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Original Paper

Diversity Of Physical Grain Quality Traits In Tropical Sorghum Genotypes

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Abstract **-- The current study envisioned to assess the physical traits of sorghum grain for selected sorghum genotypes. Seed for the genotypes was sourced from the Lupane State University Gene Bank and grown during the 2022/23 agricultural season at Lupane State University Farm experimental plots. At maturity, laboratory tests on kernel/grain hardness, 100 kernel weight, bulk density, kernel diameter, colour and determination of presence of tannins through qualitative tests were done for all the 24 sorghum genotypes. Results from analysis of variance demonstrated highly significant differences (P<0.001) on kernel weight, kernel diameter, kernel hardness and grain hardness showing a great diversity of physical traits among all the 22 genotypes and 2 commercial varieties of sorghum. Mean 100 kernel weight was 2.59g, kernel diameter was 3.49mm, bulk density was 1.23g/cm^3 and kernel hardness was 28.9%. Visual assessment was done on grain colour and seed was classified under red, cream, white and brown sorghums, and mixed colours. A chi-square test found a significant relationship between grain colour and presence of tannins. Genotypes NPGRC3124, IS9405 showed moderate levels of tannins while IS13996, IS29925, NPGRC1699, NPGRC1156 and NPGRC1478 had high levels. A highly significant strong positive correlation was shown for sorghum genotype between kernel diameter and kernel weight (r=0.81 at p≤0.05). Highly significant positive correlation was also observed between bulk density and kernel weight (r=0.4173 at p≤0.001). Kernel hardness has a strong positive correlation with bulk density (r=0.6242). Quantification of tannins is recommended to prevent negative effects on human and livestock health.**

Keywords - Color; kernel; hardness; tannins, shape

I. Introduction

Physical grain quality traits are amongst important attributes that need to be evaluated and classified in sorghum for improvement and utilization purposes. Great diversity particularly in physical grain attributes has been established and confirmed by various research studies (Prasad and Staggenborg, 2009; Adugna et al., 2016; Bean et al., 2019; Rumler et al., 2021). However, vast sorghum germplasm available in gene banks worldwide have not been assessed for physical grain traits. Important physical parameters of sorghum grains include size, weight, endosperm texture and hardness (Mishra et al., 2015; Wu et al., 2016; de Oliveira et al., 2022). Physical traits like grain hardness, pericarp thickness and roundness are often linked to processing like milling quality through dehulling, resistance to storage pests, diseases, physical damage and end use quality traits (Rooney, 2003; Gwekwe et al., 2024). The particle size of the flour and its cooking qualities have been linked to grain size, hardiness and endosperm texture (Rami et al., 1998; Mofokeng et al., 2016; Geisen et al., 2021). Endosperm texture is determined often by the ratio between the vitreous and the floury endosperm [12]. The vitreous endosperm portion has a continuous protein matrix that engulfs starch granules and protein bodies [13]. Physical quality of grain deteriorates due to mold and other physical factors like weathering but the chemical properties does not always get affected [14].

Nutritional traits of sorghum are also highly considered for the purposes of human and animal consumptions since it is one of the small grains recommended to people with chronic illnesses such as diabetes [15]. Sorghum, being gluten free, is recommended as a diet component for patients with celiac diseases (allergy to gluten)[16]. It has also been highlighted as a potential food for the prevention and modulation of chronic diseases [17]. Sorghum grain has been identified as a potential source of phenolic compounds (Kang et al., 2016; Nasidi et al., 2019), which is related to its high content of dietary fiber, lipids, phenolic compounds, tannins and flavonoids such as anthocyanins, flavones and flavanones (Arbex et al., 2018; Saithalavi et al., 2021). Polyphenols are the main substances that contribute to the antioxidant properties in sorghum that is why consumption of sorghum-based diets with high levels of polyphenolic substances can exert a positive role in preventing and reducing the risk of chronic diseases, like breast and colon cancer, as well as diabetes (Hariprasanna et al., 2015; Xiong et al., 2019). Sorghum grain varies widely in their phenolic composition and content, with both genetics and environment affecting the kind and level of phenolic compounds [22].

