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Variability and Character Association Among Forage Biomass and Nutritional Quality Traits of Sorghum Collections in Ethiopia

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Abstract

In Ethiopia sorghum is important food-feed crop, but no focus has been given for forage value until recently. A study was conducted to fill gap with objective of understanding nature of variability, and explore selection and breeding traits. The study was conducted at Melkassa Agricultural Research Center where 166 collections were sown by row column design in RCBD with three replications on 2.25m^2 plot area. Field based biomass and laboratory based nutritional quality data were obtained at booting on nine and seven traits, respectively, and subjected to variability analysis using descriptive statistics; classified the variability by three different methods in to either low, medium, high or very high, and also ran correlation analyses in SAS 9.4. The results showed large dispersions in all measures with wide range of differences for days to reach cutting (134.4 days), plant height (297.7 cm), stalk diameter (29.2mm), total dry matter (302.3g/plant), crude protein (8.2%), and in vitro organic matter digestibility (15.1%) among others. Classification of the observed variability also showed similarities and discrepancies among methods and traits studied. Two of the three methods indifferently classified variability among genotypes for five of the biomass and three of the nutritional quality traits as low, and conversely three of the biomass and two of the nutritional quality traits as very high variability. The third method classified all nutritional quality traits (except crude protein) as low variability showing no single method could do the same for all. . Correlation analyses also showed that genotypes of earliness with more leaf have more crude protein, and in vitro organic matter digestibility contents. Therefore, it can be recommended that there is a need for nationally coordinated breeding activities targeting selection for specific traits, and crossing with lines of either stay green traits for dual purpose grain-stover quality, and/or with lines of high fodder digestibility traits, and also to select methods of variability classification contingent up on nature of each trait under study.

Keywords: *coefficient of variability, pseudo sigma, sorghum fodder*

1. Introduction

Ethiopia is one of the countries in the tropics endowed with diverse agro-ecologies - hosting wide range of floras and fauns of economic and environmental importance (Alemayehu Kefalew and Sara Sintayehu, 2018; Simachew B.Wassie, 2020). The country is a center of origin and diversity to a number of plant species of cultivated and uncultivated genera (Alemayehu Kefalew and Sara Sintayehu, 2018). Sorghum bicolor L. Moench is one of such cultivated crops domesticated first in Ethiopia roughly around 3000 years ago with extra areas of origin in other parts of Africa (Nigeria, Congo, Sudan,) and India (Amsalu Ayana and Endeshaw Bekele, 1998; Deshmukh *et al*., 2018).

In Ethiopia, sorghum is cultivated for multiple uses by about 4.96 million small holder farmers on about 1.85 million hectares of land (Federal Democratic Republic of Ethiopia Central Statistical Agency, 2020). It is predominantly grown in the mid and highland of the northern, eastern, northern eastern, and in sections of the humid and sub humid western and southwestern lowlands of the country (Asfaw Adugna and Endashaw Bekele, 2013; Taye T. Mindaye et al., 2016). In many of such areas, sorghum biomass covers for the larger part of the cultivated feeds obtainable by the livestock keeping households. Recent studies have shown that about 62-87% of the sorghum biomass produced as crop residue goes to livestock feeding in parts of the major sorghum growing areas of North Gonder, North Wello and East Hararghe Zones (Asheber Tegegn *et al.*, 2021).

In Ethiopia, sorghum exists in greater diversity for the different traits across all sorghum growing areas and seasons with broader genetic bases of more than 9000 collections in both the cultivated and wild forms (Asfaw Adugna and Endashaw Bekele, 2013; Taye T. Mindaye et al., 2016) This has been seen as an advantage for improvement in traits of interest through selection and hybridization programs within the country and globally (Taye Tadesse *et al*., 2019). In Ethiopia, breeding efforts so far characterized only portion of the wider germplasm pool (Taye Tadesse *et al*., 2019; Kidanemaryam Wagaw *et al*., 2020; Dagnachew B. Besha, 2020). However, both the characterization, and the improvement efforts were limited to grain productivity and somehow on tolerance to biological and climatic stresses (Taye Tadesse *et al*., 2019). In process, a sizable number of improved varieties have been released for commercial production of grain.

Experiences have shown that forage, and grain yields (for which sorghum is grown traditionally) are complex characters controlled by many genes (Abubaka and Bubuche, 2013: Poonia *et al*., 2017) and improvements in one of those traits may result in simultaneous improvement or deterioration in the other traits (Mukondwa *et al*., 2020). Most of the high grains yielding modern varieties of sorghum are shorter in plant height, and low in stover productivity (DeLacy *et al*., 2010). The adoption of those varieties by small holder farmers in Ethiopia is low (Etaferahu Kassa *et al*., 2022). Most farmers, if not all, depend on traditional varieties of less grain yielding, but tall in plant height and are larger in stover biomass accumulation.

On the other hand, experiences have showed that there exists considerable variation in agro-morphological traits and nutritional quality among sorghum lines and collections (Oliver *et al*., 2005; Kumari *et al*., 2016). Understanding such nature of variability, and the associations present among the different forage biomass and nutritional quality traits (Prakash *et al*., 2010; Kumari *et al*., 2016) would help choose important trait for simultaneous improvement. To this effect, correlation studies revealed that forage yield is positively and significantly correlated with plant height, stem diameter and crude fiber, and negatively associated with days to maturity, crude protein and *In vitro* dry matter digestibility in sorghum, pearl millet and forage oat (Poonia *et al*., 2017; Prakash *et al*., 2010; Govintharaj *et* *al*., 2018). Thus this article, describes an account of studies done to understand variability, and classify that to low, medium ,high, and very high, and explore traits association among Ethiopian sorghum collections to aid identify selection method and breeding traits for sorghum fodder improvement in Ethiopia.

