GENETIC DIVERSITY OF NIGERIAN ACCESSIONS OF SORGHUM (*Sorghum bicolor* L. Moench) BASED ON AGRONOMIC AND PHYTOCHEMICAL TRAITS

BY

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April, 2018

DECLARATION

I hereby declare that this dissertation has been written by me and is a record of my own research work. It has not been presented in any previous application for higher degree of this or any other University. All citations and sources of information are clearly acknowledged by means of references.

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DADA MUFTAU IDOWU

Date……

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CERTIFICATION

This dissertation entitled "Genetic diversity of Nigerian accessions of sorghum (*sorghum bicolor* L. moench) based on agronomic and phytochemical traits" by Dada M. I., meets the regulation governing the award of the degree of Master of agriculture of the University of Agriculture, Abeokuta and is approved for its contribution to scientific knowledge and literary presentation.

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ABSTRACT

Interest in sorghum in Africa is increasing because of its use as a raw material for feed production and human consumption. However, high tannin content in the seeds poses huge challenges for sustainable use. The study therefore evaluated genetic diversity of sorghum and investigated the relationship between tannin and agro-morphological traits. Thirty-two landraces (NG/MR/12/11/124[(10)], NGB/SA/07/065, NG/AO/11/08/113, NGB 01900 and NGB 01896 among others) and seven improved Sorghum accessions (SAMSORG 43, SAMSORG 42, and SAMSORG 17 among others) were obtained from National Center for Genetic Resources and Biotechnology, Ibadan, Nigeria. The experiment was carried out during the late cropping season of 2015 at the Teaching and Research Farms of Federal University of Agriculture, Abeokuta, Ogun State, Nigeria on altitude 76 m above sea level, latitude 7^0 15^1 N and longitude 3^0 28^1 E. The experiment was laid out in a Randomized Complete Block Design in three replicates with a total of fifteen Sorghum plants maintained per plot. Data on thirteen agronomic traits (Grain yield/plant, Panicle/plant and 1000-grainweight among others) and tannin content of each accession were recorded on ten randomly selected plants and subjected to Analysis of Variance, mean values were separated using Duncan's Multiple Range Test at $p < 0.05$ and broad-sense heritability was estimated from the variance components. Genotypic and phenotypic correlations among the agro-phyto-chemical traits were calculated. Principal Component and Cluster Analyses using Ward's method were employed to study the variation pattern among the accessions. Result showed significant genotypic effect at both 1% and 5% probability levels for all investigated traits. High broad-sense heritability estimates of 99.8, 99.4, 74.2 and 71.5 were obtained for 1000-grain weight, tannin content, number of days to 50% tasseling and number of panicles per plant, respectively. Progress that could be expected from selecting the top 5% of the accessions for genetic advance ranged from 13.6% (for number of days to 50% tasseling) to

88.03% (for tannin content). Of the 14 principal components, only four had Eigen values greater than one and cumulatively explained approximately 78% of the total variation. Significant negative phenotypic and genotypic correlation were observed between grain yield per hectare and tannin content (r= -0.32**, r= -0.43**). Using Ward's method, the dendrogram, produced five (I, II, III, IV, V) homogenous clusters. The three accessions found in cluster IV had higher 1000-grain weight (39.33 g) with lower tannin content (0.29 mg/g). Cluster V had 6 accessions with higher number of panicles per plant (4.33), grain yield per plant (341.61 g) and grain yield per hectare (22204.64 kg). The results indicated that sorghum is genetically diverse and there is possibility to exploit selection of relevant characters to increase the grain yield and reduce tannin content of sorghum. The study concluded that accessions: NG/MR/12/11/124[(10)], NGB/SA/07/065, SAMSORG 14, NG/AO/11/08/113, NGB 01900 and NGB 01896 were the highest grain yielders with moderate tannin content while NGB 01894, SAMSORG 43, SAMSORG 42 and SAMSORG 17 were accessions with low tannin content. Selection for seed yield improvement with low tannin content should therefore include an indirect selection for sorghum since they had significant role in improving the yield and low tannin content.

DEDICATION

This research work is dedicated to Almighty God and to my late brother Dada, Adeola Sulaimon.

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CHAPTER ONE

1.0 INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is a grass species native to the arid and semi-arid regions of Africa (Kimber, 2000). It is an annual grass similar in appearance to maize (corn), although it has more stems and more finely branched roots. Sorghum is a tall plant of 5-7 feet. Through genetic improvement, recent varieties now have 2-3 dwarf genes, resulting in a plant with 2-4 feet tall, less prone to lodging and easier to harvest. Historically, Africa's indigenous cereal grains including sorghum have been a major food for humans and livestock because their constituents are of nutritional importance. Sorghum is one of the five most important cereal crops after rice, wheat, corn and barley. It is considered as source of diet to over 500 million people in about 30 countries including Nigeria (FAOSTAT, 2012). In 2012 about 57 million tonnes was produced all over the world with larger percentage coming from the top producers like Mexico, Nigeria, U.S.A and India. Africa accounts for 23.35 million tonnes. In West Africa, 12.3 million tonnes were produced in 2012 and Nigeria, being the largest producer in Africa, produced 6.9 million tonnes (FAOSTAT, 2012). This makes the crop the largest cereals crop in Nigeria (Aba *et al.*, 2004). The Bulk of the Sorghum produced in Nigeria is produced in the Savannah zones of the country (FMEST, 1984).

About 55% of the crop is being used in the production of food (Reddy *et al*., 2010) such as Bread, Porridge, Fura, Akamu e.t.c. Sorghum flour is also incorporated into wheat flour of various percentages to produce cakes, cookies and bread (Abdelghafor *et al*., 2011). It is considered as a principal source of energy, protein, vitamins and minerals for millions of poor people in Africa (Abdulkadir *et al*., 2017). Furthermore, significant amount is being

used as fuel mostly in the semi-arid tropics of Asia, Africa and America (McLaren *et al*., 2003).

Sorghum is a nutritionally rich, energy producing cereal that can be grown in areas of the world that are too hot or too dry for other crops to be grown successfully. It serves as a staple food in most parts of Northern Nigeria. The grain has assumed commercial relevance lately, especially in the food and beverage industry. It has been found to be a valuable ingredient next to malted barley used in the food industry. The grain is also used in the production of alcohol (Burukutu) and Malts (Adegbola *et al.,* 2013; Momoh, 2012; Eleke, 2011).

Sorghum grain contains relatively high amount of anti- nutritional compound called tannin which has been reported in many literatures (Hancock, 2000; Ravindran *et al*., 2005; Sell *et al*., 2010). Many studies have demonstrated an array of deleterious influences of tannin including: (i) depressed feed intake, (ii) increased endogenous protein secretion, (iii) formation of less digestible tannin-dietary protein complex, (iv) inhibition of digestive enzymes, (v) toxicity of absorbed tannin or its metabolites (Sell *et al*., 2010). It appears that these negative effects result from the ability of tannins and specially condensed tannins, to bind and precipitate proteins including grain proteins and digestive enzymes (Butler and Rogler, 1992).

The prevailing dominance of maize seems to suggest an agricultural sector that is seriously in need of crop diversification if crop failure risk is to be kept to the minimum. Sorghum is considered as a good alternative source of energy in livestock feeding (Reddy *et al*., 2010; Manson, 2010). However, the grain contains anti-nutritional factor (Tannin) that makes it less digestible than Maize. Genetic improvement of Sorghum and incorporating it into mainstream diet of farm animals are necessary in order to realize the benefits it may offer.

Sorghum tannins are of condensed type while hydrolysable tannins apparently do not occur in sorghum (Nyachoti *et al*., 1997). Tannins, naturally occurring polyphenolic compounds, are mostly found in dicotyledonous plants, most commonly in legumes. Important grains which are used for human and animal consumption are known to contain a significant amount of tannin contents like sorghum (*Sorghum bicolor*), millet (*Panicum milisceum*), barley (*Ordeum vulgare*) and a number of other legume seeds (Arija *et al*., 2006; Rana *et al*., 2006).

1.1 Justification

The increase commercial value of sorghum may be due to its substitute for barley in the brewery industry and maize in the poultry industry. As sorghum gains commercial relevance, its tannin content, which is an anti-nutritional factor that limits it usage in the aforementioned industries is also gaining research attention. Tannin affects malting quality and digestibility of nutrients in human, it also reduces weight gain in poultry birds coupled with other deleterious effects in some livestock. Nigeria has a long history of sorghum production and there are quite a number of genotypes which are cultivated nationwide. Nigeria is recognized as one of the most precious sources for studying sorghum genetic diversity. Hence assessment of genetic diversity in sorghum germplasm would help to know the breeding potentials of the accessions and identify accessions suitable for both food and poultry industries in Nigeria.

1.2 Objectives

The objectives of this study were to:

1. evaluate phenotypic diversity among Nigeria sorghum accessions;
2. compare tannin content among Nigeria sorghum accessions;
3. estimate broad-sense heritability for the traits evaluated;
4. determine genetic correlation between tannin content and agronomic traits.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin of Sorghum

The origin of sorghum is believed to have been from northeastern part of Africa where it was domesticated about 5,000 years ago (Mann *et al.*, 1983) and spread to West Africa at an early date across Sudan to the upper Niger River (Abdulhmid *et al.*, 2011). Moreover, the seeds obtained from the ancient Holocene archeological site at Nabta Playa near the Egyptian-Sudanese border showed that the seeds date back some 8,000 years ago (Wendorf *et al.*, 1992). The early domestication of the crop aided it distribution through the major trading and migratory patterns of the early Africans and Asians (Dahlberg *et al.*, 2011). The Cushites, who occupied favorable sites on high grounds and practiced terraced agriculture extended the distribution of sorghum to East Africa (Etuk *et al.*, 2012). At about the middle of the ninth century sorghum was introduced to the United States of America (USA) as Guinea corn from West Africa through slave trade (Etuk *et al.*, 2012). Although, literatures suggested Africa as the origin of sorghum which is widely accepted, Damania (2000), was of contrary opinion to the premise that sorghum emanated from Indian sub-continent but this is considered as minority belief.

2.2 Biology of Sorghum

Sorghum is a C4 crop in the grass family and is characterized by its high photosynthetic efficiency. It is an annual crop with considerable variability in growth characteristics. Grain, sweet, and forage types are all compatible with current agricultural production systems. Crops with a four-carbon (C4) photosynthetic pathways produce 30% more dry matter (DM)

per unit of water than three-carbon (C3) crops and are more adapted to semi-arid production regions (Samson and Knopf, 1994). Sorghum plants have the ability to counterbalance production situations. Habyarimana *et al.* (2004) reported that lower plant density results in higher leaf weight per plant, higher grain weight per panicle and higher tillering ability. Sorghums have an extensive root system that can penetrate 1.5 to 2.5 meters into the soil and extend one meter away from the stem. The large amount of root material contributes to the build-up of soil organic carbon after removal of the aerial parts of the plant, and can alleviate concerns about depletion of soil organic matter resulting from the removal of Stover (Wilhelm *et al.,* 2004). Sorghum requires less fertilizer than corn to achieve high yield (Lipinsky and Kresovich, 1980), can tolerate a wide range of soil conditions; from heavy clay soils to light sand, with pH ranging from 5.0 to 8.5 (Smith and Frederiksen, 2000). Sorghums become dormant in the absence of adequate water but do not wilt readily and are more efficient than corn in utilizing phosphorus and potassium. These characteristics make sorghum suitable for cultivation as a crop in optimal conditions and on marginal land.

2.3 Constraints of Sorghum Production

The potential productivity of sorghum is constrained by a number of abiotic and biotic stresses. Nutrient deficiency in the soil and extended dry spell predominate among the abiotic factors. Biotic constraints of sorghum production include the parasitic weed; *Striga* (*Striga* species), foliar and panicle diseases, stem borers, and shoot fly (Wortmann *et al.,* 2006). Sorghum production constraints vary from region to region within Nigeria. However, birds, drought and *Striga* are the most the most prominent production constraints across regions. According to Ejeta (2007), a vast area of land of the African savannah zones have been infested by this parasitic weed.

