Use of Additive Main and Multiplicative Interaction and Linear Regression Models to Analyze the Effects of Genotype x Environment Interaction for Sorghum [Sorghum bicolor (L.) Moench] Grain Yield

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Date of examination: 4, December, 2014
DEDICATION

To my parents, brothers, and sister,

My wife (Arwa) and our kids (Lameis and Ahmed) and all those who contributed to this work
ACKNOWLEDGEMENTS

Thanks and praise to Allah, who gave me health and patience during my study to complete this work. I am thankful to my supervisor at the university of Gezira Prof. Abu Elhassan Salih Ibrahim for the skillful supervision, constructive criticism and active guidance during the course of this work. Also my thanks are extended to my co-supervisor Dr. Ibrahim Nour Eldin Elzein for his guidance, unlimited help, suggestions and encouragement during this study. Deepest appreciation and sincere gratitude will be to Prof. Ibrahim Eljack Mursal, the external examiner and Dr. Abbas Mohamed Suliman, the internal examiner for their invaluable advice and comments. I wish to place on record my deep sense of gratitude to Sudan government, Sorghum Research Program staff in Agricultural Research Corporation (ARC) and Crop Science department in Faculty of Agricultural Sciences at University of Gezira for their technical support. I also want to acknowledge all staff in plant breeding at Gedarif and Wad Medani Research Station for their unlimited help. I am thankful to all those known and unknown faces that directly or indirectly contribute to this work.
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Abstract

In the Sudan, sorghum is the most important cereal crop by production and consumption. It is the staple food specially in rural areas of the country, and is used in different forms. The objectives were to evaluate these genotypes under different irrigation and rainfed conditions for grain yield and its related attributes. In this study, 18 sorghum genotypes were collected from Gedarif area and from the Gene Bank (Wad Medani). They were evaluated for three consecutive seasons (2009, 2010, and 2011) at three locations, viz. Rahad Research farm of the Agricultural Research Corporation (ARC) Sudan; North Gedarif and South Gedarif. Both North and South Gedarif were rainfed, while Rahad station was irrigated. Significant differences among genotypes were found in almost all seasons, indicating that these sorghum genotypes were highly variable for the characters studied, and therefore, expected to respond to selection. The interaction effects of genotype x location were highly significant for most traits indicating that genotypes responded differently to different environments and some were environmentally specific. The early maturing, short genotypes (60 days) across seasons and locations were Milo, Gesheish and AG-8 while the late maturing, tall ones were Faki Mustahi and Tetron (80 days). Across seasons and locations the highest grain yielding genotypes were Mugod, Bashayier, Wad Ahmed and Gadambalia bloom, while the lowest yielding ones were Faki Mustahi, Gesheish and AG-8. Correlation and path coefficient analysis indicated that head width and number of heads/m² could be used as potential selection criteria in breeding programs for developing high yielding sorghum genotypes. Also, this finding indicated the importance of these components in affecting the phenotypic performance of the evaluated sorghum genotypes. Both stability models [Eberhart and Russel as well as Additive Main and Multiplicative Interaction (AMMI) analysis] pointed out that genotypes Mugod, Gadambalia bloom, Safra and Tetron were high yielding and stable under the favorable environments of South Gedarif and Rahad Irrigated Scheme. Genotypes Wad Baku, Farhoda, Gesheish and Wad Fahal were low yielders but quite stable under unfavorable environments like North Gedarif. Comparing the effectiveness of joint regression and AMMI analysis for analyzing GE interaction, the present study showed that the first two axes PCA1, PCA2 in AMMI accounted for the GE sum of squares by 56.7% and 19.3%, respectively, while the regression analysis accounted for GE sum of squares by 21.9%. Hence, AMMI analysis was superior to regression techniques and more effective in partitioning the interaction sum of squares. In conclusion, Mugod, Gadambalia bloom, Safra and Tetron were suggested to be grown under high rainfall conditions and Wad Baku, Farhoda, Gesheish and Wad Fahal to be grown under low rainfall conditions in small holdings because they are tall, late and uncombinable. However, this study failed to identify genotypes stable across the nine environments under study.
تأثير استعمال نماذج التجميع الرئيسي والتفاعل المتراكم ومعامل الارتداد الخطي في تحليل تفاعل التركيب [Sorghum bicolor (L.) Moench] الوراثي والبيئة على الانتاجية الحبوب في الذرة الرفيعة