Though sorghum plays a great role in healthy diets, its end use quality for human and animal consumption can be compromised by the presence of high levels of anti-nutritional properties associated with its grain such as high tannin and phytate content (Abdelhalim et al., 2019; Saithalavi et al., 2021; [24]. High levels of tannins and phytates associated with some sorghum genotypes have been identified as the leading anti-nutritional elements that compromise its role in human and animal diets and other effects include increased incidences of carcinogens (Luo and Xie, 2013). The anti-nutritional components interfere with the digestive process and prevent effective utilization of nutrients (Nasidi et al., 2019; Slamet et al., 2021). Such effects are caused by the formation of complexes with protein and iron, which prevents protein digestibility and iron absorption (Luo and Xie, 2013)

Tannin levels have been linked to the grain colour, precisely the red pigment [27]. The colour of sorghum grain varies greatly due to pericarp colour and thickness, presence of testa, and endosperm texture and colour [28]. The pericarp colour and testa in sorghum is influenced by the phenolic component mostly tannins thus sorghum can be classified according to the pigmentation [14]. Type I sorghums do not have a pigmented testa and are tannin free and are sometimes called sweet sorghum; type II sorghums have a pigmented testa layer that contains condensed tannins and contains moderate tannins; and type III sorghum contain tannin both in the testa and the pericarp and it is often pigmented and these are called bitter sorghums [29].Type III sorghums contain almost ten times higher tannin concentration than other tannin-containing cereals (Boren and Waniska, 1992). Besides the undesirable anti-nutritional properties of high tannin concentration in sorghum it offers an agronomical advantage in protecting the grains against pathogens making them resistant to molds damage and more importantly to bird damage (Menkir et al., 1996; Derese et al., 2018; Gunawan et al., 2022)

The vast genotypic variations in sorghum grain quality traits mandates the need for evaluation of potential genotypes for crop improvement. A more robust method used is the single kernel characterization system (SKCS 4100 Perten Instruments, Huddinge, Sweden)[33], however the availability and cost of the instruments is a major hindrance factor in many laboratories. Thus, this study used low cost and equally effective laboratory procedures to determine the physical grain traits of 22 diverse sorghum genotypes and two popular varieties sourced from the gene bank at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and National Genetic Resources and Biotechnology Institute of Zimbabwe. No information is available on the physical properties of the assessed genotypes yet such information is critical in determining milling quality, uses and adoption by farmers.

II. MATERIALS AND METHODS

A. Experimental design and procedure

Seed for 22 diverse sorghum genotypes and two popular varieties that were evaluated in different laboratory tests was sourced from the gene bank at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and National Genetic Resources and Biotechnology Institute of Zimbabwe and multiplied under rainfed system in the current season of the study at the experimental plot in Lupane State University, Zimbabwe. To assess the physical traits of sorghum grain for the 22 selected sorghum genotypes and two commercial varieties a completely randomized design with two replicates (CRD 24×2) was set up. Panicles of each genotype were harvested at physiological maturity and air dried to a moisture content of 12.5%, cleaning of grain was done to remove foreign material before conducting laboratory tests.

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B. Laboratory procedures and data collection

The physical parameters that were assessed through various laboratory techniques are kernel/grain hardness, kernel weight, kernel shape colour, particle density, bulk density and tannins levels. The laboratory procedures are detailed as follows:

a) Kernel Weight Test (g)

Kernel weight for 100 randomly selected kernels was done for the sorghum genotypes understudy. 100 sorghum kernels were randomly selected for each genotype and placed in petri dishes. Weight for 100 sorghum kernels was measured using a digital scale with four digits to determine a 10^{-4} and recorded for each genotype.

b) Kernel Hardness Test (%)

Grain hardness of the genotypes was conducted using a floater test (Hallgren and Murthy, 1983). A total of 100 kernels for each genotype were randomly selected and placed in a solution of sodium nitrate with a specific gravity of 1.250 g/mL (as measured with a hydrometer). The percentage of floating kernels (low density) and sunk kernels (high density) was recorded.

c) Bulk density (g/cm3)

Bulk density of sorghum grain was measured following method by (Waziri and Mittal, 1983). 8cm^3 measuring container was filled to the brim with sorghum grain samples. The grain was densely packed by gently tapping the container ten times in the same manner for all measurements to allow the grains to settle in the container so as to obtain uniform density. The grains which filled the container were weighed using an electronic meter balance.