2.4 Sorghum Production and its Distribution

Sorghum is one of the most important feed and food crops in the arid and semi- arid tropics (Hulse *et al*., 1980). It is widely grown in several parts of the world including Nigeria. In West Africa, Issa *et al*. (2007) reported that it is the second most important cereal grain after millet and just before corn. Moreover, it is produced extensively in Sahelian countries like Burkina Faso, Mali, Senegal, Niger and Nigeria and could play an important role in feeding poultry (Issa *et al.*, 2007; Kwari *et al.*, 2011). It is the main food grain in Africa (Tukur, 2011) and mainly grown in the Northern part. Sorghum can be grown successfully on poorer soils and under drier conditions than maize. FAO (2007) also reported that 440,000 square kilometres were devoted worldwide to sorghum production. In Nigeria, 50% of the total area devoted to cereal crops is occupied by sorghum, with estimated area of 6.86 million hectares extended north-wards from Latitude 8°N to 14°N (Aba, *et al.*, 2004). Nigeria, is the highest sorghum producer accounting for 71% of the regional total output. In the world, the country leads in sorghum production for human consumption which has risen from its fifth position in 1995 (FAO, 1995) to be the second largest producer in the world after USA and India where more than 90% of their sorghum harvest is used for animal feed (Obilana, 2005). Sorghum is one of the most important staple food crops in Nigeria and its production surpasses all other crops. According to FMEST (1984), sorghum in the Nigerian savannah zone is grown on an estimated area of 4.5 million hectares with annual production output of about 6 million tons.

2.5 Uses of Sorghum

The ability of Sorghum to grow in areas where maize may not grow gives it a comparative advantage of mitigating against shortage in local food and livestock feed production

(Legodimo and madibela. 2013). About 55 percent of the grain is being used in the production of food (Reddy *et al.,* 2010) such as bread, porridge ("Ogi" and "Tuwo"), "Fura", "Akamu", de-hulled cracked sorghum meal ("Pate"), coucous, popped grain, gruel and snacks (Adegbola *et al.*, 2013; Dahlberg, 2011; Reddy *et al.*, 2010.). Sorghum flour is also incorporated into wheat flour at various percentages to produce cakes, cookies and bread (Abdelghafor *et al.*, 2011). Among the poor people in Africa and Asia, Sorghum is considered as a principal source of energy, protein, vitamins and minerals (abdulkadir *et al.,* 2015). In developed countries, about 33 % of sorghum grain is used in livestock production (Reddy *et al.*, 2010; Manson, 2010). The grains are also used in the production of alcoholic and non-alcoholic beverages such as beer ("burkutu") and malts (Adegbola *et al.,* 2013; Momoh, 2012; Eleke, 2011). The stalks are used as building material and fencing (Rooney and Waniska, 2000). The stem and foliage are used for green chop, fodder, hay, silage and pasture (Dahlberg, 2011). Sorghum can also be utilized in the production of bio-industrial products such as bio-plastics (McLaren *et al.*, 2003).

The leaves and grains are also used for livestock feeds and the stalks for thatching houses and making fences (NAERLS, 1997). It is used to substitute maize to a reasonable extent in livestock feeding. The use of sorghum in livestock feeding is limited by its contents of tannin (polyphenols), phytates and cyanogenic glycosides (Awika *et al.,* 2003). Sorghum is also used in human food in various forms especially in the Northern part of the country (Shaib *et al.,* 1997). Sorghum is a very valuable industrial crop for brewing alcoholic and non-alcoholic drinks as well as in the baking and confectionery industries in Nigeria. According to Samson *et al* (1981), sorghum has greater untapped potentials than any other crop, it was even postulated that if the twentieth century was the century of wheat, rice and maize, then

the twenty-first century could become the century of sorghum. The potential for sorghum to be the driver of economic development in Africa especially Nigeria cannot be over emphasized.

2.6 Genetic Diversity of Sorghum

Sorghum is a genetically diverse crop and contains some genotypes that have a pigmented testa and therefore contain tannins (Rooney *et al* 1980; Rooney and Miller 1982). Sorghum varieties come in a wide range of colors described as white, cream, yellow, orange, bronze, red, brown, and various combinations of these colors. The sorghum kernel has three distinct parts, the pericarp or bran at the outside, the germ or embryo, and the endosperm or storage tissue. In general, the endosperm represents 85% of the whole grain, the germ 9%, and the pericarp only 6% (Haikerwal and Mathienson, 1971). Some varieties have a thin layer of cells underneath the pericarp called testa. This layer may contain tannins, which are phenolic compounds similar with those in fruits and red wine. The pericarp can be white, red, or yellow, and the endosperm can be white or yellow. Pericarp thickness can vary from very thin (8 μm) to very thick (160 μm). Pericarp color and thickness, endosperm color, and presence or absence of testa determines the grain color (Rooney and Miller, 1981). Usually, sorghum high in tannin content is brown but may also be white, yellow-pink, orange, red, or bronze.

Both the cultivated and the wild races sorghum possess a significant amount of genetic diversity for traits of agronomic importance (Hart *et al.,* 2001). Approximately 4,000 cultivars of sweet sorghum are distributed throughout the world (Grassi *et al.,* 2004), providing a diverse genetic base for the development of highly productive cultivars within

various climate regions. Various biological techniques, including tissue culture (Baskaran and Jayabalan, 2005), genetic

transformation (Godwin and Seetharama, 2005), molecular markers, genomics, and proteomics have been successfully exploited in sorghum (Dillon *et al*., 2005). The sorghum genome has recently been sequenced, providing a better understanding of genetic and biochemical traits which will assist in developing a better genomics-assisted breeding program in sorghum (Paterson et al., 2009).

2.7 Tannin Content of Sorghum

Tannin is the most uniquely important phytochemical components of sorghum since it possess properties that produce obvious and significant effects in animals, and has also been associated with various positive (treatment of obesity) and negative (affects digestibility of nutrients) impacts on human health. Sorghum varieties and hybrids differ in palatability and nutritional value, which may be associated with the level of tannin in the grain (Kim *et al.,* 2000). Tannins are a group of compounds that bind proteins, thus impairing protein digestion (Adewusi and Matthew 1994). Sorghum tannins are of condensed type while hydrolysable tannins apparently do not occur in sorghum (Nyachoti *et al.*, 1997). Sorghum is mostly cheaper than maize and abundantly available in most parts of the Northern Nigeria. Literature reports that the old varieties of sorghum grain contained relatively high amount of an anti-nutritional compound called tannin (Hancock, 2000; Ravindran *et al*., 2005; Sell *et al.*, 2010). Many studies have attributed an array of deleterious influences to tannin including: (i) depressed feed intake, (ii) increased endogenous protein secretion, (iii) formation of less digestible tannin-dietary protein complex, (iv) inhibition of digestive enzymes, (v) toxicity of absorbed tannin or its metabolites (Sell et al., 2010). It's appeared that these negative

effects resulted from the ability of tannins and specially condensed tannins, to bind and precipitate proteins including grain proteins and digestive enzymes (Butler and Rogler, 1992).

2.7.1. Production and Genetics of Tannin Sorghum

Decades of breeding efforts to eliminate tannins from sorghum were motivated mostly by the reduced feed value of the tannin sorghums. Tannins bind with protein and reduce digestibility of various food/feed nutrients, thus negatively affecting productivity of livestock. Current non-tannin sorghums grown for livestock feed have virtually the same energy profile as corn. However, in many other parts of the world where pests and diseases are common, tannin sorghums are still grown in significant quantities since they are more tolerant of such conditions than the non-tannin varieties (Hahn *et al*., 1983; Waniska *et al*., 1989). Tannins are present in sorghums with a pigmented testa (classified as type II and III sorghums). These sorghums have dominant B1_B2_ genes. The B1 and B2 genes control the presence or absence of the pigmented testa layer (Hahn and Rooney, 1986). Both genes must be dominant for a pigmented testa to develop. When the S gene (spreader gene) is dominant concurrently with the dominant B1 and B2 genes, pericarp color becomes phenotypically brown (Earp *et al*., 1983). The sorghums with the dominant S_ gene generally contain tannins that are more easily extractable than the ones with the recessive gene (Hahn and Rooney, 1986). Such sorghums (with dominant S_ gene) also produce greater anti-nutritional effects in animals (Cousins *et al*., 1981). Since the pericarp color and secondary plant color of sorghum is genetically controlled, it is possible to develop different combinations of pericarp and plant color with and without the pigmented testa and spreader genes, which opens the possibility of significantly different levels and combinations of phenolic compounds.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of experimental site

The experiment was carried out at the experimental field of College of Plant Science and Crop Production of Federal University of Agriculture Abeokuta, Ogun State, Nigeria. The experimental site is situated at an altitude of 76m above sea level of 7^0 15^1 N and longitude 3^0 28^1 E. In the forest savanna transition zone of Nigeria, there are two main cropping seasons, wet season (April - October) and dry season (November - March). Sorghum performs best during the transition from wet to dry season period. The site experiences bimodal rainfall from April to September, peaking in July and September separated by a short dry spell in august and a long dry spell from November to March (Table 11).

3.2 Seed source

Thirty-nine (39) accessions of sorghum were obtained from National Center for Genetic Resources and Biotechnology (NACGRAB), Ibadan. These included thirty two (32) land races and seven (7) improved accessions (Table 1).

Table 1: Thirty-nine sorghum accessions used in the study with their seed coat colour

S/No	Accessions	Seed coat color	S/No	Accessions	Seed coat color
1	NGB 01952	Red	**21**	07/0127	Off-white
2	NGB 01707	Off-white with black spot	**22**	NG/AA/SEPT/09/159	Orange
3	NGB 01894	Off-white	**23**	NGB/06/0004	White
4	NGB 01739	Pink	**24**	NG/AA/SEPT/09/160	Off- white
5	SAMSORG 43	Cream	**25**	SAMSORG 41	Off-white
6	NG/SA/DEC/070220	Pink	**26**	SAMSORG 42	White
7	NG/SA/JAN/09/0088	Pink	**27**	NGB 01709	Red
8	NGB 01270B	Red	**28**	NG/AO/APR/09/0061	Orange
9	NGB 01716^{H}	Orange	**29**	SAMSORG 14	White
10	SAMSORG CSR-01	White	**30**	NG/MR/12/11/113	Orange
11	NGB 01727	Gold	**31**	NG/OJ/MAY/09/009	Red and cream
12	NGB 01704	Red and cream mixed	**32**	NG/OJ/MAY/09/010	Red
13	NGB/AA/SEP/09/162	White with red spot	**33**	NG/AO/11/08/113	Red
14	NGB/SA/07/065	Pink	**34**	SAMSORG 17	Cream
15	SAMSORG 40	Off-white	**35**	NGB 01900	Off-white with red spot
16	NG/AO/APR/09/004	Red and orange mixed	**36**	NGB 01896	Off-white
17	NG/AA/MAY/09/038	White with black spot	**37**	$NG/MR/12/11/124^{(10)}$	Orange
18	NG/AO/11/08/119	Red	**38**	NGB 01969	Red
19	NG/TO/APR/09/108	Red and orange mixed	**39**	$NGB\ 01879^{B5}$	Red
20	$NGB\ 01721^{H}$	Red and orange mixed			

Source: National Center for Genetic resources and Biotechnology (NACGRAB), Ibadan, Nigeria.

3.3 Soil Analysis

A composite sample from the well mixed soil of the experimental site was collected before planting for analysis to determine the physico-chemical properties of the soil (i.e. particle size distribution, cation exchange capacity (CEC), exchangeable bases, organic carbon, soil pH, organic matter concentration, total nitrogen (N), potassium (K) concentration, extractable phosphorus (P) etc.