محمد حمزة محمد أدم

الخلاصة

الذرة الرفيعة هي المحصول الأول في السودان من حيث مجمل الإنتاجية والاستهلاك، وهو محصول الغذاء الرئيسي في الرفي ويستخدم في عدة أشكال. الهدف من الدراسة هو تقويم ثمانية عشر سلالة من الذرة الرفيعة تحت ظروف بيئية مختلفة للانتاجية والصفات ذات العلاقة بها. تم جمع السلالات من القضارف وسلاسل مصدرية الوراثية (واد مدني). زرعت ثلاث مواسم متتالية (2009-2011) وفي ثلاث مواقع هي مزرعة محطة بحوت الرهد (بالريف الإنشائي) ثم محطة بحوت القضارف (شمالي جنوب القضارف) وثانيهما تم فيهما الزراعة بالأمطار. وجدت هناك فروق معنوية بين السلالات للصفات التي درست في معظم المواسم، وعليه يمكن استجابة السلالة للاختلاف البيئي، وبعض منها في بيئة محددة. السلالات المبكرة والقصيرة (60 يوم) في كل المواسم والواقع هي قشيش، ارفع قدمك -8، أما السلالات المتأخرة والطويلة هي، فكي مستحي، أرفع قدمك 8، أما السلالات المتاخرة والطويلة هي، رده أحمد وزهرا القميبلية. أما السلالات التي أعطت انتاجية قليلة هي فكي مستحي، قشيش وارفع قدمك -8.

أوضح ارتباط الصفات ومعامل تحليل المسار ان عرض القندول وعدد القناديل / متر² يمكن استخدامها بفاعلية كصفات انتخاب في برامج التربية لتطوير الانتاجية العالية لسلالات الذرة. هذا يوضح أهمية هذه المكونات في التأثير على الاداء المظاهرى لسلالات الذرة التي تم تقريضاها. كل من نماذج تحليل ثبات الإداء (طريقة تحليل معامل الارتداد الخطى وطريقة الاثر التجميعي الرئيسي والتفاعل المتراكم) أعطت ان السلالات مقد، زهرة القميبلية، صفراء وتترون ذات انتاجية عالية وثابتة في بيئات مناخية كجود القضارف ومشروع الرهد. السلالات ود باكو، فرهوده، قشيش، ود فحل ذات انتاجية قليلة ولكنها ثابتة في البيئات الغير مناسبة كشمل القضارف. مقارنة فعالية طريقة تحليل معامل الارتداد الخطي وطريقة الاثر التجميعي الرئيسي والتفاعل المتراكم تحديد اثر التفاعل بين الصف والموقع، واقصى فورز يمكن مراقبتها في طريقة الاثر التجميعي الرئيسي والتفاعل المتراكم. فورز 75% من قيمة تفاعل البيئة مع التركيب الوراثي، أما معامل الارتدااد الخطي قد فورز حوالي 76% من قيمة التفاعل بين البيئة والتركيب الوراثي، وعليه طريقة الاثر التجميعي الرئيسي والتفاعل المتراكم تتوقف على طريقة تحليل معامل الارتداد الخطي، وهي ذات كفاءة عالية في تقسيم مجموع تراصات الاختلافات. في الخاتمة، قد، زهرا القميبلية، صفراء، وتترون يمكن مراقبتها في المناطق عالية الأمطار في مساحات صغيرة لأنها لا تتأثر الصحراء الآلي. أما ود باكو، فرهوده، قشيش، ود فحل يمكن زراعتها في بيئات ذات امطار قليلة. هذه الدراسة قمت في ايجاد سلالات ثابتة انتاجية في تسع بيئة التي درست.
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CHAPTER ONE
INTRODUCTION

Sorghum (Sorghum bicolor (L.) Moench) belongs to Andropogoneae tribe of the Poaceae family. Sorghum is diploid 2n=20 and predominantly self-pollinated, out crossing was rated at 5% to 15% in cultivated sorghum and up to 30% or more in wild sorghum (Rana and Obliana, 1979; House, 1982 and Doggett, 1988). It is an important cereal crop it consists of cultivated and wild species, ranks fifth worldwide after wheat (Triticum spp), rice (Oryza spp), maize (Zea mays) and barley (Hordeum vulgare) (FAO. 1995). It was first domesticated in the region of North East Africa. In particular, the region of Eastern Sudan and Ethiopia is considered a center of probable origin (Doggett and Prasada Rao, 1995). Doggett (1988) reported that, the greatest genetic diversity of cultivated and wild sorghum is present in East Africa. The crop is an annual grass that varies in height between 0.5-5.0 meters. Sorghum plant produces one or several tillers, that emerge from the base and later from the stem nodes. The panicle is usually erect, but sometimes recurved to form a goose neck (Doggett, 1988). Taxonomically, sorghum has 15 races, 5 races are; bicolor, caudatum, kafir, durra and guinea type, as well as their 10 intermediate (Harlan and De Wet, 1972).