Bulk density was then computed using the following formulae;

Bulk density = $\frac{mass\ of\ seed}{volume}$

d) Classification of sorghum kernels according to colour

Classification of grains according to colour was also done following a method by Taylor and Duodu (2010). This test is applicable to whole grain sorghum. A total of 100 intact sorghum kernels for each genotype without glumes were counted and spread evenly over the surface of white sheet of paper so that none of the grains are touching each other and they were assessed visually to determine colour of kernels. Examination of the grains was conducted through counting the number of “white” or “coloured” grains, which-ever is the least. Duplicate determinations should not differ by more than $\pm$ 5 grains, for example first determination 90%, second determination 85%, or 95%.

e) Classification of sorghum according to shape

Visual of assessment of grain colour for the 22 genotypes and two varieties was conducted and grains were classified according to oval, round and flat round shapes.

f) Presence of tannins in sorghum grain

Detection of presence of tannins in sorghum grain was conducted using the bleach test method (Taylor and Duodu, 2010). Hundred whole sorghum grains were placed in a 50 ml beaker and a bleaching reagent made from sodium hypochlorite solution (bleach) was added to just cover the sorghum grains placed in a beaker covered at the top with an aluminum foil. The beaker was incubated at room temperature (20-30 °C) for 20 minutes, swirling contents of each beaker every 5 mins. Contents of each beaker were emptied into tea strainer, discarding bleaching reagent. Rinsing of sorghum grains in tea strainer with tap water was done and contents of tea strainer emptied onto sheet of paper towel. Sorghum grains were spread out into a single layer and gentle blotted off to dry them with using a piece of paper towel. Counting of tannin sorghum grains was done. Tannin sorghum grains are those grains that are black over the entire surface of the grain, with the exception of where the germ is, which is somewhat lighter in colour. Non-tannin sorghum grains are those which are either completely white, or are brown over part of the surface of the grain. The solution dissolves away the outer pericarp layer of sorghum grain, revealing the presence of a black pigmented testa layer in the case of tannin sorghums, or its absence in the case of non-tannin sorghums. Ratings on presence of tannins was done using high, moderate, less and not present.

g) Diameter of kernel grains

Diameter of 10 kernels of each genotype was measured using a digital Venier caliper for all the 22 genotypes and two varieties.

C. Data analysis

To analyze for significant differences between physical traits for 22 genotypes and two varieties of sorghum. A one way - Analysis of Variance (ANOVA) was performed in GenStat version 14 and separation of means were done using Bonferroni's test at 5% level of significance. Pearson's correlation analysis was used to determine significant correlations between the quantitative physical traits of the grain for the 22 genotypes and two commercial varieties used in the study. A Qualitative traits such as colour and shape were assessed visually while a Chi-square test was used to test for independence of association between colour and presence of tannins in SPSS version 21.

III. RESULTS

The twenty-two (22) genotypes and two commercial sorghum varieties showed diverse physical attributes in relation to kernel weight, bulk density, diameter and hardness indicated by highly significant ($P \leq 0.001$) difference between means of all the four physical traits in the analysis of variance results (Table 1).