3.4 Land preparation, experimental setup and cultural operations

The field was cleared and ridges were constructed using hoes and cutlasses for tillage. The experiment was laid out in a randomized complete block design (RCBD) in three replicate. Seeds were sown in December, 2015 in a single row plot of 5m long with inter row spacing of 0.9m and 0.35m of plant-to plant distance within a row. A total of fifteen plants were maintained per row and ten randomly selected plants within each row were used for data collection.

3.4.1 Planting operations

Five (5) seeds of sorghum were planted per hole at a depth of 2 cm – 5 cm at an intra-row spacing of 30 cm on the ridge and later thinned to 1 plant per stand at three weeks after sowing.

3.4.2 Weeding

Weeding was carried out manually as the need arose.

3.4.3 Harvesting

Final harvesting of sorghum was carried out manually when dark black spot appeared at the basal portion of the grain and the glume turned reddish brown.

3.5 Data collection

3.5.1 Growth Parameters

Data were collected on growth and yield parameters. The following growth parameters were collected at 50% tasseling;

Plant height (cm): The height of sorghum plants was measured using meter rule from the base of the plant to the collar of the topmost leaf in the plant of the five tagged plants on a plot and then divided by five to obtain a mean value.

Stem girth (cm): This was measured with the aid of calibrated Vernier calipers

Number of leaves: The number of leaves on the tagged plants was counted.

Leaf area (cm^2): The length and width of the tagged plants leaves was measured with meter rule. Leaf area was determined using the methods described by Sticker *et al*. (1961) and Mass *et al*. (1987) as follows: LA = W x L x 0.75. Where LA = Leaf area (cm^2), W = Maximum leaf width (cm), L = Leaf length (cm) and 0.75 = Correction factor for sorghum.

Number of days to 50% tasseling: This was calculated by counting the number of days to which half of the plot has tasseled.

3.5.2 Yield parameters

The following parameters were taken on the yield components;

Number of panicles per plant: The number of panicles on each tagged plant was counted and the average mean was calculated.

Spikelet per panicle: The number of spikelet contained in each panicle on each tagged plant was counted and the average mean was calculated.

Grains per spikelet: The number of grains contained in each spikelet on each tagged plant was counted and the average mean was calculated.

Number of grains per panicle: The number of grains on each tagged plant panicles was counted and the average mean was calculated.

1000-grain weight (g): 1000 grains was counted and weighed using sensitive scale.

Grain yield per panicle: The grains on each tagged plant panicles was weighed and the average mean was calculated.

Grain yield per plant (g): The grain yield per plant was determined by averaging the grain yield of the tagged plants on each plot.

Grain yield per hectare (kg): This was calculated by harvesting the total plot and weighed, later converted to per hectare.

3.6 Tannin Content Determination

Blended dry sample of sorghum seeds (1 g) was weighed into a flask, 10 ml of distilled water was added and agitated. The mixture was allowed to stand for 30 min at room temperature and centrifuged at 2500 rpm for 15 min. Two (2 ml) of the supernatant was measured into 10 ml volumetric flask, I ml of folin-ceocalteu reagent was added. Two (2 ml) of saturated Na_2CO_3 solution was added and diluted with 10 ml distilled water and later incubated for 30

min at room temperature. The procedure was repeated for tannic acid standards 20, 40, 60, 80, 100, 120 mg/l from a stock of 500 ppm (50mg of Tannic acid standard dissolved in 100ml of distilled water) excluding centrifugation. The absorbance's of the tannic acid concentration was read at a wavelength of 725 nm.

A calibration curve was drawn for the tannic acid standards that is absorbance against concentration. Extrapolation was done by tracing the absorbance of the sample down the concentration axis to obtain the tannic acid concentration of the sample.

$$\text{Tannic Acid content (mg/kg)} = \frac{\text{Conc. obtained in mg/l} \times \text{volume of sample} \times \text{DF}}{\text{Sample weight}}$$

DF: Dilution factor. If not diluted, then DF = 1

(Jaffe, C.S., 2000 and Rajeev *et al*., 2012.)

3.7 Statistical Analysis

The data were compiled by taking the means of all the plants taken for each treatment and replication for different traits. Data observation recorded on agronomic and tannin content characters were subjected to analysis of variance using SAS software version 6.08. Simple statistic (mean and co-efficient of variation) were used in order to compare genetic variation between populations and mean results were compared using Duncan multiple range test (DMRT).

Variance components (genotypic variance, phenotypic variance, genotypic coefficient of variation, phenotypic co-efficient of variation, heritability and genetic advance) were estimated as described by Allard (1960).

Genotypic and phenotypic correlations were calculated following Al-jibour et al, (1958). The correlation significance was tested against r values as described by fishers and yates (1963) at (n-2) degree of freedom; when n is the number of genotypes.

The genotypic and phenotypic coefficient of variation were calculated using Burton and De vane method (1953).

$$\text{Genotypic coefficient of variation (GCV) \%} = \frac{\sqrt{\text{genotypic variance (vg)}}}{\text{General mean of population (X)}} \times 100$$

$$\text{Phenotypic coefficient of variation (PCV) \%} = \frac{\sqrt{\text{genotypic variance (vg)}}}{\text{General mean of population (X)}} \times 100$$

Broad sense heritability was calculated according to Allard (1960) $H\% = Vg/Vp \times 100$

Where H is heritability (%), Vg is genotypic variance [Vg = (Mt - Me)/r], Vp is phenotypic variance (vg + ve).

Where Mt is treatment mean sum of squares, Me is error mean sum of squares, r is replication(s).

Genetic advance $= H \times \alpha p\, k$ (Allard, 1960), where H is heritability, αp is phenotypic standard of deviation, and K is 2.06 (selection differential at 5% selection index).

Genetic gain expressed as percentage of genetic advance of the population mean, was calculated by the method of Johnson *et al.* (1955).

$$\text{Genetic gain (\%)} = \frac{\text{Genetic advance (GA)}}{\text{Genetic mean of the population (X)}} \times 100$$

The multivariate statistical procedure, principal component analysis (PCA) was performed to determine the similarities and differences of the measured traits. Eigen vectors and eigen values of the first four principal components axes were calculated on the basis of similarities correlation matrix.

The character profile of the genotypes and the relationship among the agronomic and phyto-chemical traits were also investigated further by PCA and visualized by biplot as described by Yan and Rajcan (2002). Genotypes and agro-phytochemical traits scores from the first two PCA, which explains the most important part of the data, were used prior to visual presentation of the results of the multivariate analysis. The interpretation of the biplot graph is based on the inner-product principle (Yan and Rajcan, 2002). A positive correlation between two traits is presented by an acute angle between them and obtuse angle represent a negative correlation.

Hierarchical clustering was then carried out using Ward's minimum variance method (Ward 1963) that minimizes within a cluster sums of squares across all partitions. The intra and inter cluster distances were calculated following the method described by Rao (1952).

CHAPTER FOUR

4.0 RESULTS

The mean squares from analysis of variance for grain yield and agronomic traits of sorghum accessions are presented in Table 2. Significant to highly significant differences were observed among the accessions for all traits studied.

4.1 Performance of thirty-nine sorghum accessions for growth characters

The mean performance of the sorghum accessions with respect to growth characters are shown in Table 3. Significant differences ($p < 0.05$) were observed among the thirty-nine accessions for all growth traits. Genotypes NG/AO/APR/09/004, NG/OJ/MAY/09/009 and NG/AO/11/08/113 were among the accessions with the tallest plant height with 363.15 cm, 363.90 cm and 344.27 cm, respectively. NGB 01894 and SAMSORG 17 significantly ($p < 0.05$) had the widest stem of 3.15 cm and 2.52 cm, respectively compared to other accessions. The highest number of leaves was produced by NGB 01894 (14.67) while the least number of leaves were observed in NG/SA/JAN/09/0088 (5.42) and SAMSORG 41 (5.38). The genotypes NGB 01894, SAMSORG 40 and NGB 01707 significantly ($p < 0.05$) had the largest photosynthetic area of 638.45 cm^2, 555.61 cm^2 and 517.15 cm^2 respectively.

Table 2: Mean squares from Analysis of Variance (ANOVA) for seed yield and agronomic traits of Sorghum accessions

CHARACTERS	SORGHUM ACCESSIONS	REPLICATION	ERROR
Plant height	8575.74**	6481.29	4053.17
Stem girth	0.64**	0.33	0.25
Number of leaves	9.26**	40.19**	3.09
Leave area	21818.29*	13848.61	12889.63
No of days to 50% tasseling	169.74**	3.31	43.73
Panicle/ plant	2.60**	1.85	0.74
Spikelet/ panicle	139.23**	31.42	73.03
Grains/ spikelet	1395.07*	1155.73	752.22
Grains/ panicle	3890047.1**	3558395.9	1866671.1
1000 grain weight (g)	71.81**	80.99**	0.10
Grain yield/ panicle	3739.27**	6634.1*	1649.18
Grain yield/ plant	33044.89**	66038.48*	15332.49
Grain yield/hectare (kg)	139614663**	279012580*	64779785
Tannin content (mg/g)	0.18**	0.004*	0.001

*Significant at 5% level of probability; **Significant at 1% level of probability

TABLE 3: Mean performance of thirty-nine sorghum accessions for growth characters

Accessions	Plant height (cm)	Stem girth (cm)	Number of leaves	Leave area (cm^2)
NGB 01952	331.50abc	1.53b-i	9.40b-e	330.24b-f
NGB 01707	336.80abc	2.38bc	8.30b-f	517.15abc
NGB 01894	330abc	3.15a	14.67a	638.45a
NGB 01739	200.15de	1.66b-i	5.88ef	368.01b-f
SAMSORG 43	187.68de	1.33d-i	8.30b-f	311.72c-f
NG/SA/DEC/070220	188.07de	1.34c-i	6.80def	313.38c-f
NG/SA/JAN/09/0088	174.30de	1.01f-i	5.42f	240.63ef
NGB 01270B	268.70a-e	1.79b-i	8.92b-f	376.30b-f
NGB 01716^H	174.85de	0.92ghi	7.07c-f	195.85f
CSR-01	216.25b-e	1.29d-i	9.00b-e	389.80b-f
NGB 01727	301.77a-d	1.64b-i	9.18b-e	357.89b-f
NGB 01704	303.07a-d	1.68b-i	8.27b-f	387.69b-f
NGB /AA/SEP/09/162	302.33a-d	1.56b-i	8.73b-f	335.24b-f
NGB/SA/07/065	295.17a-e	1.77b-i	11.08b	343.83b-f
SAMSORG 40	214.48dce	1.77b-i	7.05c-f	555..61ab
NG/AO/APR/09/004	363.15a	1.71b-i	10.52b	428.51a-f
NG/AA/MAY/09/038	267.87a-e	1.60b-i	6.65def	385.73b-f
NG/AO/11/08/119	303.40a-d	1.68b-i	9.13b-e	418.02b-f
NG/TO/APR/09/108	265.63a-e	1.24e-i	6.97c-f	359.76b-f
NGB 01721^H	262.37a-e	1.86b-h	5.92ef	456.19a-e

Means followed with the same alphabet in a column are not significantly different from each other at $p < 0.05$