It is the main staple crop of people’s diet in Africa, the Middle East and Asia, it is consumed in the form of stiff or thin porridges as a steam-cooked product, such as couscous, or a beverage. In Western Africa, Nigeria has emerged as a pioneer in the industrial utilization of sorghum. In addition, in many developing countries, sorghum’s Stover is often used to feed cattle; it is economically important in the semi-arid plains of central USA (Duncan et al., 1991). About 48% of the worldwide
production is used for animal feed and 42% is used for food. Human consumption wise, sorghum is eaten as thin porridge, thick porridge and fermented bread in central eastern Africa and as un fermented bread in India and central America. Moreover, in Africa grains are used for making alcoholic and non alcoholic beverages (Grenier et al., 2004). Due to its good adaptation to marginal, hot, and drought prone areas, sorghum consumption is highest in the poorest, most food insecure regions (ICRISAT and FAO, 1996). In the Sudan, sorghum is the most important cereal crop by production and consumption. It’s the main staple food specially in rural areas of the country and is used in different forms. In many parts the crop is wholly utilized (Ejeta, 1980). The grains are used for making kisra (unleavened bread from fermented dough) a significant portion is also used as thick porridge (Assida). The straw and stalks are used as fodder, building materials and fuel.

Exploitation of genetic variability is the most important tool in plant breeding especially in sorghum breeding and this has to be inferred by phenotypic expression. The consequences of the phenotypic variation depend largely on the environment. This variation is further complicated by the fact that all genotypes do not react in similar way to change in environment and no two environments are exactly the same. Mean yield across environments is adequate indicator of genotypic performance only in the absence of Genotype by Environment (GE) interaction. GE is differential genotypic response across environments. Most often GE complicates breeding, testing and selection of superior genotypes. It is important for plant breeders to identify specific genotypes adapted or stable to environment(s), thereby achieving quick genetic gain through screening of genotypes for high adaptation and stability under varying environmental conditions prior to their release as cultivars (Ariyo, 1989;

Ninety percent of sorghum is grown under rain-fed condition in the Sudan. Sorghum has an outstanding potential to withstand harsh environments. Its adaptation to these stress environments makes sorghum an important major cereal in Sudan as well as worldwide. It plays a major role in the semi-arid region of the world where drought, heat, and poor soil conditions make the production of other major cereals difficult (Doggett, 1988 and House, 1995). Sorghum, after millet, is superior in drought tolerance and adaptability to poor soils and therefore, has great potential in providing food security in the country.

Many regions in the country were affected by civil strife and recurrent drought. As a result many people are at risk because of crop production decrease in both rain-fed and irrigation areas. This in combination with food security issues prompts farmers in the country to grow early maturing drought tolerance sorghum landraces and improved cultivars. The total area under sorghum production is estimated to about 6-8 million ha (Elzein et al, 2008), which is 73% of the total cropped area in the country. Only 10% of this area is irrigated and 90% under rain-fed. However, productivity is constrained by drought and the use of low yielding varieties and landraces giving an annual average yield of 0.6 ton/ha.

Meteorological data and the simulated prediction models indicate a drastic decrease in the amount of rainfall, its patterns and length of the rainy seasons in the Sub-Saharan Africa. These climatic changes adversely affect traditional sorghum-growing areas of North and South Gadaref, Gezira, Sennar, White Nile and North Kordofan, causing a drastic shift towards the south. These drought prone areas now constitute more than 50% of the total sorghum producing area, which
may increase with the climatic changes to approach 100% in the near future. In these drought prone areas, (200 to 450 mm rainfall) farmers are still using low yielding landraces that suffer severe drought at all growth stages, resulting in low yields and occasionally in a complete crop failure.