2. Materials and Methods

2.1. Description of the study area

The study was conducted at the Melkassa Agricultural Research Center. The Research Center is situated in the Oromia National Regional State of Ethiopia at $8^0$24' N latitude and $39^0$21'6 E longitude, 120 km from Addis Ababa to the South of Adama town in the Rift Valley. The Research Center has an elevation of 1550 m asl with semiarid climate. The long term mean annual rainfall is about 750 mm with mean annual maximum temperature of 28 ^oC and minimum temperatures of 12 ^oC. The rainfall is bimodal with over 70% occurring during the months from end of June to early September. The small rain occurs during March to April. Rainfall is characterized by high coefficient of inter annual and seasonal variability both in amount, occurrence and distribution (Girma Mamo *et al*., 2019). The soils are slightly alkaline with pH of 7.8, low in organic carbon content (1.2%), and total nitrogen (0.1%), medium in B (0.58 mg/kg), Na (109.39 mg/kg) and S(8.65 mg/kg), but high in Ca (3276.68 mg/kg), Cu (1.19 mg/kg), Fe (81.26 mg/kg), K(986.83 mg/kg), Mg (368.91 mg/kg), Mn (237.45 mg/kg), available P (18.45 mg/kg) and Zn (2.25 mg/kg) (Dejene Abera *et al*., 2019).

2.2. Experimental design, seeding and crop management practices

Soils of the experimental site were finely tilled at the beginning of small rainy season. Then 166 sorghum collections of Ethiopian landraces, pre-screened on basis of their relative leafiness among over 2200 collections (collected by the Sorghum and Millet Innovation Lab (SMIL project) from the Ethiopian Institute of Biodiversity Conservation (IBC), were sown each in a single rows of three meter at a plant to plant spacing of 25 cm with in a row, and at a row to row spacing of 60 cm using row by column spatial arrangement in a randomized complete block design with three replications. Planting/sowing was done on third and fourth of March. At sowing, a blended fertilizer NPSB (nitrogen, phosphors, sulfur and boron with formula 18.9 – 37.7 - 6.9 - 0.1, respectively) was applied at 100 kg/ha by band placement around the seeds. Urea fertilizer was also top dressed around the seedlings 30-35 days after planting at 50 kg/ha. Irrigation was supplemented to rain to meet water requirement of the crop as deemed necessary.

2.3. Data collection

Data were collected at booting stage of plant growth and development on days to booting, plant height, number of leaf, and total soluble solid (as brix value), stalk thickness/diameter, leaf and stem weights from three randomly selected plants and averaged for each replication.. The days taken to harvesting/cutting was determined as a difference between days to reaching booting, and that of days to sowing following the day of the year format. Whereas, plant height (cm) was measured in cm tap from the base at ground to the tip of the flag leaf (longest leaf) and the number of leaf by counting all leaves present in a cut plant. Following this stem thickness was measured as stalk diameter (mm) at the thickest portion of the plant-close to the ground. On the other hand, brix value (percentage of total soluble solid) was measured by refracto-meter. Then leaves were separated from the stalk at leaf collar and weighted categorically as fresh leaf and stem weights to the nearest gm The samples were then dried in oven at 70^oC for 72 hours to constant weight and weighed with sensitive balance to the nearest gm for dry matter accumulation in the leaf and the stem categorically. The total dry matter accumulation (gm) in aerial plant part was determined as a sum of the dry matter accumulations in the leaf and the stem. The leaf to stem ratio was calculated as the ratio of the dry matter accumulation in the leaf to that of the respective stem.

The oven dried leaves and stems of each the three plant were put together categorically for each replication and grinded to less than one millimeter sieve size by laboratory Hammer mill. Then the grinded samples were , annualized for *In vitro* Organic matter Digestibility (IVOMD %), Metabolizable Energy (ME Mj/KgDm), Crude protein (CP %), Neutral detergent fiber (NDF %), Acid detergent fiber (ADF %), Acid detergent lignin (ADL% and mineral (Ash %) content using Near Infrared Reflectance Spectroscopy (NIRS) FOSS 6500 equipment at 1108 - 2492 nm with an 8-nm step at Ethiopian Institute of Agricultural Research (EIAR) headquarter quality laboratory with software package WinISI II as described by Bidinger and Blummel (2007), and Blummel *et a*l.(2007). Estimations of the quality parameters were done based on equations calibrated and supplied by the International Livestock Research Institute's (ILRI) laboratory for sorghum as a forage crop. The equations had a goodness of fit (R^2) of 95 % for CP, 91% for NDF, 94% for ADF, 93% for ADL, and 91% for IVOMD between values from wet chemistry analysis and NIRS predictions, (Aklilu Mekasha *et al*., 2021).

2.4. Data analysis

The data obtained from field based measurement and lab analysis were subjected to descriptive statistics (mean, maximum, minimum, standard deviation, 1st Quartile, 3rd Quartile, midquartile ((Q1 + Q3)/2), inter quartile range (IQR), Pseudo-sigma (PS) and coefficient of variability (CV) IQR was determined as difference between 3rd Quartile and 1st Quartile (3rd Quartile - 1st Quartile) and PS was obtained by dividing IQR by 1.35 as described in Peternelli *et al*.,(2013) and Ferreira *et al*.(2016). The CVs were determined for each trait in two ways. These were by dividing the SD by respective mean and multiplying by 100 which assume normal distribution of the data set, and secondly by dividing the PS by the respective Midquartile and multiplying by 100 which takes the assumption that the data set may or may not satisfy the assumption of normal distribution (Ferreira *et al*., 2018). Reports have shown that for normally distributed data sets, the PS is the same as the SD (Couto *et al*., 2013; Salmito et *al*., 2018).