TABLE 3 cont'd

Accessions	Plant height (cm)	Stem girth (cm)	Number of leaves	Leave area (cm^2)
07/0127	258.55a-e	1.7b-i	8.57b-f	455.42a-e
NG/AA/SEPT/09/159	237.27a-e	0.81i	7.60c-f	323.14c-f
NGB/06/0004	189.78de	1.42c-i	6.77def	271.85def
NG/AA/SEPT/09/160	261.20a-e	1.01f-i	6.87def	359.76b-f
SAMSORG 41	251.05a-e	1.96b-f	5.38f	406.12b-f
SAMSORG 42	338.90abc	2.25bcd	8.63b-f	491.91a-d
NGB 01709	267.60a-e	0.89hi	7.30c-f	279.55def
NG/AO/APR/09/0061	282.15a-e	1.34d-i	8.80b-f	419.60b-f
SAMSORG 14	251.88a-e	1.65b-i	9.75bcd	354.10b-f
NG/MR/12/11/113	283.30a-e	1.72b-i	8.60b-f	357.83b-f
NG/OJ/MAY/09/009	274.73a-e	1.30d-i	6.67def	375.64b-f
NG/OJ/MAY/09/010	264.00a-e	1.32d-i	8.33b-f	347.58b-f
NG/AO/11/08/113	344.27ab	1.91b-g	9.60bcd	430..48a-e
SAMSORG 17	171.73e	2.52ab	8.75b-f	396.98b-f
NGB 01900	363.90a	1.92b-g	9.8bcd	499.24a-d
NGB 01896	242.15a-e	1.45c-i	8.48b-f	354.54b-f
NG/MR/12/11/124$^{(10)}$	240.33a-e	2.07b-e	8.83b-f	370.09b-f
NGB 01969	231.65b-e	1.34d-i	7.12c-f	258.99ef
NGB 01879^{B5}	229.63b-e	1.64b-i	6.90def	363.23b-f

Means followed with the same alphabet in a column are not significantly different from each other at $p < 0.05$

4.2 Performance of thirty-nine sorghum accessions for yield and yield related characters

The sorghum accessions significantly ($p < 0.05$) differ with respect to their yield and yield related characters (Table 4). NGB 01894, NGB 01270B and NGB 01707 were among the accessions that were late flowering with 102.33 days, 94.67 days and 93.67 days, respectively. The accessions SAMSORG 14, NG/MR/12/11/124$^{(10)}$, NG/AO/11/08/113 and NGB 01896 gave the highest number of panicles per plant (5, 4.67, 4.33 and 4.33, respectively) compared to other accessions. SAMSORG 43 and NGB 01894 significantly produced the highest number of spikelets per panicle (55.67 and 53.67) while NGB 01969 had the lowest number of spikelets per panicle (21.33). The number of grains per spikelet was significantly higher in CSR-01 (122.35), NGB 01894 (114.44) and NGB 01707 (112.32) compared to other accessions. The genotype NGB 01894 (6080) produced the highest number of grains per panicle, followed by NG/MR/12/11/124(10) (5260) and CSR-01 (5112) while the least was observed in NGB 01969 (1167). The heaviest 1000-grain was observed in SAMSORG 43 (43 g), followed by NGB 01739 (39 g) and SAMSORG 42 (38.8 g) while NG/MR/12/11/124(10) produced the lowest 1000-grain weight (21.5 g) among the accessions. The genotypes CSR-01, SAMSORG 43, 07/0127, NGB 01707 and NGB 01894 significantly had the highest grain yield per panicle (187.8 g, 163.8 g, 158.9 g, 157.8 g and 156.4 g, respectively) among the accessions. However, accession NGB 01969 has the least grain yield per panicle (29.43 g). The highest grain yield per hectare were observed in NG/MR/12/11/124$^{(10)}$ (35610kg), followed by CSR-01 (28118 kg) then NGB 01707 (26228 kg) while the lowest grain yield were produced by NGB 01709 (6664 kg) and NGB 01961 (5795 kg)

TABLE 4: **Mean performance of thirty-nine sorghum accessions for Yield and yield related characters**

Accessions	No of days to 50% tasseling	Panicle/ plant	Spikelet/ panicle	Grains/ spikelet	Grains/ panicle	1000 grain weight (g)	grain yield/ panicle	grain yield/ hectare(kg)
NGB 01952	91.67a-f	3.00b-e	45.33a-e	97.21a-d	4457a-f	24.10u	109.22a-f	19248b-g
NGB 01707	93.67ab	2.67b-f	43.67a-f	112.32ab	4900a-d	32.13ijk	157.77abc	26228abc
NGB 01894	102.33a	1.00f	53.67ab	114.44ab	6080a	25.77t	156.37abc	10164c-g
NGB 01739	77.00g-l	2.00def	42.33a-f	55.05cde	2310cd-h	39.00b	89.99b-f	11698c-g
SAMSORG 43	78.67f-l	1.67ef	55.67a	68.39a-e	3890a-h	43.00a	163.81ab	17383b-g
NG/SA/DEC/070220	85.00b-j	1.67ef	46.67a-e	55.85cde	2689b-h	30.90mn	81.22c-f	9868d-g
NG/SA/JAN/09/0088	73.67i-l	2.00def	29.33fg	97.39a-d	2833b-h	23.00v	65.01def	8451efg
NGB 01270B	94.67ab	1.33ef	40.33a-f	89.67a-e	3890a-h	24.10u	92.36b-f	8041efg
NGB 01716^{H}	76.33h-l	2.33c-f	41.67a-f	51.00cde	2235d-h	32.00ijk	71.23def	9260d-g
CSR-01	93.00a-e	2.33cdef	42.67a-f	122.35a	5112abc	36.80d	187.80a	28118ab
NGB 01727	91.00a-f	2.67b-f	46.00a-e	60.00b-e	2728b-h	37.20cd	100.83b-f	17051b-g
NGB 01704	93.33a-d	2.00def	42.67a-f	92.33a-e	3835a-h	30.70n	115.22a-e	14978b-g
NGB/AA/SEP/09/162	90.00a-g	3.00b-e	31.67efg	66.33b-e	2112e-h	31.90jkl	66.97def	13060b-g
NGB/SA/07/065	85.00b-j	4.00abc	40.00a-f	71.06a-e	2643b-h	31.40lm	82.74b-f	22413a-f
SAMSORG 40	79.67e-l	2.33c-f	36.67b-g	84.33a-e	3113b-h	27.50s	84.51b-f	12456b-g
NG/AO/APR/09/004	91.00a-f	2.67b-f	48.33a-d	91.67a-e	4467a-f	29.70pq	133.54a-d	24115a-e
NG/AA/MAY/09/038	85.67b-j	2.67b-f	40.33a-f	76.67a-e	3031b-h	30.50no	92.34b-f	16024b-g
NG/AO/11/08/119	93.67abc	2.33c-f	45.00a-e	80.00a-e	3648a-h	28.40r	103.68b-f	15432b-g
NG/TO/APR/09/108	80.67c-l	2.67b-f	35.00c-g	100.33abc	3462a-h	28.60r	99.11b-f	17389b-g
NGB 01721^{H}	82.67b-l	1.67ef	38.67a-f	76.74a-e	2932b-h	28.40r	83.16b-f	9048d-g

Means followed with the same alphabet in a column are not significantly different from each other at $p < 0.05$

TABLE 4 cont'd

Accessions	No of days to 50% tasseling	Panicle/ plant	Spikelet/ panicle	Grains/ spikelet	Grains/ panicle	1000 grain weight (g)	grain yield/ panicle	grain yield/ hectare (kg)
07/0127	88.33b-h	2.67b-f	50.00abc	96.00a-d	4802a-e	32.50hi	158.59abc	24847a-d
NG/AA/SEPT/09/159	77.67g-l	1.67ef	43.33a-f	50.33cde	2223d-h	32.90h	74.11def	9090d-g
NGB/06/0004	92.33a-e	2.67b-f	40.00a-f	77.33a-e	3080b-h	32.30ij	101.01b-f	19556b-g
NG/AA/SEPT/09/160	88.67b-h	2.67b-f	43.33a-f	75.33a-e	3347b-h	29.20q	99.23b-f	18320b-g
SAMSORG 41	70.67kl	2.33cdef	27.67gf	82.20a-e	2285d-h	28.10r	64.40def	9133d-g
SAMSORG 42	76.33h-l	1.67ef	43.67a-f	72.80a-e	3173b-h	38.80b	123.45a-e	8024efg
NGB 01709	85.00b-j	1.67ef	34.33c-g	51.14cde	1730fgh	35.60f	61.58def	6664fg
NG/AO/APR/09/0061	87.67b-h	2.67b-f	43.67a-f	38.17e	1626gh	35.17f	57.21def	9662d-g
SAMSORG 14	85.33b-j	5.00a	39.33a-f	47.88cde	1848fgh	37.50c	69.00def	20648a-g
NG/MR/12/11/113	85.67b-j	2.33c-f	45.00a-e	67.33a-d	3082b-h	32.30ij	100.62b-f	16661b-g
NG/OJ/MAY/09/009	86.67b-i	2.67b-f	46.33a-f	51.00cde	2468c-h	29.80p	73.65def	13814b-g
NG/OJ/MAY/09/010	85.67b-j	2.00def	41.67a-f	43.00de	1748fgh	31.60kl	56.55def	7468efg
NG/AO/11/08/113	88.00b-h	4.33ab	34.33c-g	61.68b-e	2045e-h	22.60v	46.90ef	13620b-g
SAMSORG 17	68.00l	3.00b-e	46.00a-e	74.90a-e	3513a-h	36.20e	128.43a-e	22820a-f
NGB 01900	86.00b-j	3.67a-d	47.67a-d	52.26cde	2485c-h	31.77jkl	78.91c-f	18985b-g
NGB 01896	84.00b-j	4.33ab	44.00a-f	51.15cde	2251d-h	34.40g	77.56c-f	21951a-g
NG/MR/12/11/124[(10)]	80.00e-l	4.67a	49.00a-d	102.45abc	5260ab	21.50w	113.09a-e	35610a
NGB 01969	73.00jkl	2.33c-f	21.33g	51.15cde	1167h	24.60u	29.43f	5795g
NGB 01879[B5]	76.00h-l	2.33c-f	45.33a-f	91.35a-e	4280a-g	30.00op	130.72a-d	18204b-g

Means followed with the same alphabet in a column are not significantly different from each other at $p < 0.05$

4.3 Tannin content of Thirty-nine Sorghum accessions

NGB 01270B significantly had the highest tannin content (1.23 mg/g), followed by NGB 01969 (0.98 mg/g) and NGB 01879^{B5} (0.94 mg/g) while the lowest tannin content was found in SAMSORG 43 (0.24 mg/g) and SAMSORG 42 (0.22 mg/g) as presented in Table 5.

4.4 Mean, Phenotypic and Genotypic Co-efficient of variability, Broad Sense Heritability and Genetic Advance for some Characters of Thirty-nine Sorghum Accessions

The estimate of phenotypic and genotypic co-efficient of variability as well as heritability and genetic advance for the thirty-nine sorghum accessions are presented in Table 6. Genotypic variance for the characters ranged from 0.1 for stem girth and tannin content to 24944959.3 for grain yield per hectare. Similarly, the phenotypic variance ranged from 0.1 for tannin content to 46538221for grain yield per hectare. The genotypic co-efficient of variation was highest for tannin content (42.85), followed by grain yield per hectare and grain yield per plant (31.86) while the least was observed in number of days to 50% tasseling (7.65). Similar pattern was observed for the phenotypic co-efficient of variation (PCV) with tannin content, grain yield per hectare and grain yield per plant exhibited the highest PCV of 42.97, 43.52 and 43.52 respectively and least PCV in number of days to 50% tasseling (8.88).

Leave area, grains per spikelet and spikelet per panicle had low heritability estimates of 40.9, 46 and 47.5 respectively. Moderate to high heritability values of 52, 52.7, 53.6, 55.8, 60.9 and 66.5 were observed for grains per panicle, plant height, grains yield per hectare, grain yield per panicle, stem girth and number of leaves respectively. Very high heritability estimates of 99.8, 99.4, 74.2 and 71.5 were obtained for 1000-grain weight, tannin content, number of days to 50 % tasseling and number of panicles per plant respectively.

The values for genetic advance were expressed as percentage of the genotype mean for each character so that comparison could be made among various characters, which had different unit of measurement. Progress that could be expected from selecting the top 5% of the accessions ranged from 13.6% for number of days to 50% tasseling to 88.03% for tannin content.