A. 100 kernel weight and bulk density of sorghum genotypes

Analysis of variance results revealed highly significant ($P<0.001$) differences in weight of 100 kernels of the 22 sorghum genotypes and two commercial varieties with an overall mean average weight of 2.59 g (Table 1). There was a small variability in grain size of the genotypes as indicated by a very low percentage of coefficient of variation. Kernel weight for genotypes means ranged from 1.72 g to 3.49 g for 100 kernels. Genotypes NPGRC1782, IS30047, NPGRC3102, NPGRC1478 and NPGRC3127 had the highest mean weight ranging from 3.19 to 3.40 g in descending order of weight. Eleven landraces had higher kernel weight means than the two commercial varieties "SV4" weighing 2.58 g ranking twelfth and "Macia" with a mean of 2.25 g which was below the overall average kernel weight of 2.59 g, ranking seventh from the lowest mean kernel weight. However, the two check varieties significantly differed in terms of mean kernel weight. Five genotypes weighed the least and these are NPGRC 3124, IS30164, IS9548, NPGRC3087 and NPGRC1593 with mean weights ranging from 1.72 g to 2.15 g (Table 1). The last three aforementioned genotypes had significantly different kernel weights from other genotypes (Table 1).

B. Bulk density (g/cm3) of sorghum genotypes

The overall mean for bulk density was 1.23 gcm^{-3} (Table 1). The genotypes showed highly statistical differences ($P\leq0.001$) in the analysis of variance of bulk density. The ten genotypes with highest bulk density were NPGRC1699, NPGRC3102, IS9405, NPGRC1593, NPGRC1782, NPGRC3133, IS24426, IS2847, NPGRC1478 and NPGRC3087 with means ranging from 1.24 g/cm^3 to 1.33 g/cm^3.Genotypes NPGRC3087, NPGRC1478, IS2847, IS24426 and NPGRC3133 were not significant from each other but highly significant to IS13904, IS29925, IS9548, NPGRC3093 and NPGRC3124. Genotype NPGRC3087 had the highest significantly different mean bulk density of 1.33 g/cm^3 amongst all the genotypes assessed. Genotypes NPGRC3124, NPGRC3093 and IS29925 had the lowest means of 1.04 g/cm^3, 1.09 g/cm^3 and 1.12 g/cm^3 respectively. Bulk density for "SV4" was 1.24 g/cm^3 which was slightly above the overall average of the sorghum grain of 1.23 g/cm^3 and the bulk density for "Macia" was 1.19 g/cm^3 below the average mean bulk density.

C. Kernel diameter (mm) of sorghum genotypes

Results for sorghum kernel diameter revealed highly significant differences ($P<0.001$). Genotype IS30047 had the highest kernel diameter with a mean of 4mm followed by 3.98 mm for genotype NPGRC1478 though not significantly different from IS29925, IS24426 and NPGRC3127 with means 3.94, 3.93 and 3.93 mm respectively (Table 1). Kernel diameter for commercial variety "SV4" was equal to the overall average of 3.49 mm while "Macia" was below the average at 3.44 mm. Genotypes IS13996 and IS630164 had significantly lower means of 2.83 and 2.75 mm respectively.

TABLE 1. MEAN COMPARISON FOR GRAIN PHYSICAL TRAITS OF 22 GENOTYPES AND TWO COMMERCIAL VARIETIES OF SORGHUM AND INFERENTIAL STATISTICS

Genotypes	**100 kernel weight (g)**	**Bulk density (g/cm3)**	**Kernel diameter (mm)**	**Kernel hardness (%)**
IS13904	2.29^{ghi}	1.17^{Efgh}	3.18^{f-i}	7.5^{G}
IS13996	2.37^{fgh}	1.24^{a-f}	2.83^{ij}	19.5^{E-g}
IS24426	2.91^{bc}	1.30^{Abc}	3.93^{ab}	58.5^{A-c}