Then after, for each traits of the study, the variability among the genotypes were classified in to low, medium, high and very high variability using three classifications each proposed by Garcia (1989), Costa *et al*. (2002) and Pimentel-Gomes (2009). According to Garcia (1989) CV < mean - SD was classified as "low"; mean - SD < CV< mean + SD as "medium"; mean + SD < CV< Mean+2SD as "high", and CV > Mean +2SD as 'very high" variability. On the other hand, according to Costa *et al*. (2002) CV < Midquartile – PS was classified as "low"; Midquartile - PS < CV< Midquartile + PS) as "medium"; Midquartile + PS < CV < Midquartile + 2PS as "high", and CV > midquartile + 2PS as "very high" variability, whereas the Pimentel-Gomes's (2009) classification of variability is considered as a standard method. It classifies CV<, 10 as "low"; 10 < CV<20 as "medium"; 20 < CV < 30 as "high", and CV > 30 as "very high" variability. Finally the degrees of association among the different traits were determined by the, Pearson's correlation using SAS 9.4, and significant differences were identified at P<0.05 probability level

3. Results and Discussion

3.1.Variability in forage biomass traits

Characterization of Ethiopian sorghum collections showed large dispersions in all statistical measures considered in the present study - signaling considerable variation (Table 1) for all forage biomass traits studied. The results showed there is a large range of difference between the minimum and maximum observed values for days to reach cutting at booting (134.4 days), plant height (297.7 cm), stalk thickness/diameter (29.2 mm), number of leaf (11.3), dry matter accumulations in stalk (234.9 gm), leaf (102.1 gm) and areal plant part (302.3 gm). On the other hand, the differences observed between the mean and the corresponding Midquantile values were less than a unit for five traits (stem dry matter, number of leaf, dry matter accumulation in leaf and total aerial plant part, leaf to stem ratio and brix value), and the maximum was for plant height (4cm). This could be showing that the data set for most of the traits studied follow normal distribution (Couto *et al*., 2013; Ferreira *et al*., 2018)

From the present study it was apparent that there are genotypes among the collections that took less than 3 to over 6 months to reach booting stage of cutting which could be taken as a positive opportunity to select genotypes fitting to the different length of crop growing period which in turn could vary from location to location depending on the agro-ecological conditions (Amsalu Ayana and Endeshaw Bekele, 1998; Asfaw Adugna and Endashaw Bekele, 2013; Alemayehu Kefalew and Sara Sintayehu,, 2018; Kidanemaryam Wagaw *et al*, 2020; Dagnachew B. Besha, 2020). Furthermore, some of the collections were as short as 1.5 meters while others are growing to more than four meters in plant heights indicating the need for different management interventions among the genotypes for optimal performance. For example short growing genoypes are resistant to lodging compared to the tall growing counter parts (Ouda *et al*., 2005) and could be ideal to grow dense for fodder production including under environment where lodging could be a problem (Aklilu Mekasha, *et al*, 2021),

Moreover, the variation in stalk thicknesses, measured as stalk diameter, could also be taken as indicator of opportunities among the genotypes to consider selection for post-harvest processing.. Studies have shown that sorghum genotypes with thick stalk have less palatability/ intake by ruminating animal when compared to that of the fine stalked genotypes and hence needs chopping to smaller pieces for enhanced intake (Bidinger, and Blummel; 2007; Aklilu Mekasha *et al*, 2021) . The range of variability in leaf number observed in the present study could also be taken as indicator of possible variation in nutritive values of the genotypes. Studies have shown that plants with more number of leaves could have better nutritional values as they tend to have short internodes (Ouda *et al*., 2005). The variation among the genotypes observed in dry matter accumulations through the different aerial plant parts observed in the present study corroborates that of Diwakar *et al* (2016) who found same variation for green forage yield, dry forage yield and leaf to stem ratio indicating wider opportunities of genotype selection for higher biomass yield under specific environment (DeLacy *et al*., 2010; Abubakar and Bubuche, 2013; Taye T. Mindaye et al, 2016; Dagnachew B. Besha; 2020; Bidinger, and Blummel; 2007). Leaf to stem ratio is often considered by breeders and agronomists as a key characteristic of asserting nutritional quality (Oliver et *al*., 2005; Bidinger, and Blummel; 2007; Mganga *et al*., 2021 ;) and

Table 1. Variability in forage biomass traits among 166 sorghum collections in Ethiopia based on mean values of three replications.

	Mean & SD based variability					Midquantile & PS based variability					
Trait	Mean	SD	CV	Minimum	Maximum	1st Quartile	Midquantile	3rd Quartile	IQR	PS	CV
DBC	155.9	40.5	26.0	72.3	206.7	114.3	153.2	192.0	77.7	57.6	37.6
PLH	273.4	50.0	18.3	126.0	423.7	237.4	269.4	301.4	64.0	47.4	17.6
STD	27.4	5.3	19.3	15.4	44.6	23.4	27.1	30.8	7.4	5.5	20.3
NLP	5.7	1.7	29.8	1.9	13.2	4.6	5.6	6.6	2.0	1.5	26.8
DMS	165.3	52.8	31.9	51.1	286.0	126.5	164.2	201.9	75.4	55.9	34.0
DML	57.6	23.4	40.6	22.9	125.0	40.7	55.2	69.7	29.0	21.5	38.9
TDA	222.9	68.0	30.5	74.1	376.4	173.5	222.6	271.7	98.2	72.7	32.7
LSR	0.4	0.1	25.0	0.2	2.0	0.3	0.4	0.5	0.2	0.1	25.0
BRV	8.4	2.2	26.2	3.0	15.7	7.0	8.4	9.7	2.7	2.0	23.8