TABLE 5: Tannin content of Thirty-nine Sorghum accessions

Accessions	Tannin content (mg/g)	Accessions	Tannin content (mg/g)
NGB 01952	0.64h	07/0127	0.35no
NGB 01707	0.38n	NG/AA/SEPT/09/159	0.79f
NGB 01894	0.29opq	NGB/06/0004	0.31op
NGB 01739	0.29opqr	NG/AA/SEPT/09/160	0.29opq
SAMSORG 43	0.24qr	SAMSORG 41	0.48jkl
NG/SA/DEC/070220	0.52ijk	SAMSORG 42	0.22r
NG/SA/JAN/09/0088	0.63h	NGB 01709	0.87cd
NGB 01270B	1.23a	NG/AO/APR/09/0061	0.53ij
NGB 01716^{H}	0.42lmn	SAMSORG 14	0.38n
CSR-01	0.40mn	NG/MR/12/11/113	0.51ijk
NGB 01727	0.66gh	NG/OJ/MAY/09/009	0.84def
NGB 01704	0.80ef	NG/OJ/MAY/09/010	0.84def
NGB/AA/SEP/09/162	0.47jkl	NG/AO/11/08/113	0.53ij
NGB/SA/07/065	0.50ijk	SAMSORG 17	0.40mn
SAMSORG 40	0.55i	NGB 01900	0.69gh
NG/AO/APR/09/004	0.86de	NGB 01896	0.27pqr
NG/AA/MAY/09/038	0.45klm	NG/MR/12/11/124$^{(10)}$	0.51ijk
NG/AO/11/08/119	0.71g	NGB 01969	0.98b
NG/TO/APR/09/108	0.87dc	NGB 01879^{B5}	0.94b
NGB 01721^{H}	0.89cd		

Means followed with the same alphabet in a column are not significantly different from each other at $p < 0.05$

TABLE 6: Mean, Phenotypic (PCV) and Genotypic (GCV) Co-efficient of variability, Broad Sense Heritability and Genetic Advance for some Characters of Thirty-nine Sorghum Accessions

Traits	Mean	Genotypic variance	Phenotypic variance	GCV	PCV	Heritability (%)	Genetic advance
Plant height	263.37	1507.5	2858.6	14.74	20.30	52.73	22.1
Stem girth	1.62	0.1	0.2	22.26	28.51	60.94	35.8
Number of leaves	8.15	2.1	3.1	17.58	21.56	66.52	29.5
Leaf area	380.15	2976.4	7272.9	14.35	22.43	40.92	18.9
50% tasseling	84.71	42.0	56.6	7.65	8.88	74.24	13.6
Panicle/plant	2.56	0.6	0.9	30.76	36.37	71.54	53.6
Spikelet/panicle	41.84	22.1	46.4	11.23	16.28	47.55	15.9
Grains/spikelet	74.39	214.3	465.0	19.68	28.99	46.08	27.5
Grains/panicle	3145.97	674458.7	1296682.4	26.10	36.20	52.01	38.8
1000-grain weight	31.07	23.9	23.9	15.74	15.75	99.86	32.4
GY/panicle	96.97	696.7	1246.4	27.22	36.41	55.89	41.9
GY/plant	241.14	5904.1	11015.0	31.86	43.52	53.60	48.1
GY/hectare	15674.29	24944959.3	46538221	31.86	43.52	53.60	48.1
Tannin content	0.57	0.1	0.1	42.85	42.97	99.44	88.0

4.5 Genotypic and phenotypic correlation among traits of Sorghum accessions

4.5.1 Genotypic correlation

Genotypic and phenotypic correlation among traits of thirty-nine Sorghum accessions used are presented in Table 7. The grain yield per hectare was significantly and positively correlated with number of leaves (r = 0.26*), number of days to 50% flowering (r = 0.31**), panicle per plant (r = 0.67**), spikelet per panicle (r= 0.54**), number of grain per panicle (r = 0.42**), grain yield per panicle (r = 0.47**) and grain yield per plant (r = 1.00**). However, a negative or inverse correlation was observed between grain yield per hectare with leaf area (r = -0.27*) and tannin content (r = -0.32**). The tannin content was significantly and negatively correlated with stem girth (r = -0.31**), spikelet per panicle (r = -0.42**), 1000 grain weight (g) (r = -0.44**), grain yield per panicle (r = - 0.43**) grain yield per plant (r = -0.43**) and grain yield per hectare (r = -0.43**) except with plant height where a significant positive correlation was observed (r = 0.26*).

4.5.2 Phenotypic correlation

The grain yield per hectare was significantly and positively correlated with stem girth (r = 0.25*), number of leaves (r = 0.28*), panicle per plant (r = 0.63**), spikelet per plant (r = 0.44**), grains per spikelet (r = 0.46**), grains per panicle (r = 0.57**), grain yield per plant (r = 1.0**) and negatively correlated with tannin content (r = -0.43**). The tannin content was significantly and negatively correlated with stem girth (r =-0.25**), grain yield per spikelet (r = -1.0**), 1000-grain weight (r = -0.44**), grain per panicle (r = -0.33**), grain per plant (r = -0.32**) and grain yield per hectare (r = -0.32**).

Table 7: Genotypic (lower) and phenotypic (upper) correlation co-efficient among traits of 39 sorghum accessions used in the study

	PH (cm)	SG (cm)	NL (cm)	LA (cm)	ND 50% T	P/P	S/P	G/S	G/P	1000 GW (g)	GY/PAN	GY/PLT	GY/H (kg)	TC (mg/g)
PH (cm)		0.39*	0.60* *	0.54**	0.56**	0.15	0.14	0.12	0.17	-0.18	0.06	0.09	0.09	0.17
SG (cm)	0.38**		0.57**	0.77**	0.19	0.59**	0.29*	-1.00**	0.50**	-0.11	0.41**	0.25*	0.25*	-0.25*
NL (cm)	0.59**	0.63**		0.49**	0.59**	0.22	0.40**	0.20	0.39**	-0.09	0.29*	0.28*	0.28*	-0.09
LA (cm)	0.49**	0.85**	0.41**		0.35	-0.06	0.34**	0.38**	0.46**	-0.7	0.40**	0.14	0.14	-0.16
ND 50% T	0.64	0.17	0.65**	0.48**		0.004	0.36**	0.29*	0.41**	-0.12	0.31*	0.19	0.19	0.03
P/P	0.01	-0.03	0.22	-0.50**	0.02		-0.04	-0.13	-0.13	-0.11	-0.19	0.63**	0.63**	-0.19
S/P	0.03	0.32**	0.54**	0.29*	0.53**	-0.02		0.15	0.58**	0.33**	0.66**	0.44**	0.44**	-0.29
G/S	0.07	-1.00**	0.28*	0.45**	0.48**	-0.28*	0.23		0.88**	-0.36**	0.72**	0.46**	0.46**	-1.00**
G/P	0.08	0.62**	0.53**	0.47**	0.62**	-0.22	0.66**	0.88**		-0.18	0.89**	0.57**	0.57**	-0.15
1000 GW (g)	-0.25*	-0.14	-0.11	-0.11	-0.15	-0.13	0.48**	-0.51**	-0.25*		0.28*	0.06	0.06	-0.44**
GY/PAN	-0.13	0.47**	0.33**	0.36**	0.43**	-0.30**	0.81**	0.58**	0.79**	0.37**		0.58**	0.58	-0.33**
GY/PLT	-0.20	0.10	0.26*	-0.27*	0.31**	0.67**	0.54**	0.24	0.42**	0.09	0.48**		1.00**	--0.32**
GY/H (kg)	-0.20	0.10	0.26*	-0.27*	0.31**	0.67**	0.54**	0.24	0.42**	0.09	0.47**	1.00**		-0.32**
TC (mg/g)	0.26*	-0.31**	-0.11	-0.22	0.05	-0.23	-0.42**	-1.00	-0.19	-0.44**	-0.43**	-0.43**	-0.43**	

PH: Plant height; SG: Stem girth; NL: number of leaves; LA: leave area; ND 50% T: number of days to 50% tasseling; P/P: panicle per plant; S/P: spikelet per panicle; G/S: grains per spikelet; G/P: grains per panicle: GW: grain weight; GY/PAN: grain yield per panicle; GY/PLT: grain yield per plant; GY/H: grain yield per hectare; TC: tannin content.

4.6 Principal component analysis

Out of the 14 principal components, only four had eigen values greater than one (Fig.1) and cumulatively explained approximately 78% of the total variation (Table 8). The eigen values ranged from 5.49 in PC1 to1.55 in PC4. The first principal component, which accounted for 36.6% of the total variation and described the patterns of variation in grain yield per panicle, grain yield per plant and grain yield per hectare, which increased at the expense of tannin content because of its negative coefficient. The second principal component (PC2) illustrated the variation pattern in number of panicle per plant which had high positive correlation coefficients, which increased at the expense of grains per panicle (negative coefficient) and accounted for 17.1% of the variation. Third principal component (PC3) explained 13.8% of the total variance and described the variation pattern in plant height, number of leaves, leaf area and number of days to 50% tasseling. The fourth Principal Component (PC 4) accounted for the lowest percentage of variability (10.4%) and revealed that spikelet per panicle and 1000-grain weight which increased at the expense of the grains per spikelet and tannin content.

4.7 Genotype × trait biplot

The visualization of the separation of 39 sorghum accessions into groups, according to variables is represented by the first two axes in figure 2, 3 and 4. The two axes divided the investigated sorghum into four homogenous groups, with each group having similar agronomic characters and tannin content.

Figure 2 shows biplot of PC1 against PC2 with marker traits and vector traits. The first group (quadrant I) containing 10 genotypes had positive scores for both PC1 and PC2, this implies that genotypes in this group performed very well.

