, Oguho GW, Tuitoek JK (2001). Effects of sorghum tannins,a tannin binder (polyvinylpyrrolidone) and sorghum inclusion level on the performance of broiler chicks. Asian-Austr. J. Anim. Sci. 14:1276-1281.

Amir MA, Muralikrishna G, El Tinay AH, Mustafa AI (2009). Characterisation of Tannins and Study of in vivo Protein Digestibility and Mineral Profile o Sudanese and Indian Sorghum Cultivers. Pak. J. Nutr. 8(4):469-476.

AOAC (1999) Official Methods of Analysis Method 988.05. Chapter. 4, AOAC International Press, Gaithersburg. p 13.

Arora KP, Lucchesi PA, Wurster RD (1999). Proliferation of cultured human astrocytoma cells in response to an oxidant and antioxidant. J. Neurooncol. 44:213-221.

Arun G, Kulamarva A, Venkatesh R, Sosle A, Vijaya Raghavan GS (2009). Nutritional and Rheological Properties of Sorghum. Int. J. Food. Prop. 12 (1): 55-69

Awika JM, Rooney LW (2004) Sorghum phytochemicals and their potential aspects on human health. Phytochemistry 65: 1199 – 1221.

Beattie J, Crozier A, Duthie GG (2005). Potential health benefits of berries. Curr. Nutr. Food Sci. 1: 71- 86.

BSTID-NRC (Board on Science and Technology for International Development-National Research Council) (1996). Lost crops of Africa. Academic Press, Washington DC, pp.127-213.

Bullard RW, Elias DJ (1980). Sorghum polyphenols and bird resistance. In Polyphenols in Cereals and Legumes, [Ed J. Hulse,]. Ottawa: International Development Research Centre. p. 4349.

Ciacci C, Maiuri L, Caporaso N, Bucci C, Del Giudice L, Massardo DR, Pontieri P, Di Fonzo N, Bean SR, Ioerger B, Londei M (2007). Celiac disease: *In vitro* and *in vivo* safety and palatability of wheat-free sorghum food products. J. Clin. Nutr. 26(6):799-805.

Del Bello B, Paolicchi A, Comporti M, Pompella A, Maellaro E (1999). Hydrogen peroxide produced during gamma-glutamyl transpeptidase activity is involved in prevention of apoptosis and maintenance of proliferation in U937 cells. FASEB J. 13:69-79.

Dicko MH, Gruppen H, Traore AS, Van Berkel WJH, Voragen AGJ (2005). Evaluation of the effect of germination on phenolic compounds and antioxidant activities in sorghum varieties. J. Agric. Food. Chem. 53:2581-2588.

Dicko MH, Gruppen H, Traoré AS, Voragen AGJ, Van Berkel WJH (2006). Sorghum grain as human food in Africa: relevance of content of starch and amylase activities. Afr. J. Biotechnol. 5: 384 - 395.

Elkhier MKS, Hamid AO (2008). Effect of malting on the chemical constituents, anti-nutrition factors, and ash composition of two sorghum cultivars (Feterita and Tabat). J. Agric. Biol. Sci. 4(5):500-504.

Food and Agricultural Organization (FAO) (2005). FAOSTAT agricultural database. Available on line http://faostat.fao.org/faostat/.

Food and Agriculture Organization (FAO) (2012). Sorghum bicolor (L.) Moench. In: Grassland Species Profiles Database [online]. www.fao.org/ag/agp/agpc/doc/gbase/ data/pf000319.h tm (accessed 12 March 2015).

Hodge JE, Hofreiter BT (1962). In: Methods in Carbohydrate Chemistry, (Editors. Whistler, R.L. and Be Miller, J.N.), Academic Press, New York.

Hugo LF, Rooney LW, Taylor JRN (2003). Fermented sorghum as a functional ingredient in composite breads. Cereal Chem. 80: 495-499.

Jambunathan R, Subramanian V (1987). Grain quality and utilization of sorghum and pearl millet. In: Biotechnology in tropical crop improvement. Proceedings of the International Biotechnology Workshop, ICRISAT. Patancheru, India.

Jansman AJM (1993). Tannins in feedstuffs for simple- stomached animals. Nutr. Res. Rev. 6:20Y-236.

Jones WT, Anderson L B, Ross MD (1973). Bloat in cattle. Detection of protein precipitants (flavolans) in legumes. N. Z. J. Agric. Res. 16:441-446.
Lasztity R (1999) Cereal chemistry. Akademiai Kiado Budapest, Hungary.
Lepleaideur M (2004). Poultry farming - A disease called competition. In: SPORE Magazine. 114:4-5.
Mc Cready RM, Guggolz J, Siliviera V, Owens HS (1950). Starch. Anal. Chem. 22: 11- 56.
Muir LA, Wien S, Duquette PF, Rickes EL, Cordes EH (1983). Effect of exogenous growth hormone and diethylstilbestrol on growth and carcase composition of growing lambs. J. Anim. Sci. 56:1315-1323.
Normell JM, Sajid A, Scott RB (2010). Sorghum Proteins: The Concentration, Isolation, Modification, and Food Applications of Kafirins. J. Food. Sci. 75:5
Obilana T (2004). In Sorghum genetic enhancement- Research process, dissemination and impacts (Bantilan, M.C.S., Deb UK, Gowda CLL).
Sandvik L (2004). Anthocyanins useful for the treatment of diabetes, cardiovascular disorders and to lower the risk of adverse effects of hormone replacement therapy. PCT Int. Appl. p. 28.
Schanderl SH (1970). In: Method in Food Analysis. Academic Press, New York. p. 709.
Sharma A, Yadav BS, Ritika BS, (2008) Resistant starch: physiological roles and food applications. Food Rev. Int. 24:193-234.
Smith CW, Frederiksen, RA (2000). Sorghum: Origin, history, technology and production, John Wiley and Sons Inc., New York. NY 824, p. 668.
Smithhard R (2002). Secondary Plant Metabolites in Poultry Nutrition. In: Poultry Feedstuff: Supply, Composition and Nutritive Value. Mc Nab JM, Boorman KN (eds.) CAB International, Wallingford, UK, p. 254.
Stintzing FC, Stintzing AS, Carle R, Frei B, Wrolstad RE (2002). Colorand Antioxidant Properties of Cyanidin-Based Anthocyanin Pigments. J. Agric. Food Chem. 50: 6172 - 6181.
Talavera S, Felgines C, Texier O, Besson C, Mazur A, Lamaison JL, Remesy C (2006). Bioavailability of a bilberry anthocyanin extract and its impact on plasma antioxidant capacity in rats. J. Sci. Food Agric. 86:90-97.
Taylor JRN (2004). Grain production and consumption: Africa. In: Wrigley C, Corke H, Walker CE. (Eds.), Encyclopedia of Grain Science. Elsevier, London. pp. 70-78.
Taylor JRN, Schober TJ, Bean SR (2006). Novel food and non-food uses for sorghum and millets. J. Cereal Sci. 44:252-271.
Waniska RD, Venkatesha RT, Chandrashekar A, Krishnaveni S, Bejosano FP, Jeoung J, Jayara J, Muthukrishnan, S, Liang GH (2001). Antifungal proteins and other mechanisms in the control of sorghum stalk rot and grain mold. J. Agric. Food. Chem. 49:4732-4742.