SD = standard deviation; CV= coefficient of variation(%);IQR=inter quartile range; PS=Pseudo-Sigma; DBC= Days to booting/ cutting (# days) ; PLH= Plant height (cm); STD= Stalk thickness/diameter (mm) ; NLP= Number of leaf/ plant ; DMS= Dry matter accumulation in stem/plant(gm) ; DML= Dry matter accumulation in leaf /plant(gm) ; TDA= Total dry matter accumulation in aerial plant part/plant(gm); LSR= Leaf to stem ratio ; BRV= Brix value (%)

those genotypes with more leaf to stem ration are of better forage types, and could be seen as potential materials for selection in terms of fodder biomass quality. Though the present study has also shown similar variation in the total soluble solids contents of the sorghum collections, the values recorded were less than the 7.10 to 37.19 % reported by Diwakar *et al*.(2016) and others (Schafranski *et al*., 2014; López-Sandin *et al*., 2021) . The less total soluble solids (brix) of the present genotypes could be due to harvesting at early stage before ripening - often attained at full maturity termed dough stage.(Diwakar *et al*., 2016; López-Sandin *et al*., 2021). In line of this, Schafranski, *et al*. (2014) reported that the total soluble solid content in sorghum increases with age of the crop, and the highest total soluble solids, and juice sugar concentrations could be observed at the physiological maturity stage (López-Sandin *et al*., 2021)

3.2. Classification of variability for forage biomass traits

The coefficient of variation (CV) calculated from the mean and the standard deviation (SD) here after referred to as Garcia's method. as well as the Midquartile and the pseudo-Sigma (PS) referred to as Costa's method that were employed to explore the extent of variability for all forage biomass traits classified as low, medium, high and very high variability showed differences among the response traits/ forage biomass traits studied (Table 2). Among others, both classification methods indifferently, classified the CV of five of the nine traits namely the days to cutting at booting (DBC), plant height (PLH), stalk thickness/ diameter (STD), dry mater accumulation through stem (DMS) and total dry matter accumulation through the aerial plant part (TDA), as low variability indicating existence of less variation among the genotypes with respect to those traits. On the other hand, the CVs of one out of the nine traits (dry matter accumulation through leaves (DML) were indifferently classified by both methods as medium variability indicating medium variation among the genotypes with respect to those traits. In a similar way, the CVs of the three remaining traits out of the nine included i.e. number of leaves (NLP), leaf to stem ratio (LSR) and brix value (BRV) were also classified indifferently by both methods as very high variability indicating existence of high variation among the genotypes with respect to those traits. This shows that traits with large standard deviation or larger Pseudo-Sigma values relative to the mean and midquartiles expressed as percentage of mean or midquartiles could record more CV values (Couto *et al*., 2013; Ferreira *et al*., 2018

The lack of difference between the two methods (Garcia's and Costa's methods) in CV range classification of the present study for all traits could be an indication of absence of extremes/ outlier values in the data set of each respective trait adequate to affect the distribution. .Several studies have shown that the CVs computed based on mean and the standard deviations could be susceptible to outliers and could result in inflated values, whereas, the midquartile and the pseudo-sigma statistics as a non-parametric alternative is more resistant to the effects of outliers (Salmito *et al*., 2018). However, in case the data set is normal in its distribution, the two methods give equivalent classifications of CV(Couto *et al*., 2013;Salmito *et al*., 2018; Ferreira *et al*., 2018)),

Nevertheless results of the CV classifications of the present study done by both Garcia's and Costa's methods contradicted the classification results obtained by using method proposed for agricultural field based trails by Pimentel-Gomes (2009). Pimentel-Gomes suggested general classification for CV values less than 10% as low, from 10 to 20% as medium, 20-30% as high and greater than 30% as very high (Pimentel-Gomes, 2009; Couto *et al*., 2013; Salmito et *al*., 2018; Ferreira et al., 2018). According to this classification among traits of the present study, the CV of one trait (plant height (PLH)) was classified as medium variability, whereas three traits ((number of leaf (NLP), leaf to stem ration (LSR), and brix value (BRV) were classified as high variability, and three other traits (dry mater accumulation through leaf, stem and total aerial plant part) were classified as very high variability. using both SD & Mean and PS & Midquartile approaches for CV determination, and it corroborates Couto *et al*. (2013), and could be showing normal distribution of the data set with respect to those traits.

However, there are discrepancies in CV classification using Pimentel-Gomes's method between CV values obtained using the SD & Mean and PS & Midquartile for two traits (days to booting and stalk thickness/ diameters (SDM)). The Pimentel-Gomes's method classified CV of the present study computed by using SD & Mean for days to booting(DBC) as high variability, and conversely as very high variability for the same trait computed by PS & Midquartile..Similarly Pimentel-Gomes's method classified the CV of the stalk thickness/diameter/ (SDM) computed by using SD & Mean as medium variability, and the one computed by PS & Midquartile as high variability. The discrepancies could be due to effects of outliers that might be present in the data set with respect to those traits (Salmito *et al*., 2018) and shows sensitivity of the Pimentel-Gomes method of CV classification to outliers. Based on this, it could be advisable to use the PS & Midquartile for the CV computation to classify using the Pimentel-Gomes's method. On the other hand, although the Pimentel-Gomes's (2009) method of CV classification is criticized for its failures to consider characters of the studied crop, traits, the variation in soil, land size and others (Peternelli *et al*.,, 2013; Ferreira *et al*., 2016; Salmito *et al*., 2018), it seems reasonably classified the variability in CV of the present study well among the different traits better than those methods proposed by Garcia (1989) and Costa *et al*. (2002). This might be because of the less range of CV classification used by this method to classify the CVs in to low, medium, high and very high ranges as opposed to the arguments of Couto *et al*. (2013), Peternelli *et al*., (2013), Ferreira *et al*. (2016), Salmito *et al*.(2018) and others.