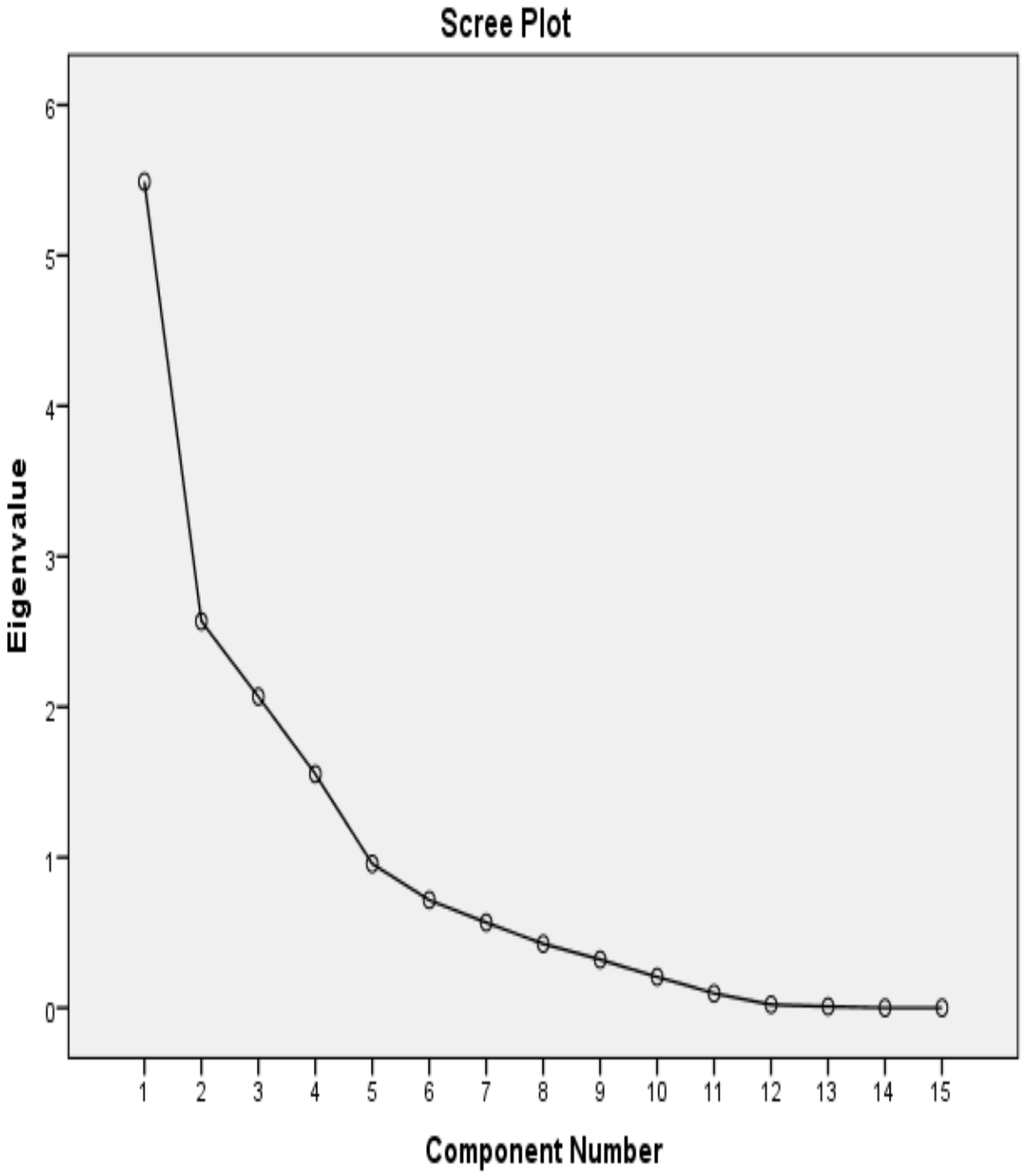

Figure 1: Scree plot showing the four principal component greater than one

Table 8: Eigen values, total variance, cumulative variance and the correlation coefficients between these traits and the first four principal components that described the variation of 14 characters measured on 39 accessions of *Sorghum bicolor*.

Traits	PC1	PC2	PC3	PC4
Plant height	0.216	0.119	**0.460**	0.039
Stem girth	0.274	-0.028	0.253	0.101
Number of leaves	0.255	0.084	**0.362**	0.157
Leave area	0.285	-0.038	**0.304**	0.104
No of days to 50% tasseling	0.161	-0.072	**0.380**	0.076
Panicle/ plant	0.162	**0.565**	-0.088	-0.033
Spikelet/ panicle	0.229	-0.195	-0.031	**0.318**
Grains/ spikelet	0.291	-0.234	-0.140	**-0.391**
Grains/ panicle	0.351	-0.289	-0.116	-0.197
1000 grain weight (g)	0.007	-0.066	-0.254	**0.624**
Grain yield/ panicle	**0.337**	**-0.316**	-0.203	0.007
Grain yield/ plant	**0.365**	0.161	-0.267	-0.081
Grain yield/hectare (kg)	**0.365**	0.161	-0.267	-0.081
Tannin content (mg/g)	-0.112	-0.030	0.236	**-0.499**
Eigen values of correlation matrix	5.49	2.57	2.07	1.55
Explained proportion of total variance %	36.6	17.1	13.8	10.4
Cumulative proportion of total variance	36.6	53.7	67.5	77.8

Bold values indicate correlation coefficients with value equal to or greater than 0.3 in absolute value.

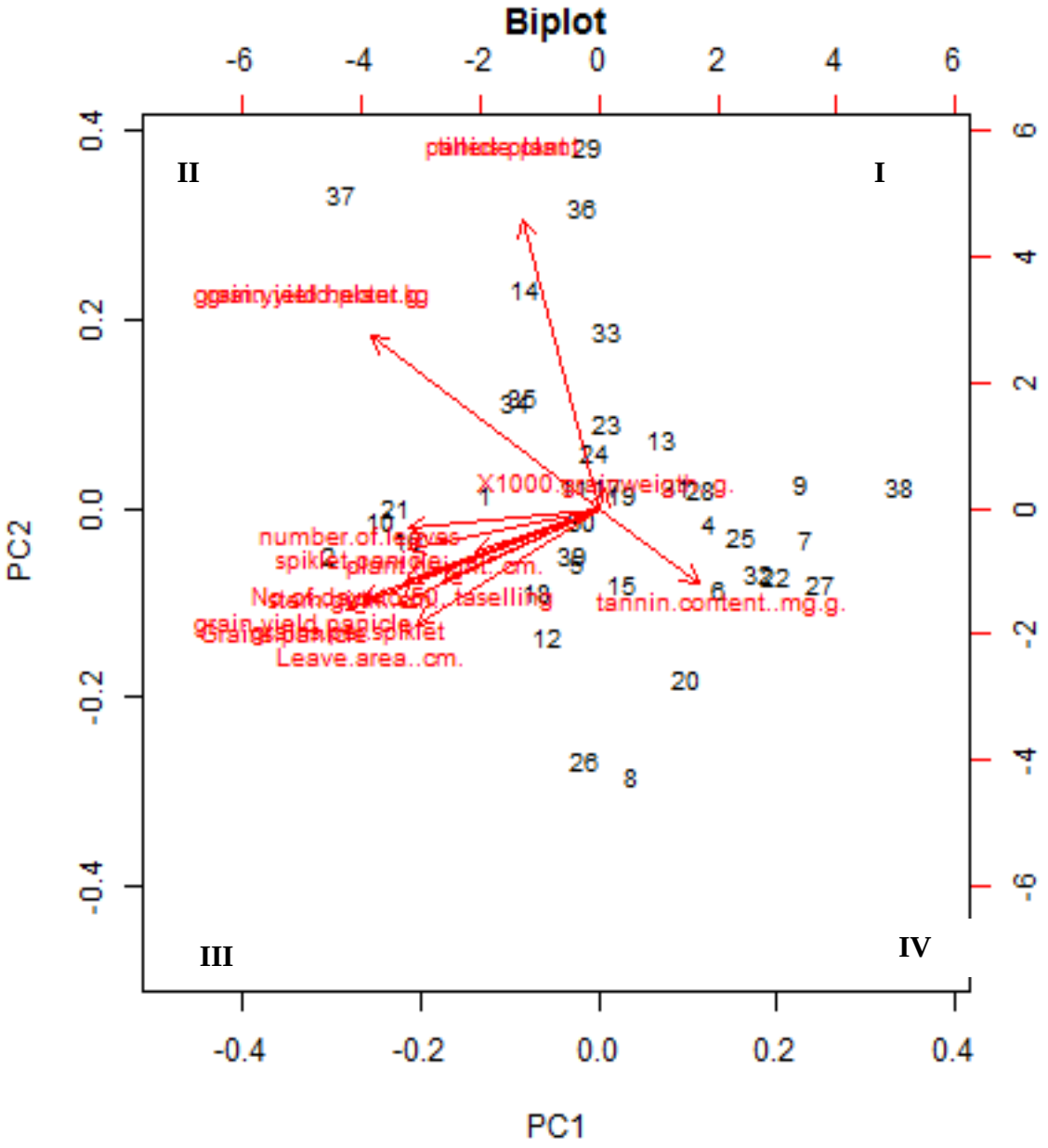

Figure 2. Plot of the first and second component scores obtained for thirteen agronomic traits and tannin content for 39 sorghum accessions.

The second group (quadrant II) had 7 genotype with negative coefficient for PC1 and positive values for PC2, this implies that genotypes in this group performed averagely. Eleven genotypes were in the third quadrant (group 3) which had negative values for both PC1 and PC2, by implication, genotypes in this group had poor performance. The last group (quadrant 1V), also containing 11genotypes had positive coefficient for PC1 and negative coefficient for PC2, genotypes in this group also performed averagely. The shorter vector for tannin content in comparison with agronomic traits with longer vectors implied that they were independent of other traits.

Biplot of PC1 against PC3 with marker traits and vector traits is shown in Figure 3. The first group (quadrant I) containing 8 accessions had positive scores for both PC1 and PC3, this implies that genotypes in this group performed very well. The second group (quadrant II) had 10 accessions with negative coefficient for PC1 and positive values for PC3, this implies average performance of the genotypes in this group. Nine accessions were in the third quadrant (group 3), which had negative values for both PC1 and PC3, by implication, genotypes in this group had poor performance. The last group (quadrant 1V), also containing 12 accessions, had positive coefficient for PC1 and negative coefficient for PC3, genotype in this group also performed averagely. The shorter vector for tannin content in comparison with agronomic traits with longer vectors implied that they were independent of other traits.

Biplot of PC2 against PC3 with marker traits and vector traits is shown in Figure 4. The first group (quadrant I) containing 7 accessions had positive scores for both PC2 and PC3, this implies that genotypes in this group performed very well. The second group (quadrant II) had 11 accessions with negative coefficient for PC2 and positive values for PC3, this implies average performance of the genotypes in this group. Ten accessions were in the third

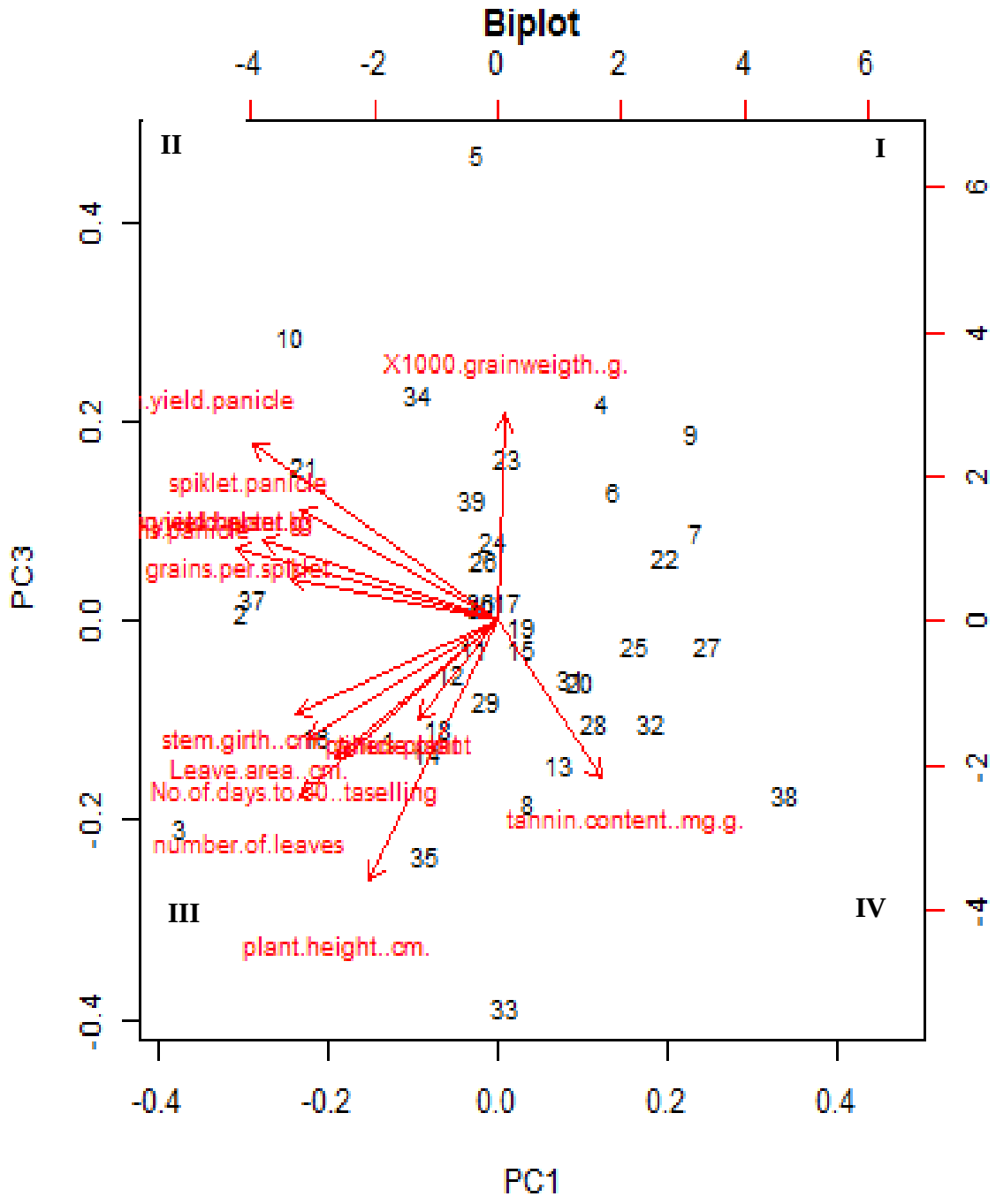

Figure 3. Plot of the first and third component scores obtained for thirteen agronomic traits and tannin content for 39 sorghum accessions.