Sorghum improvement in Sudan was started in mid-fifties, conventional methods such as introduction, hybridization and selection were used. A large number of accessions from the local germplasm were screened for morphological adaptations mainly earliness. The screened lines were further evaluated for yield potential and yield components, the drought tolerant genotypes released earlier include, Tozi Um Binien-7, TUB-11, TUB-22, and Fet. Matoug. These varieties are now out of cultivation due to their low yield potential and poor grain quality. Then from early seventies to the end of 20th century, the sorghum breeding program was involved in developing medium maturing varieties and hybrids. As a result high yielding varieties and hybrids, e.g; Ingaz, Feterita Wad-Ahmed, Tabat (Ibrahim and Mahmoud,1992), and hybrids, Hageen Dura-1 (HD-1), Rabih, and sheikan (ARC/ICRISAT,1983; Ibrahim and Mahmoud,1992), were released for high rainfall areas and irrigated sector. Then the global climate change which is reflected in change of rainfall trend, amount and distribution forced sorghum production to shift further south, an area of 4 million hectares with rainfall ranging from 250-400 mm lagged behind without suitable sorghum varieties. To solve this problem, the breeding efforts at Elobeid, Eldamazin and Wad-Medani research stations were activated to select for early maturing sorghum varieties, after long time of hybridization, selection and multi-location testing new drought tolerant sorghum varieties were released, these include; Butana and Bashayer (Elzein et al,2008) and arffagadamak-8 (AG-8) (Abdallah et al,2009) have been
released by the Agricultural Research Corporation (ARC) for commercial use in rain-fall areas with $\leq 500$ mm.

Ninety percent of the world’s area cultivated to sorghum is in developing countries. It is cultivated in the dry and hot low lands (Mukuru,1993). Low soil fertility, poor stand establishment, and a highly unpredictable drought stress pattern are major production constraints in these areas, and there is limited knowledge on adaptation to extreme and variable stress environments, and performance of sorghum grown under severe, unpredictable stress conditions.

Estimation of stability performance has become an important tool to identify consistently high-yielding genotypes (Kang,1998). Many stability statistics have been used to determine whether or not cultivars evaluated in multi-environment trial were stable (Lin et al.1986;Flores et al.1998;Hussein et al. 2000 and Robert,2002). Use of method that integrated yield performance and stability for superior genotypes become important because the most stable genotypes were not often the highest yielding (Kang,1988; Kang and pham,1991;Kang,1993;Kang and Magari,1996).

Conventional methods of partitioning total variation into components due to variety environment and variety-environment interaction conveyed little information on individual patterns of response (Kempton,1984). Other methods used include regression analysis to partition genotype x environment interaction (Gauch,1988), multivariate analysis (Westcoff,1987).

Due to climate change, development of sorghum with high yielding and desirable grain quality for different environments is one of the exciting research that leads to successful evaluation of stable genotype, which could be used for general cultivation or as breeding material.
Therefore, there is a pressing need for identifying stable genotypes with high grain yield potential and acceptable quality preference in irrigated and rain-fed traditional and modern production systems.

The objectives of the present study was, therefore, designed to investigate:

1- Estimation of the amount of genetic variation present in the sorghum genotypes under study,

2- The interrelationships between yield and its related components and determine the most important contributing traits that can be used as selection criteria for high grain yield,

3- Analysis of these interrelationships using path coefficient analysis in order to evaluate the direct and indirect effects of these traits on grain yield,

4- Estimate G x E interactions of some sorghum genotypes grown under a range of testing environments, and

5- Stability of grain yield
CHAPTER TWO
LITERATURE REVIEW

2-1 Phenotypic variability in sorghum

Progress in plant breeding depends on the extent of genetic variability present in a population that permits effective selection procedures, based on locally adapted land races.

Bushara (1999) studied the genetic variability in seventeen parental lines together with crosses and recorded highly significant differences for plant height, leaf area index, stem diameter, head diameter, head length, days to 50% flowering, number of grains per head, days to maturity, 100-seed weight, grain yield per plant and grain yield (t/ha).

Mohammed (1993) observed genetic variability in grain sorghum and scored highly significant differences among the genotypes for plant height, days to 50% flowering, grains number per head, 100-seed weight, stem diameter, head diameter, head length and grain yield (t/ha). Hoveny (2001) found variability for 13 parental lines with their 30 crosses in grain sorghum and observed highly significant differences for days to 50% flowering, plant height, leaf number, leaf length, panicle length and panicle weight.

Prabhakar (2001) observed genetic variability of 11 parents and their crosses in grain sorghum and reported significant differences for days to 50% flowering, days to maturity, 100-seed weight and grain yield per plant. Elagib (1999) studied genetic variability of 8 parents and their 16 crosses in grain sorghum and found significant differences for plant height, days to 50% flowering, stem diameter, 100-seed weight and grain yield.