3.3.Variability in nutritional quality traits

Similar to the forage biomass traits, the nutritional quality characterization of Ethiopian sorghum collections also showed variation among the sorghum collections in all measures of variability considered for all traits studied (Table 3). The results presented in Table 3 showed that the range of difference between the observed maximum and minimum records were relatively higher for traits such as neutral detergent fiber (10.2%), acid detergent fiber (13.6%),crude protein (8.2%) and *in vitro* organic matter digestibility (15.1%) contents. Similar variation was also reported by Diwakar *et al* (2016) among Indian sorghum collections and others (Ouda *et al*., 2005; Poonia *et al*., 2017). The difference between the values of the two measures of central tendency (Mean and Midquartile) for each trait measured were zero for mineral ash, acid detergent lignin and metabolizable energy concentrations,

Table 2. Classification of coefficient of variability of the different forage biomass traits of sorghum collections in Ethiopia in to low medium, high and very high based on mean values of three replications for 166 genotypes

Variable	CV classification based on Mean & SD Garcia (1989)				CV classification based on Midquartile & PS(Costa et al. (2002)			
	Low	Medium	High	Very high	Low	medium	High	Very high
DBC	CV < 115.4	115.4 < CV < 196.4	196.4 < CV < 236.9	CV > 236.9	CV < 95.6	95.6 < CV < 210.8	210.8 < CV < 268.4	CV >268.4
PLH	CV < 223.4	223.4 < CV< 323.4	323.4 < CV < 373.4	CV > 373.4	CV < 222	222 < CV < 316.8	316.8 < CV < 364.2	CV > 364.2
STD	CV < 22.1	22.1 < CV< 32.7	32.7 < CV < 38	CV > 38	CV < 21.6	21.6 < CV < 32.6	32.6 < CV < 38.1	CV >38.1
NLP	CV < 4	4 < CV < 7.4	7.4 < CV < 9.1	CV > 9.1	CV < 4.1	4.1 < CV < 7.1	7.1 < CV < 8.6	CV > 8.6
DMS	CV < 112.5	112.5 < CV < 218.1	218.1 < CV < 270.9	CV > 270.9	CV < 108.3	108.3 < CV < 220.1	220.1 < CV < 276	CV > 276
DML	CV < 34.2	34.2 < CV< 82	81< CV < 104.4	CV > 104.4	CV < 33.7	33.7 < CV < 76.6	76.7 < CV < 98.7	CV > 98.2
TDA	CV < 154.9	154.9 < CV < 290.9	290.9 < CV < 358.9	CV > 358.9	CV < 149.9	149.9 < CV < 295.3	295.3 < CV < 368	CV > 368
LSR	CV < 0.3	0.3 < CV < 0.5	0.5 < CV < 0.6	CV > 0.6	CV < 0.3	0.3 < CV < 0.5	0.5 < CV < 0.6	CV > 0.6
BRV	CV < 6.2	6.2 < CV < 10.6	10.6 < CV < 12.8	CV > 12.8	CV < 6.4	6.4 < CV < 10.4	10.4 < CV < 12.4	CV > 12.4

SD = standard deviation; CV= coefficient of variation(%);IQR=inter quartile range; PS=Pseudo-Sigma; DBC= Days to booting/ cutting (# days) ; PLH= Plant height (cm); STD= Stalk thickness/diameter (mm) ; NLP= Number of leaf/ plant ; DMS= Dry matter accumulation in stem/plant(gm) ; DML= Dry matter accumulation in leaf /plant(gm) ; TDA= Total dry matter accumulation in aerial plant part/plant(gm); LSR= Leaf to stem ratio ; BRV= Brix value (%)

and near zero for crude protein, neutral detergent fiber, acid detergent fiber and *in vitro* organic matter digestibility contents. Similarly the gap between the standard deviation and the Pseudo-Sigma values of the respective traits were zero for mineral ash and neutral detergent fiber contents, and close to zero for the rest of the studied traits. This could be taken as an indication of normal distribution (Salmito *et al*., 2018) of the data set with respect to those traits.