IS29925	2.93^{bc}	1.12^{Ghi}	3.94^{ab}	0^{G}
IS2847	2.71^{cde}	1.31^{Abc}	3.73^{a-d}	53.5^{A-d}
IS30047	3.20^{a}	1.21^{C-g}	4.0^{a}	3.0^{G}
IS30164	1.72^{k}	1.23^{a-f}	2.75^{J}	27.5^{c-g}
IS9405	2.36^{fgh}	1.27^{A-e}	3.29^{e-h}	22.5^{D-g}
IS9548	2.0^{4j}	1.14^{Fgh}	3.02^{hij}	18.0^{E-g}
IS9567	2.62^{de}	1.22^{B-f}	3.56^{b-f}	17.0^{E-g}
“Macia”	2.25^{hij}	1.19^{D-g}	3.45^{d-f}	18.5^{E-g}
NPGRC1156	2.49^{efg}	1.17^{E-h}	3.44^{d-g}	9.0^{G}
NPGRC1478	3.28^{a}	1.31^{Ab}	3.98^{A}	21.5^{D-g}
NPGRC1593	2.15^{hij}	1.27^{A-e}	3.29^{e-h}	33.0^{C-g}
NPGRC1699	2.53^{efg}	1.24^{a-f}	3.37^{d-h}	70.5^{Ab}
NPGRC1782	3.19^{a}	1.28^{A-d}	3.85^{a-c}	72.0^{Ab}
GRC1862	2.82^{bcd}	1.23^{B-f}	3.72^{a-d}	0^{G}
NPGRC3087	2.07^{ij}	1.33^{A}	3.11^{g-J}	83.0^{A}
NPGRC3093	2.30^{ghi}	1.09^{Hi}	3.36^{d-h}	21.0^{D-g}
NPGRC3102	3.25^{a}	1.25^{A-e}	3.67^{a-e}	11.0^{Fg}
NPGRC3124	1.73^{k}	1.04^{I}	3.38^{d-h}	0.5^{G}
NPGRC3127	3.40^{a}	1.29^{A-d}	3.93^{ab}	50.0^{a-e}
NPGRC3133	2.95^{b}	1.30^{A-c}	3.51^{c-f}	43.5^{b-f}
“SV4”	2.58^{ef}	1.24^{a-f}	$3.49a^{-g}$	32.5^{c-g}
Overall mean	2.59	1.23	3.49	28.9
Fpr	<0.001	<.001	<0.001	<0.001
LSD	0.11	0.05	0.20	15.75
%CV	2	1.9	6.6	26.4

Means accompanied by different letter(s) were significantly different

D. *Kernel hardness of sorghum genotypes (%)*

Results showed an overall mean of 28.9% on kernel/grain hardness test. Genotype NPGRC3087 showed a highly significant different mean kernel hardness (83%) followed by genotype NPGRC1782, NPGRC1699, IS24426, IS2847 and NPGRC3127 with means 72%, 70.5%,5 8.5%, 53.55 and 50% respectively (Table 1). On grain hardness test the two check varieties had averages of 32.5% and 18.5% i.e. “SV4” and “Macia” respectively and the means were above and below averages. However, genotypes IS30047, IS13904 and NPGRC1156 had significantly lower means on grain hardness of 3%, 7.5% and 9% respectively. Genotypes NPGRC1862 and IS29925 had the lowest means of 0 and 0.5%.

E. *Presence of tannins in sorghum grain*

Results for the assessment of the presence of tannins using a sodium hypochlorite solution showed absence of tannins in twelve genotypes cream and white in colour these are “Macia”, “SV4”, NPGRC3127, NPGRC3093, IS30047, NPGRC3102, NPGRC3087, NPGRC3133, IS9567, NPGRC1782, IS2847 and IS24426 (Table 2). These genotypes maintained their colour upon applying sodium hypochlorite solution. Five genotypes IS13904, NPGRC1862, NPGRC1593, IS9548, IS9548 and IS30163 had less tannins turning partly black upon applying sodium hypochlorite solution on conducting a bleach test. Three genotypes showed moderate presence of tannins NPGRC3124, IS9405 and IS13996 with grain turning partly black more compared to former genotypes while four genotypes showed high presence of tannins turning completely black upon applying sodium hypochlorite solution and these are IS29925, NPGRC1699, NPGRC1156 and NPGRC1478.

F. *Shape of grain for 24 sorghum genotypes*

A visual assessment was done to determine shape of grain for the 22 sorghum genotypes and two commercial varieties. The assessed genotypes were classified as oval, round and flat round in grain shapes. 12 of the genotypes had a flat round shape, eight had an oval shape and four had a round shape (Table 2). Genotypes with small grain size had an oval shape while larger grains were round shaped and flat round in shape.