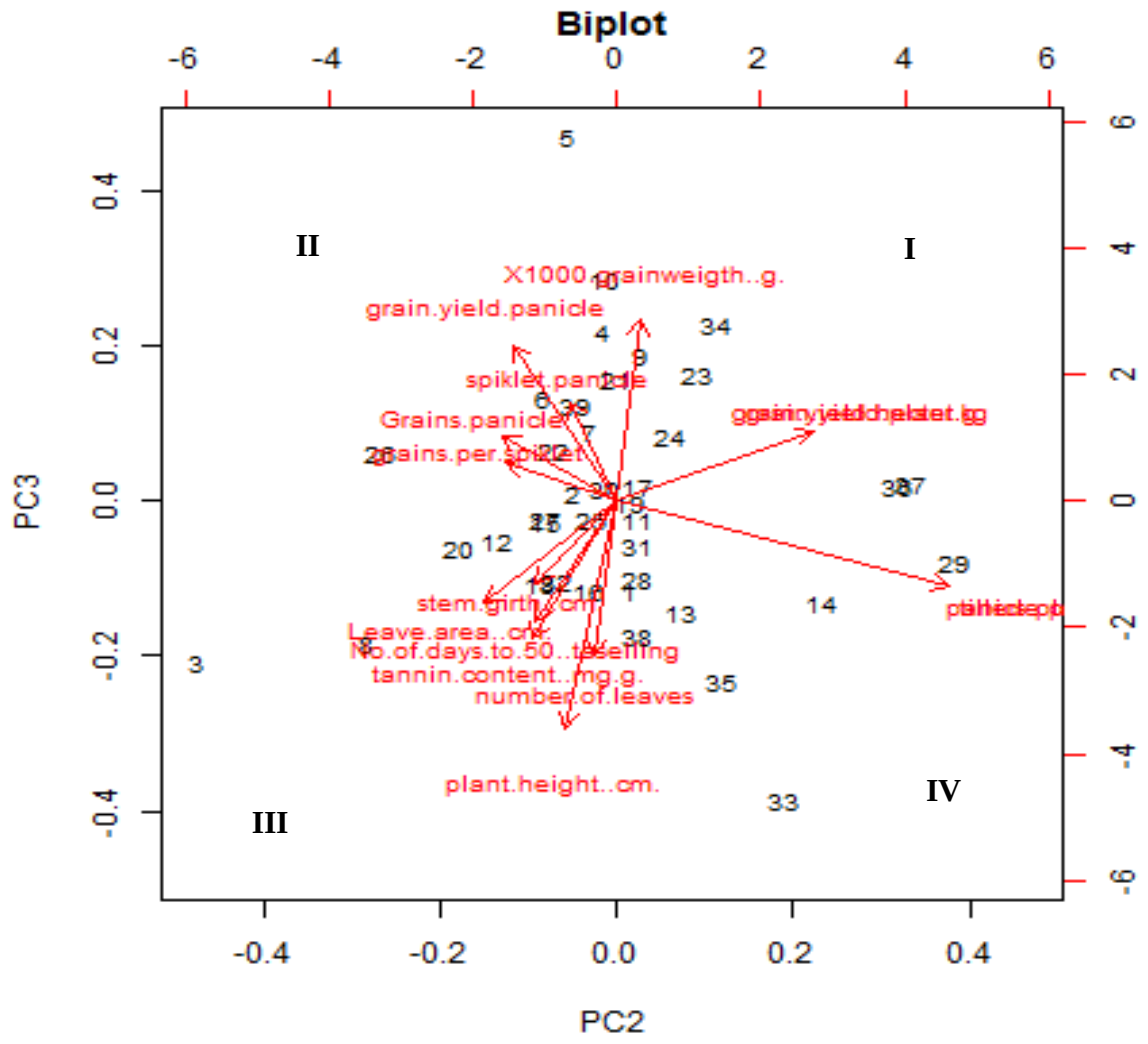

Figure 4. Plot of the second and third component scores obtained for thirteen agronomic traits and tannin content for 39 sorghum accession

quadrant (group 3) which had negative values for both PC2 and PC3, by implication, genotypes in this group had poor performance. The last group (quadrant 1V), also containing 11 accessions, had positive coefficient for PC2 and negative coefficient for PC3, genotype in this group also performed averagely.

The genotypes farther from the center in each biplot depict they are genetically diverse while those that cluster at the center in each biplot show they are genetically close. For the longer traits vectors, most especially the diverse genotypes around them have a high value for that trait genetically. That is, under normal growing conditions, these genotypes will exhibit their potential values for those traits. Of the observed traits, the trait vector for tannin content formed an obtuse angle with grain yield per hectare which indicates an inverse correlation between them. Scattered diagram of the first two respective principal component obtained for 14 grain yield, yield component and tannin content is shown in figure 5.

4.8 Cluster analysis and group characterization

Following the use of Ward's method, the dendogram drawn on four most significant principal components for the 14 agronomic traits and tannin content of 39 accessions of sorghum, produced five distinct homogenous groups (clusters) (Figure 6). Table 9 shows the Mean values of grain yield, yield component and tannin content traits for five groups revealed by ward's cluster analysis among 39 sorghum accessions. Seven accessions were grouped in cluster I. One accession was in cluster II with taller plant height (330 cm), wider stem girth (3.17 cm), higher number of leaves (14.67), larger leaf area (638.45 cm^2), longer number of days to 50% tasseling (102.33 days), higher number of spikelet (53.67), grains per spikelet (114.47), grains per panicle (6080) and grain yield per panicle (156.37 g) with lower tannin content (0.29 mg/g). Cluster III contained 22 accessions that were high in tannin

content (0.65 mg/g). The 3 accessions found in cluster IV had higher 1000-grain weight (39.33 g) with lower tannin content as those observed in cluster II (0.29 mg/g). Cluster V had 6 accessions with higher number of panicle per plant (4.33), grain yield per plant (341.61 g) and grain yield per hectare (22204.64 kg).

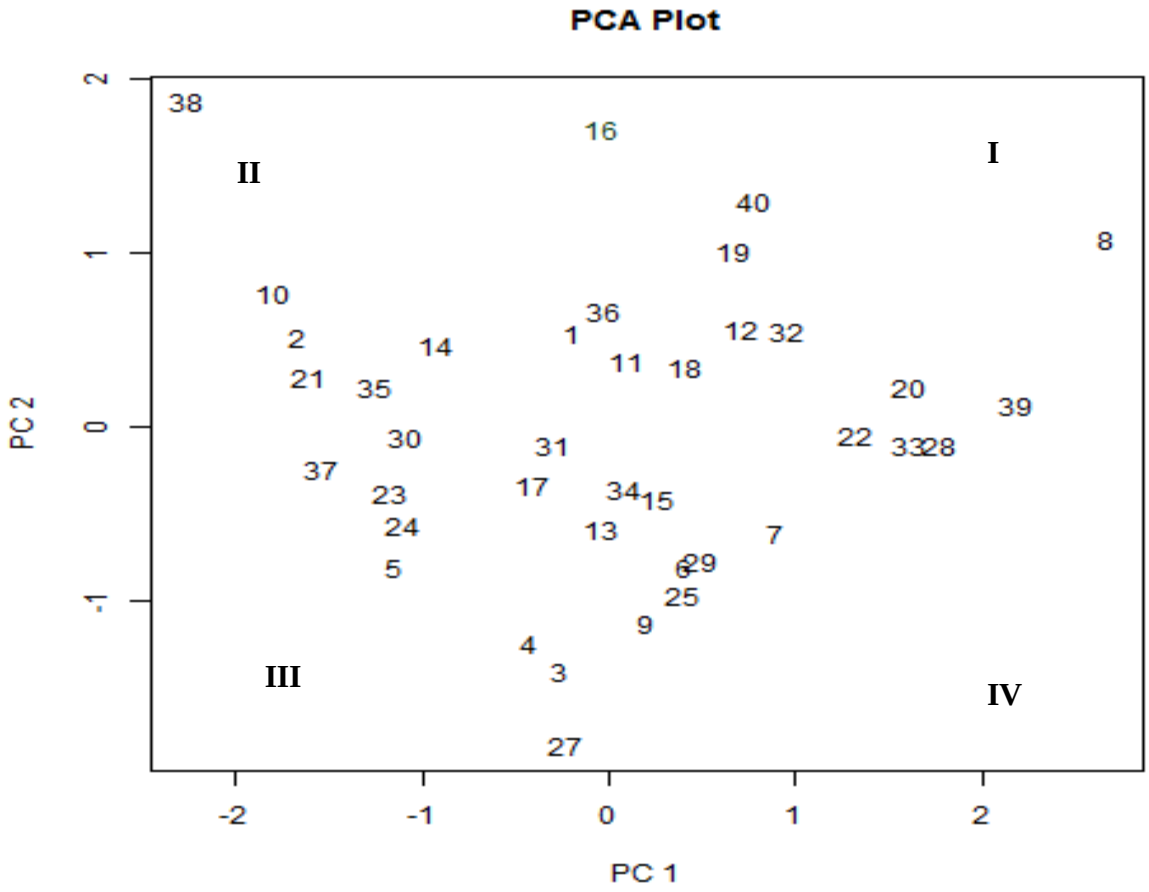

Figure 5. Scattered diagram of the first two respective principal component obtained for thirteen grain yield, yield component and tannin content.