From the present study it was clear that there are genotypes among the collections with less or high fiber (neutral detergent fiber and acid detergent fiber) contents which could be taken as positive opportunity to select genotypes with low fiber concentrations. Various studies have shown that genotypes with fewer contents of those fibers are more desirable (Casler, 1986; Bidinger and Blummel, 2007, Blümmel, 2007; Diwakar *et al*., 2016; Kumari *et al*., 2016; Mganga *et al*., 2021) to ruminants as they are more digestible than those genotypes with more fiber concentrations (Govintharaj *et al*., 2018). Ruminants animals fed on those genotypes with low fiber concentration are responsive in terms of feed intake, growth and milk yield (Oliver *et al*., 2005). Moreover, the variation in crude protein contents observed among the genotypes could also be seen as a chance to select those genotypes with high crude protein contents Studies have demonstrated that genotypes possessing high crude protein contents are important to select (Blümmel, 2007; Diwakar *et al*., 2016; Kumari *et al*., 2016; Mganga *et al*., 2021) as they are more nutritious to meet protein needs of ruminants (.Bidinger and Blummel, 2007), Forage grasses containing more crude proteins need less supplementation of ruminants with commercial grade protein supplements - often costly to farmers. The high variability observed among the genotypes in in vitro organic matter digestibility content should also be taken as an advantage to go for selection of genotypes with high digestibility (Ouda, *et al*, 2005; Oliver *et al*., 2005) Such genotypes are genotypes of primary choice as they cause animals fed on those genotypes to respond well in terms of feed intake, body weight gain and milk production (Govintharaj *et al*., 2018; Mganga *et al*., 2021), and less need for commercial grade feed supplementation. The values observed for the in vitro organic matter digestibility for sorghum however, was lower than the 52.0 to 67.8% reported by Ouda *et al*. (2005), and this could be attributable to the differences in stage of growth and development at harvesting.

3.4. Classification of variability for nutritional quality traits

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Both the Garcia's and Costa's methods of CV classification indifferently, classified CV of crude protein (CP) and acid detergent lignin (ADL) contents as very high variability, whereas the neutral detergent fiber (NDF), acid detergent fiber (ADF), and the *in vitro* organic matter digestibility (IVOMD) contents as low variability(Table 4). This could be related to the normal distribution of data set with respect to those traits (Couto *et al*., 2013; Salmito *et al*., 2018). On the other hand, the two methods (Garcia's and Costa's methods) classified CVs of minerals ash (Ash) content and metabolizable energy (ME) concentrations differently. In this respects, the Garcia's method which uses Mean & SD, classified CV of mineral ash content as medium variability while the Costa's method using midquartile & PS classified the same as low variability. With regard to metabolizable energy (ME), the Garcia's method classified it as very high variability while the Costa's method classified the same as high variability.

Table 3. Variability in forage nutritional quality traits among 166 sorghum collections in Ethiopia based on mean values of three replications.

	Mean & SD based variability					Midquantile & PS based variability					
Trait	Mean	SD	CV	Minimum	Maximum	1st Quarti	Midquartile	3rd Quarti	IQR	PS	CV
Ash	10.3	1.0	9.7	8.4	14.2	9.6	10.3	10.9	1.3	1.0	9.7
CP	7.1	1.6	22.5	4.1	12.3	5.8	7.0	8.1	2.3	1.7	24.3
NDF	61.8	1.9	3.1	56.8	67.0	60.6	61.9	63.2	2.6	1.9	3.1
ADF	43.4	2.5	5.8	34.6	48.2	42.2	43.7	45.2	3.0	2.2	5.0
ADL	5.9	0.58	9.8	4.1	6.8	5.6	5.9	6.2	0.6	0.4	6.8
IVOMD	46.1	3.1	6.7	41.0	56.1	43.9	45.9	47.8	3.9	2.9	6.3
ME	6.5	0.5	7.7	5.9	8.0	6.2	6.5	6.8	0.6	0.4	6.2

SD = standard deviation; CV= coefficient of variation(%);IQR=inter quartile range; PS=Pseudo-Sigma; Ash=mineral ash; CP=crude protein; NDF= neutral detergent fiber, ADF- acid detergent fiber; ADL=acid detergent lignin; IVOMD=In vitro organic matter digestibility, ME= metabolizable energy, This could be an indication of presence of extreme values adequate to affect the normal distribution of the data set with respect to those two traits (Couto *et al*., 2013; Salmito *et al*., 2018). .

Nevertheless, there are discrepancies in CV classification for all traits between the Garcia's and Costa's methods in one hand, and the Pimentel-Gomes's method on the other hand. Unlike the Garcia's or the Costa's methods, Pimentel-Gomes's method classified CV of all nutritional quality traits studied (with the exception of crude protein) as low variability (less than 10%) and high variability for crude protein content under both Mean & SD and midquartile & PS indicating that there are less variation among genotypes with respect to all those nutritional quality traits. This could be related to the large classification amplitude range used by this method to classify, and its inabilities to consider the nature of the traits as indicated by Peternelli et al. (2013), Ferreira et al.(2016) and Salmito et al.(2018), and also the normal distribution of data set.

3.5. Association among forage biomass and nutritional quality traits

Person's correlation analysis (Table 5) showed significant association among several traits. The days to cutting (DCH) - done at the booting stage of plant growth and development is positively associated (P<0.05) with PLH, BRV, NLP, DMS, TDA, NDF, ADF and, ADL. Similar relations were reported by other studies in other countries (Deshmukah *et al*., 2018), whereas, STD, LS, Ash, CP, ME and *IVOMD* were negatively correlated (P<0.05) with the DCH. The PLH was also found to positively correlate (P<0.05) with BRX, NLP, DMS, TDA, NDF, ADF and, ADL, and this was in agreement with findings of Abubakar and Bubuche, (2013), but negatively associated (P<0.05) with LSR, Ash, CP, ME and *IVOMD*. The SDM was also positively correlated (P<0.05) with CP, and negatively associated (P<0.05) with *IVOMD*. The BRV content was also found associated (P<0.05) with NLP, DMS, DML, DMS, TDA, NDF, ADF, and ADL, and negatively correlated (P<0.05) with LSR, CP, ME and *IVOMD.* The NLP was also positively correlated (P<0.05) with DML, DMS, TDA, ADF and ADL, and negatively associated (P<0.05) with CP, ME and *IVOMD.* The DML was positively correlated (P<0.05) with DMS, TDA, LSR and ADF. The DMS was also positively associated (P<0.05) with TDA, NDF, ADF and ADL, and negatively correlated with LSR, Ash, CP, ME and *IVOMD*. The TDA was also positively associated (P<0.05) with NDF, ADF and ADL, and negatively correlated with LSR, Ash, CP, ME and *IVOMD.* The LSR was also positively correlated (P<0.05) with Ash, CP, ADF, ADL, ME and *IVOMD*, and negatively associated (P<0.05) with NDF.