TABLE 2. PRESENCE OF TANNINS, COLOUR AND SHAPE OF SORGHUM GRAIN FOR TWENTY-TWO GENOTYPES AND TWO VARIETIES

Genotype	Presence of tannins	Colour	Shape
IS13904	Less	Light red with cream	oval
IS13996	Moderate	Red	oval
IS24426	not present	Cream	flat round
IS2847	not present	Cream	round
IS29925	High	Dark red	flat round
IS30047	not present	Cream	flat round
IS30164	Less	Red with cream	oval
IS9405	Moderate	Red	oval
IS9548	Less	Light red	oval
IS9567	not present	Light brownish	flat round
“Macia”	not present	Cream	flat round
NPGRC1156	High	Cream with black	round
NPGRC1478	High	Cream with dark red	round
NPGRC1593	Less	Cream with light red	oval
NPGRC1699	High	Light greenish	flat round
NPGRC1782	not present	Cream	flat round
NPGRC1862	Less	Cream with red	flat round
NPGRC3087	not present	White	oval
NPGRC3093	not present	Cream	flat round
NPGRC3102	not present	Cream	oval
NPGRC3124	Moderate	Red with cream	round

NPGRC3127	not present	Cream	flat round
NPGRC3133	not present	Cream	flat round
“SV4”	not present	Cream	flat round

G. Colour of 24 sorghum grain

Sorghum genotypes were classified under red, cream, white, light brown and mixed in colour (mostly red and cream and cream and black). Specific colour for each genotype upon visual assessment is shown in (Table 2) and images taken from the samples are shown below (Figure 2). A. Eleven of the genotypes from analysis were cream in colour and these are “Macia”, “SV4”, NPGRC3127, IS30047, NPGRC3093, NPGRC3102, NPGRC3133, NPGRC1782, IS2847 and IS24426 whereas genotype NPGRC 3087 white or cream. Four genotypes were classified under red colour with varying darkness genotype IS29925, IS9404, IS13996 and IS 9548. The rest of the sorghum genotypes assessed were mixed red and cream in colour, genotype IS9567 light brown and genotype NPGRC1699 light greenish in colour (Plate 1).

Fig. 1. Colour of grain of the 22 sorghum genotypes and two commercial assessed varieties

H. Relationship between grain colour and presence of tannins

The chi-square test to determine independence of association between grain colour and presence of tannins found a significant relationship between grain colour and presence of tannins in the selected sorghum genotypes that were assessed ($\chi 2$ (N = 24; 59; $p < 0.05$) (Table 3). It was noted that there was a significant relationship between colour and presence of tannins with a few exceptions noted in the current study. Genotype NPGRC1156 showed high presence of tannins yet it is white in color. It was easy to determine presence of tannins in dark colored genotypes such as IS29925 which is dark red in color and sorghum genotypes with partly darker colours like genotypes NPGRC1699, NPGRC1156 and NPGRC1478 contained high level of tannins evidenced by change in the color of the pericarp upon applying sodium hypochlorite. Contrary sorghum genotype NPGRC1156 cream in colour with bottom black spots turned completely black upon applying sodium hypochlorite indicating high presence of tannin yet pericarp is not dark coloured. Sorghum genotypes with mixed colours mostly red and cream showed presence of less and moderate level of tannins. Genotypes such as “Macia”, “SV4”, NPGRC3127, IS30047, NPGRC3093, NPGRC3102, NPGRC3133, NPGRC1782, IS2847 and IS24426 white and cream in colour did not show any presence of tannins.