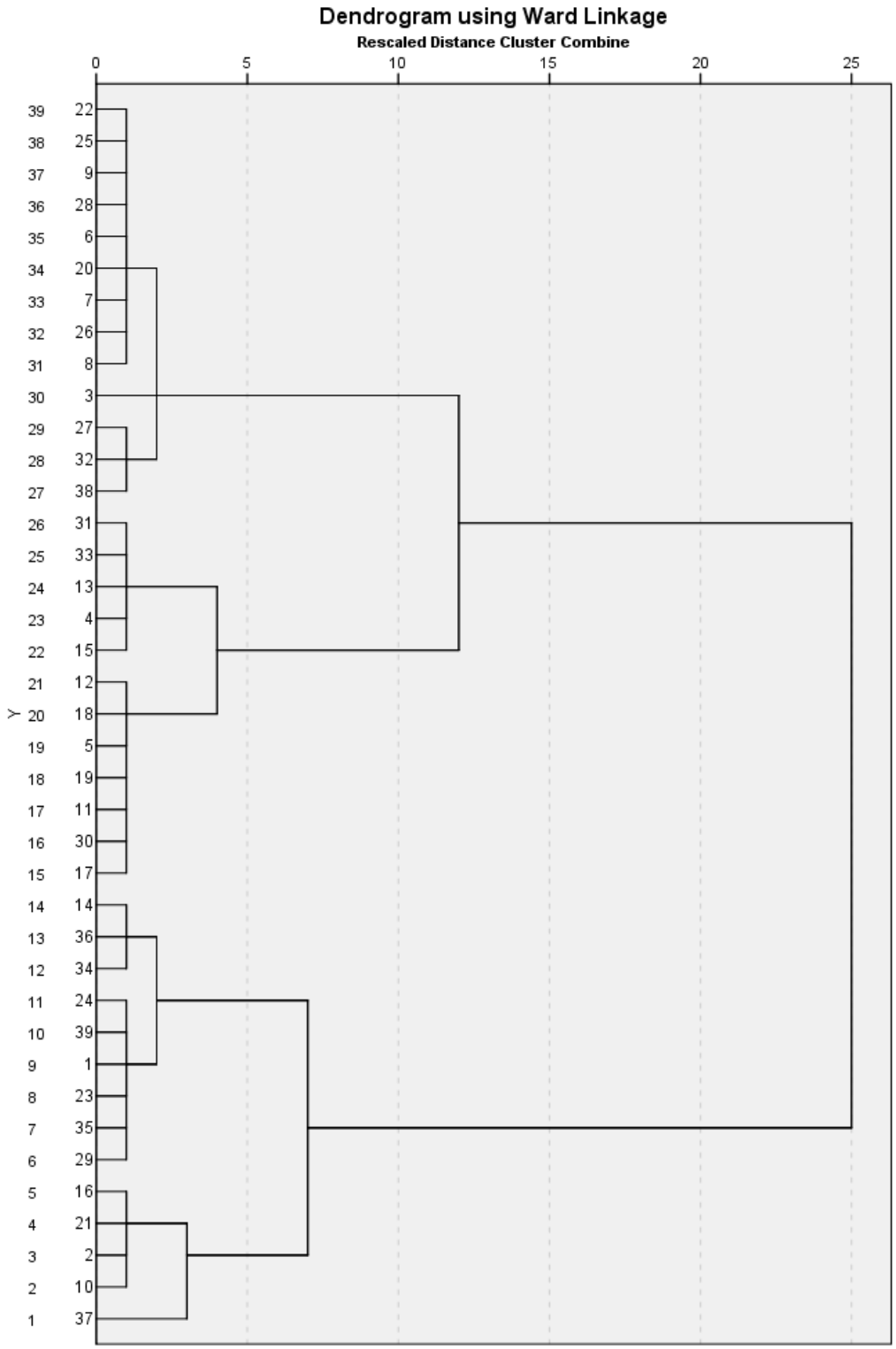

Figure 6: Dendogram of 39 Sorghum accessions Using Ward's method based on square Euclidean distance for the first four significant principal component. .

Table 9: Mean values of grain yield, yield component and tannin content traits for five groups revealed by ward's cluster analysis among 39 sorghum accessions

Traits	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
plant height (cm)	301.83	**330.00**	245.14	*232.78*	289.62
stem girth (cm)	1.72	**3.17**	*1.42*	2.03	1.80
number of leaves	9.03	**14.67**	*7.22*	7.89	9.59
Leave area (cm)	418.12	**638.45**	*350.36*	400.20	392.05
No of days to 50% tasseling	92.10	**102.33**	82.97	*74.33*	84.72
panicle/plant	2.52	*1.00*	2.24	1.89	**4.33**
spikelet/panicle	45.38	**53.67**	*39.12*	48.45	42.39
grains per spikelet	98.84	**114.47**	67.84	72.03	*64.41*
Grains/panicle	4460.10	**6080.00**	*2653.18*	3496.78	2755.28
1000 grain weight (g)	30.62	*25.77*	30.67	**39.33**	29.86
grain yield/panicle	137.98	**156.37**	80.71	138.57	*78.03*
grain yield/plant (g)	336.19	*156.37*	186.51	247.32	**341.61**
grain yield/hectare (kg)	21852.28	*10164.31*	12123.32	16075.45	**22204.64**
tannin content (mg/g)	0.59	*0.29*	**0.65**	*0.29*	0.48

Bold values indicates highest values and italic values indicates least values.

CHAPTER FIVE

5.0 DISCUSSION

Seed improvement is determined to a large extent by the effective functioning of the crop yield characters and specific traits desired. Expression of these characters depends on the overall genetic and environmental factors (Berdahl and Barker, 1997). The variations observed for the fourteen characters may be attributed to diverse genetic background of the accessions studied, which suggests that in this population of sorghum accessions, there is an opportunity to select desirable genotypes with reduced tannin content and increased seed yield which may be able to perform better to give higher yield. Highly significant mean squares for agronomic traits and tannin content among the 39 sorghum accessions, revealed the presence of substantial natural variation, upon which selection for these traits is possible.

It has been well established that the worth of genetic resource collection is known from the genetic variability in it, which is the basis for development of improved varieties (Lahoz *et al*., 2011). Phenotypic variance includes the genotypic and environmental variances. The high heritability estimates observed in number of days to 50% tasseling, number of panicles per plant, 1000-grain weight and tannin content revealed that the variation in these characters is largely controlled by genetic factors. Conversely, the low heritability values exhibited by number of grains per spikelet, number of spikelet per panicle and leaf area showed that these characters were mostly influenced by environment rather than genetic make-up. Moderately high heritability values for grains per panicle, plant height, grains yield per hectare, grain yield per panicle, stem girth and number of leaves showed that both genetics and environment played equal roles in the expression of these traits.

From the study, the genotypic co-efficient of variation of the characters studied was less than its corresponding estimate of phenotypic co-efficient of variation. This indicates the significant role of the environment in the expression of these traits which may be further improved through selection. Although, heritability estimates provide the basis for selection of phenotypic performance. The simultaneous consideration of heritability estimates and genetic advance is important as high heritability will not always be associated with high genetic advance (Johnson *et al.,* 1955). Estimate of genetic advance help in understanding the type of gene action involved in the expression of various polygenic traits. High values of genetic advance are indications of additive gene action (Singh and Marayanan, 1993).Thus, the heritability estimates is reliable if accompanied by high genetic advance.

The genotypic variance of the sorghum accessions revealed the extent of genetic variability among the accessions for the observed characters; however, it does not provide a means of assigning heritability. The high heritability in addition to high genetic advance is an important tool for predicting the resultant effect of selecting the best sorghum accessions with high yield and low tannin content. In this study, the high heritability and genetic advance obtained for panicle per plant, 1000-grain weight, grain yield per panicle, grain yield per plant and tannin content would go a long way in predicting heritable trait for further improvement since these characters seemed to be governed by additive gene action. The presence of high heritability and moderate genetic advance has been reported to suggest the effect of equal contribution of additive and non-additive gene action (Shelby, 2000).

Measurement and classification of genetic variability among the sorghum accessions provides an improved understanding of choice for parental selection (Gomez-Bacerra *et al*., 2010). To this effect, PCA and cluster analysis are complementary, valuable statistical tools.

While the extent of variability is measured via PCA, classification of the variability is accomplished via cluster analysis. The PCA analysis further confirmed the broad agronomic and tannin content differences among the accessions as the results produced a few eigen vectors that could elucidate the overall diversity observed. The first four PCs accounted for a considerable amount of variation (77.8%) in the data, with PC1 explaining 36.6% of the variation and distinguishing accessions having high correlations with in grain yield per panicle, grain yield per plant and grain yield per hectare, which increased at the expense of tannin content because of its negative coefficient. This indicated that accessions showing smaller values of PC1. Conversely, the higher values indicated the reverse. The high positive coefficients of panicle per plant and grain yield per plant in PC2 distinguished accessions having high values of these traits from those with opposite traits. From the graphical illustration of the variation among the accessions displayed by biplot of PC1 and PC2, it is evident that the landraces were substantially spread across the four quadrants, with no clear separation on account of characteristics. This was also confirmed by the dendrogram. The second component was correlated with number of tillers and panicle per plant, both having high positive correlation coefficients, which increased at the expense of grains per panicle (negative coefficient) and accounted for 17.1% of the variation. PC3 explained 13.8% of the total variance and described the variation pattern in plant height, number of leaves, leaf area and number of days to tasseling. The fourth PC explained 10.4% of the variation and revealed that spikelet per panicle and 1000-grain weight which increased at the expense of the grains per spikelet and tannin content.

One of the practicalities of classifying genotypes producing useful variabilities is to acquire information on the correlation between genetic diversity and eco-geographical background,

which is frequently, used by plant breeders for the development of well-organized genetic resource management and application strategies (Upadhyaya *et al*., 2011). In the current study, it is obvious that there was little empirical evidence for the relationship between diversity pattern and geographical origin. This finding is at variance with an earlier study which found a significant relationship between eco-geographical background and genetic diversity. On the basis of their agronomic traits and tannin content, the accessions used for this study were broadly grouped into five clusters. Group II and IV constituted accessions that were characterized by lower tannin content while cluster V had higher grain yield per plant and moderate tannin content. Members of these groups can be selected as suitable parental materials for hybridization whenever grain yield and low tannin content are the breeding objectives.

5.1 CONCLUSION

This study concluded that (NG/MR/12/11/124$^{(10)}$, NGB/SA/07/065, SAMSORG 14, NG/AO/11/08/113, NGB 01900 and NGB 01896) were the highest grain yielders with moderate tannin content while NGB 01894, SAMSORG 43, SAMSORG 42 and SAMSORG 17 were the accessions with lowest tannin contents among the thirty-nine sorghum accessions evaluated. Traits with high broad sense heritability and genotypic coefficient of variation indicate the importance of additive gene action. The results concluded that sorghum accessions used in this study are diverse both for agronomic and phytochemical traits and that there are possibilities to exploit the diversity to improve the crop. Furthermore, the inverse correlation between grain yield and tannin content revealed that developing high yielding sorghum varieties with reduced or trace level of tannin content is possible.

5.2 RECOMMENDATIONS

The high yielders with low to moderate tannin content (SAMSORG 43, SAMSORG 42 and NG/MR/12/11/124[(10)]) among the evaluated accessions are therefore recommended for farmers and industries for planting and seed processing to increase the sorghum yield and improve potentials. Selection for seed yield improvement with low tannin content should therefore include an indirect selection for sorghum since they had significant role in improving the yield and reducing tannin content. Although, the evaluation of accessions was done at a single location, the variation obtained was large. Additional assessment of this collection across multiple locations to exploit genotype × environment interaction for broad or specific adaptation is very desirable. It is further recommended that investigations should be carried out in the area of molecular analysis to identify qualitative trait loci (QTL) responsible for tannin and yield. It will also help to confirm or dismiss the extent of diversity or variability as presented by agro-morphological traits in order to facilitate its genetic improvement.

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APPENDIXES

Table 10: Physiochemical Properties of the soil

Soil parameter measured	Quantity Obtained
pH	4.44
Sand (%)	82.40
Clay (%)	8.80
Silt (%)	8.80
Ca(Cmol-1)	17.00
Mg (Cmol-1)	4.08
Na (Cmol-1)	0.43
K (Cmol-1)	0.14
H+ AL ((Cmol-1))	22.43
ECEC (Cmol-1)	22.43
% Base SALT(Cmol-1))	96.52
C (%)	4.74
N (%)	0.49
Av P(ppm)	10.05
Cu (ppm)	3.65
Fe (ppm)	1925.00
Zn (ppm)	6.30
Mn (ppm)	150.50

Soil analysis carried out at Rotas Soilab Ltd, Ibadan, Nigeria

Table 11: Agrometeorological observations during the experimental year.

Months	Total Rainfall (mm)	Temperature (^{0}C)	Relative Humidity (%)	Sunshine (Hours)
Dec 2015	8.22	30.2	59.4	6.9
2016				
January	32.0	28.1	56.3	4.6
February	0.0	30.3	56.7	3.3
March	150.3	29.6	59.1	2.0
April	68.2	29.3	63.1	6.3
May	226.2	28.9	73.6	5.1
June	150.5	26.7	72.0	4.0
July	65.2	26.3	72.2	2.75
August	68.6	25.8	72.8	2.0

Source: Department of Agrometeorological and Water Management, Federal University of Agriculture, Abeokuta.