The Ash content of the genotypes was also found positively correlated with CP and was negatively associated (P<0.05) with NDF and *IVOMD*. The CP content of the genotypes was also positively correlated (P<0.05) with ME and *IVOMD* and negatively associated with NDF, ADF and ADL. The NDF content was also positively associated (P<0.05) with ADF and ADL, and negatively correlated (P<0.05) with ME and *IVOMD*. The ADF content was also positively associated (P<0.05) with ADL and negatively correlated (P<0.05) with ME and *IVOMD*. The ADL content was also positively correlated with DCH, PLH, Brix, NLP, DMS, TDA, NDF and ADL and negatively associated with ME and *IVOMD*. On the other hand, the ME and *IVOMD* contents of the genotypes were positively

Table 4. Classification of coefficient of variability of forage nutritional quality traits in to low medium, high and very high variability in Ethiopia

Variable	CV classification based on Mean & SD Garcia (1989)				CV classification based on midquartile & PS (Costa et al. (2002)			
	Low	Medium	High	Very high	Low	medium	High	Very high
Ash	CV < 9.3	9.3 < CV < 11.3	11.3 < CV < 12.3	CV > 12.3	CV < 9.3	9.3 < CV < 11.3	11.3 < CV < 12.2	CV > 12.2
CP	CV < 5.5	5.5 < CV< 8.7	8.7 < CV < 10.3	CV > 10.3	CV < 5.3	5.3 < CV < 8.7	8.7 < CV < 10.4	CV > 10.4
NDF	CV < 59.9	59.9 < CV< 63.7	63.7 < CV < 65.6	CV > 65.6	CV < 60.0	60.0 < CV < 63.8	63.8 < CV < 65.8	CV > 65.8
ADF	CV < 40.9	40.9 < CV < 45.9	45.9 < CV < 48.4	CV > 48.4	CV < 41.5	41.5 < CV < 45.9	45.9 < CV < 48.1	CV > 48.1
ADL	CV < 5.3	5.3 < CV < 6.5	6.5< CV < 7.1	CV > 7.1	CV < 5.5	5.5 < CV < 6.3	6.3 < CV < 6.8	CV > 6.8
IV OMD	CV < 43.0	43.0 < CV< 49.2	49.2< CV < 52.3	CV > 52.3	CV < 43.0	43.0 < CV < 48.8	48.8 < CV < 51.7	CV > 51.7
ME	CV < 6.0	6.0 < CV < 7.0	7.0 < CV < 7.5	CV > 7.5	CV < 6.1	6.1 < CV < 6.9	6.9 < CV < 7.4	CV > 7.4

SD = standard deviation; CV= coefficient of variation (%); IQR=inter quartile range; PS=Pseudo-Sigma; Ash=mineral ash; CP=crude protein; NDF= neutral detergent fiber, ADF- acid detergent fiber; ADL=acid detergent lignin; IVOMD=In vitro organic matter digestibility, ME= metabolizable energy, correlated (P<0.05) with each other, the LSR and CP contents. Similar relationships were also reported by Aklilu Mekasha *et al*. (2021) On the other hand there was a negative association (P<, 0.05) with the DCH, PLH, BRV, NLP, DMS, TDA, NDF, ADF, and ADL which corporates reports of Govintharaj *et al*., (2018). From this it is apparent that the *IVOMD* could be used as surrogate traits of selection as it is strongly and positively correlated with most desirable traits, and negatively and strongly associated with most anti-nutritional traits

Table 5. Correlation analysis among different forage biomass and nutritional quality traits of sorghum collections in Ethiopia based on mean values of three replications for 166 genotypes