TABLE 3. CHI-SQUARE RESULTS ON INDEPENDENCE OF ASSOCIATION OF GRAIN COLOUR AND PRESENCE OF TANNINS FOR 22 SORGHUM GENOTYPES AND TWO CHECK VARIETIES (N = 24)

Colour	Presence of tannins					
	Not present	Less	Moderate	High	$\chi 2$	t-pr
White	1 (4.1%)	0 (0%)	0 (0%)	0 (0%)	59	0.00
Dark red	0 (0%)	0 (0%)	0 (0%)	1 (4.1%)		
Cream	10 (41.6%)	0 (0%)	0 (0%)	0 (0%)		
Cream with light red	0 (0%)	0 (0%)	0 (0%)	1 (4.1%)		
Light brown	0 (0%)	1 (4.1%)	0 (0%)	0 (0%)		
Cream with red	0 (0%)	3 (12.5%)	1 (4.1%)	0 (0%)		
Cream and dark red	0 (0%)	0 (0%)	0 (0%)	1 (4.1%)		
Cream and black	0 (0%)	0 (0%)	0 (0%)	1 (4.1%)		
Light red	1 (4.1%)	1 (4.1%)	0 (0%)	0 (0%)		
Red	0 (0%)	0 (0%)	2 (8.3%)	0 (0%)		

Factors significantly associated at P≤0.05.

I. Linear correlation (Pearson’s coefficients) between physical attributes of sorghum grain for 22 genotypes and 2 commercial varieties

A highly significant strong positive correlation was shown between kernel diameter and kernel weight (r = 0.81 at p≤0.05) (Table 4). Highly significant weak positive correlation was also observed between bulk density and kernel weight (r = 0.42 at p≤0.001). Kernel weight was found to be strongly correlated to bulk density of sorghum genotypes. A strong positive significant correlation was also shown for kernel diameter and kernel weight (r = 0.81 at p≤0.05). Kernel hardness has a moderated positive correlation with bulk density (r = 0.62). No significant correlations were observed between kernel diameter and bulk density, kernel diameter and hardiness and kernel weight and hardiness in sorghum grains for the genotypes that were assessed (Table 4). Genotype IS30047 had the largest diameter of 4.0 mm and weighed 3.20 g, fourth in the genotype assessed. Genotype NPGRC1478 ranked second on diameter with 3.98 mm and ranked second on weight at 3.28g.

TABLE 4 CORRELATION COEFFICIENTS (R) AMONG SORGHUM GRAIN PHYSICAL TRAITS FOR 22 GENOTYPES AND TWO COMMERCIAL VARIETIES

Physical traits	100 Kernel weight	Kernel diameter	Bulk density
Kernel diameter	0.82***		
Bulk density	0.42**	NS	
Hardiness	NS	NS	0.62***

*Significant at p≤0.05; **Significant at p≤0.01; ***Significant at p≤0.001; NS- non significant.

IV. DISCUSSION

In the current study genotypes that scored highest in kernel weight are landraces mostly from Zimbabwe except for IS30047 which is a research material. Noteworthy, genotype NPGRC3127 from Chipinge, Zimbabwe had the highest mean kernel weight. This could explain preference of some local landraces by smallholder farmers in many parts of sorghum producing areas in Africa since some maybe yielding better compared to the commercial varieties. The observed overall mean kernel weight of the assessed genotypes in the current study is lower than findings from Liu et al., (2012) where twenty-five (25) superior genotypes had an average mean grain weight of 3.35 g for 100 grains, with a mean diameter of 3.35 mm. However, the kernel weight for the assessed genotypes in the present study was within the range between 3.0-3.8 g, similar to Indonesian sorghum accessions comprising of local and hybrid varieties assessed by Mukkun et al., (2021).

Bulk density of sorghum is the dry matter density in-terms of weight compared to volume. The higher the bulk density the denser the sorghum kernels, the lower the bulk density the less dense the kernels. Sorghum genotypes with high kernel density provide high yield of flour [5]. Low bulk density affects yield of processed products [27]. Another grain size attribute that was assessed is diameter which showed a mean within the range of values obtained in a similar study which found an arithmetic and geometric mean diameters of sorghum grain of 3.31 mm at 8.89% wb and 4.18 mm at 16.50% wb [35].