.	DCH	PLH	STD	BRV	NLP	DML	DMS	TDA	LSR	Ash	CP	NDF	ADF	ADL	ME
PLH	0.34 (0.000)														
STD	-0.17 (0.026)	0.01 (0.889)													
BRV	0.61 (0.000)	0.16 (0.037)	-0.11 (0.146)												
NLP	0.21 (0.007)	0.33 (0.000)	0.02 (0.781)	0.20 (0.012)											
DML	0.07 (0.391)	0.14 (0.079)	0.02 (0.757)	0.16 (0.039)	0.14 (0.07)										
DMS	0.48 (0.000)	0.42 (0.000)	0.02 (0.807)	0.40 (0.000)	0.28 (0.000)	0.53 (0.000)									
TDA	0.39 (0.000)	0.37 (0.000)	0.02 (0.767)	0.36 (0.000)	0.27 (0.000)	0.75 (0.000)	0.96 (0.000)								
LSR	-0.36 (0.000)	-0.23 (0.003)	-0.01 (0.887)	-0.20 (0.009)	-0.12 (0.136)	0.47 (0.000)	-0.39 (0.000)	-0.14 (0.075)							
Ash	-0.19 (0.013)	-0.03 (0.667)	0.06 (0.456)	-0.14 (0.068)	0.15 (0.058)	0.10 (0.179)	-0.33 (0.000)	-0.22 (0.005)	0.47 (0.000)						
CP	-0.85 (0.000)	-0.41 (0.000)	0.15 (0.048)	-0.59 (0.000)	-0.19 (0.013)	-0.06 (0.420)	-0.58 (0.000)	-0.47 (0.000)	0.49 (0.000)	0.36 (0.000)					
NDF	0.23 (0.002)	0.37 (0.000)	-0.07 (0.348)	0.19 (0.014)	0.10 (0.196)	0.08 (0.320)	0.41 (0.000)	0.35 (0.000)	-0.33 (0.000)	-0.55 (0.000)	-0.43 (0.000)				
ADF	0.47 (0.000)	0.56 (0.000)	-0.11 (0.158)	0.40 (0.000)	0.30 (0.000)	0.20 (0.012)	0.44 (0.000)	0.40 (0.000)	0.19 (0.016)	0.12 (0.110)	-0.59 (0.000)	0.61 (0.000)			
ADL	0.58 (0.000)	0.47 (0.000)	-0.13 (0.102)	0.48 (0.000)	0.39 (0.000)	0.15 (0.050)	044 (0.000)	0.40 (0.000)	0.22 (0.005)	0.13 (0.090)	-0.61 (0.000)	0.46 (0.000)	0.92 (0.000)		
ME	-0.70 (0.000)	-0.49 (0.000)	-0.15 (0.062)	-0.53 (0.000)	-0.37 (0.000)	-0.14 (0.074)	-0.49 (0.000)	-0.43 (0.000)	0.28 (0.000)	-0.13 (0.036)	0.72 (0.000)	-0.38 (0.000)	-0.87 (0.000)	-0.94 (0.000)	
IVOMD	-0.76 (0.000)	-0.50 (0.000)	-0.15 (0.049)	-0.56 (0.000)	-0.34 (0.000)	-0.13 (0.092)	-0.55 (0.000)	-0.47 (0.000)	0.35 (0.000)	-0.04 (0.578)	0.81 (0.000)	-0.42 (0.000)	-0.86 (0.000)	-0.92 (0.000)	0.99 (0.000)

DCH= Days to cutting at booting; PLH=Plant height (cm); STD= Stalk diameter (mm) ; BRV = Brix value(%) NLP = Number of leaf/ plant ; DML = Dry matter accumulation in leaf /plant(gm) ; DMS = Dry matter accumulation in stem/plant(gm) TDA = Total dry matter accumulation in aerial plant part /plant (gm) ; LSR= Leaf to stem ratio ; Ash=mineral ash ; CP=crude protien ; NDF= neutral detergent fiber(%) ; ADF=acid detergent fiber (%) ; ADL= acid detergent lignin(%) ; ME=metabolizable energy (Mj/KgDm) ; *IVOMD*=Invitro Organic matter digestibility(%).

4. Conclusion and Recommendations

From the results of the present study, it is apparent that the Ethiopian sorghum collections- most of which if not at all- sourced from local land races across the different agro-ecological settings of the country showed great variation for the different traits of forage biomass and nutritional quality traits. Most of the forage biomass traits studied including days to reach cutting at booting, plant height, stalk thickness/diameter, number of leaves, brix value, and dry matter accumulations through leaf, stem and aerial plant part; the leaf to stem ratios, and among the nutritional quality traits such as crude protein, neutral detergent fiber, acid detergent fiber and *in vitro* organic matter digestibility contents showed large range of variation between respective minimum and maximum values recorded. On the other hand, there were close to zero differences between values of the two measures of central tendency (Mean and Midquantile) for each of the traits like stalk thickness/ diameter, number of leaf, total dry matter accumulation in aerial plant part, leaf to stem ratio, brix value, mineral ash, crude protein, neutral detergent fiber, acid detergent fiber, metabolizable energy and *in vitro* organic matter digestibility contents. Apart from this, the classification of variation among genotypes using the Garcia's and the Costa's methods indifferently classified the days to booting, plant height, stalk thickness/ diameter/, dry mater accumulation through stem and total aerial plant part, neutral detergent fiber, acid detergent fiber, and the *in vitro* organic matter digestibility as low variability; the dry matter accumulation through leaf as medium variability, and .the number of leaf, leaf to stem ratio, brix value, crude protein and acid detergent lignin contents as very high variability traits. On the other hand, the Pimentel-Gomes's classification contradicted those of Garcia's and Costa's classification. The Pimentel-Gomes's method classified variation in all nutritional quality traits (with the exception of crude protein) as low variability; plant height as medium variability; number of leaf, leaf to stem ration, and brix value as high' variability; and that of the dry mater accumulation through leaf, stem and total aerial plant part as very high variability traits among the genotypes irrespective of either Mean & SD or Midquantile & PS methods for CV computation. The selection of a particular method of variability classification for a particular trait is thus contingent up on nature of the trait, as a single method could not do the same for all traits. Moreover, the person's correlation analysis also showed that genotypes possessing characters of earliness with more proportion of leaf to stem ratio have more contents of crude protein, metabolizable energy and i*n vitro* organic matter digestibility. Whereas, those genotypes having character of late maturity and tall plant height with less proportion of leaf to stem ratio have more dry matter yield and soluble solids (sugar/ sweetness) dominated by fibers (NDF, ADF, and ADL) and hence have less crude protein, metabolizable energy and *in vitro* organic matter digestibility contents.. Therefore, from the results of the present study it can be recommended that there is a need to have nationally coordinated breeding activities to exploit the genetic variability among sorghum collections of Ethiopia. Target selection could be specific traits of forage value from land races, and crossing with lines of either post anthesis stay green/ delayed leaf senescence for dual purpose grain-stover quality, or crossing with brown mid rib (bmr) lines known for high digestibility traits to improve fodder nutritional quality.

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