Kernel hardness is a property that shows resistance of seed to breaking when subjected to compressive forces and in sorghum kernels is associated with moisture content, shape, size, and thickness of the seeds [36]. Genotypes with higher percentage of hardness have better dehulling properties and are not prone to molds and attack by storage pests. Hard grains allow for complete removal of bran without breaking grains due to better resistance to abrasion thus the harder the grains, the better is quality of dehulling (Guindo et al., 2019[8]. However kernel diameter seems not related to kernel hardness. Grain shape is another important physical trait in separation operations during processing and also in pneumatic conveyance (Emesu and Amos, 2013) which is an indication that some physical properties of sorghum are closely related to chemical composition.

Correlation analysis results showed that improvement of one trait in one directions improves other traits in other direction [38]. Thus, correlation is used to find degree and direction of relationship between two or more variables. Dense genotypes weigh more and have a high bulk density giving more yields and less dense genotypes have a low weight, low bulk density and yield less. The relationship between kernel weight and diameter of a sorghum kernel shows that the bigger the grain in size the more it weighs. Sorghum genotypes that were in the top 10 in kernel weight were also in top ten in kernel diameter indicating a positive relationship.

Genotypes that contained high level of tannins evidenced by change in the color of the pericarp upon applying sodium hypochlorite and are classified under sorghum type III [13]. The presence of dark red pigment and dark pigments in sorghum indicates the presence of bioactive compounds such as tannins (de Morais Cardoso et al., 2017; Espitia-Hernández et al., 2022). Findings are similar to other studies conducted by other researchers such as Boren and Waniska, (1992) who concluded that though colour of sorghum grains maybe used to detect presence of tannins but seed color is a poor indicator of tannin content in sorghum containing low to moderate tannin levels. It is easier for dark-coloured sorghums with high tannin content (Hariprasanna et al., 2015). Genotypes with high tannin levels are known to be bitter in taste and have a longer shelf life compared to those genotypes containing no tannins, less and moderate levels (Mashao and Prinsloo, 1994; Nasidi et al., 2019). These varieties are less susceptible to molds and attack by birds and pests. Sorghum grain containing condensed tannins (located in sorghum testa and pericarp) protect the seed against pest invasion, fungi, birds and other rodents [42].

Results of the current study are similar to those from other studies where red sorghum were classified as low-tannin sorghum and these are classified under sorghum type I [40]. Both genotypes containing less and moderate tannins are safe for human consumption and important in management of some chronic illnesses [13] . Such varieties like “Macia” and genotypes are said to be sweeter in taste and suitable for human consumption and livestock feed, however they may be susceptible to storage pests and bird damage [43].

V. CONCLUSIONS AND RECOMMENDATIONS

All the 22 sorghum genotypes and two varieties differed in physical traits (grain colour, kernel weight, kernel diameter and bulk density). Genotype NPGRC3127 had the highest kernel weight while IS30047 had highest kernel diameter. Genotype NPGRC3087 had highest bulk density and hardness which is suitable for processing. Genotypes IS29925, NPGRC1699, NPGRC1156 and NPGRC1478 detected high presence of tannins while IS13904, NPGRC1862, NPGRC1593, IS9548 and IS9548 coloured cream and red had less tannins. “Macia” a commercial variety, “SV4” a commercial variety, and genotypes

NPGRC3127,NPGRC3093,IS30047,NPGRC3102,NPGRC3087, NPGRC3133, IS9567, NPGRC1782, IS2847 and IS24426 tested negative on tannins indicating its absence. Some physical traits are strongly correlated (kernel weight and bulk density while for some the correlations are very weak and showed negative correlation (kernel diameter and grain hardness). Seed colour provided an indication of presence of tannins, yet it is easy for genotypes with a dark colored pericarp, it is a poor indicator for light colored sorghum grains. However, it is recommended to conduct a quantitative analysis to determine level of content for tannins and nutritional traits. High yielding varieties of high bulk density, diameter and less tannins are more suitable for human consumption while the red genotypes with high tannins are preferred for brewing purposes. Genotypes with small grains (in diameter) and less tannins are more suitable for poultry feed.

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