Kumara Vadivel and Rangasany (1994) found significant differences among genotypes with regard to days to 50% flowering,
panicle length and grain yield. In a study of 30 Sudanese grain sorghum genotypes Abu Elgasim and Kambal(1975) reported a wide range of variability for grain yield, number of grains per panicle, head exertion, leaf area and 100 seed weight. Asthana et al (1995) observed maximum range of variability for grain yield. Ahmed (2000) studied variability in some sorghum genotypes collected from Nuba mountains, and recorded significant differences among genotypes for days to 50% flowering, plant height, 100- seed weight, and grain yield.

Lamb et al.(1987) reported that there is high significant differences among entries for grain yield. Stemperier (1990) found a wide range of the variability for grain yield, plant height, days to 50% flowering and 100- seed weight, during the evaluation of several thousands of inbred lines in hybrid combinations. Geremew (1993) reported a wide range of variability for days to 50% flowering, stem thickness, seed size, number of grains per head, yield per plant and yield per plot.

Bello et al. (2007) studied genetic variability in sorghum and reported significant differences among cultivars for days to 50% flowering, plant height, 100- seed weight and grain yield. Tadesse and Ejeta (2008) studied genetic variability of introduced sorghum parental lines and scored the male parents that exhibited considerable variability for plant height, panicle exertion, panicle length, 100-seed weight and grain yield. Sindagi et al (1970) observed that grain yield and fodder yield showed the maximum genotypic variability. Sridehar et al (2003) studied the nature and magnitude of genetic variability for grain and fodder yields and its component traits in sorghum germplasm and reported highly significant differences among genotypes for plant height, days to 50% flowering and grain yield. This indicated considerable variability in the experimental material.
Mohammed et al. (1999) studied 76 lines selected from an advanced random-mating sorghum population showed that heritability estimates were high for most of the studied characters except for grain yield. Patel et al. (1980) studied components of variability in sorghum and found that plant height and 100-seed weight had high estimate of heritability, 85.47% and 80.56%, respectively.

Babat and Shinde (1980) studied genetic variability for grain yield in sorghum and reported estimates of heritability in broad sense ranging from 45.38% to 67.34%. Singh and Makne (1980) found that estimates of heritability were high for plant height and number of days to 50% flowering. Mamdouh et al. (1971) studied heritability and expected genetic advance in five crosses in sorghum, and reported that seed weight exhibited relatively high heritability (75.6%).

Phul and Rang (1986) reported high broad-sense heritability estimate for yield, bloom date and plant height, while Kulkarni and Shinde (1988) found low heritability for days to 50% flowering. Cheralu and Rao (1989) stated that high heritability estimate were obtained for grain yield, total dry matter, ear length and ear weight. Kumar and Singh (1986) revealed that high heritability estimate for plant height, internode length and 1000 grains weight ranged from 85.30-93.99 %, indicating that selection for these traits should lead to improvement in sorghum.

Kumar and Singh (1986) analyzed 40 diverse genotypes for the data on grain yield/plant and 13 related traits and revealed that differences among genotypes for all traits were significant and the coefficient of variability ranged from 5.70 to 39.18%. Genotypic and phenotypic coefficients of variability were high for grain yield/plant as well as heritability (90.62%) and genetic advance (73.14%) and heritability for plant height, panicle weight, internodes length and 1000-
grain weight ranged from 85.30 to 93.99% indicating that selection for these traits would lead to crop improvement.

Nimbalkar et al. (1988) noticed the highest (11.6) and lowest (1.7) coefficients of variation for grain yield and number of days to 50% flowering while heritability was high for all characters except for number of leaves. Cheralu and Rao (1989) observed high heritability for grain yield, total dry matter, ear length and ear weight. Amrithadevarathinam et al. (1994) noticed high heritability and low genetic advance for plant height and leaf area among 30 genotypes of sorghum.

Asthana et al. (1995) studied 20 plant characters in 52 germplasm and noticed a high magnitude of genetic coefficients of variability for seven quantitative characters viz., tillers per plant, internodes size, leaf area, seed weight/panicle, seeds per head, gross panicle weight and dry fodder yield per plant. The heritability estimates were medium to high and higher genetic advance as percentage of mean was associated with the characters peduncle size, seed size, seed volume indicating the predominance of additive genetic variance.

Biradar et al. (1996a) studied 128 sorghum genotypes involving restorers and maintainers in which they have noticed high value of genotypic and phenotypic coefficients of variation in internodes length, panicle length, panicle breadth and grain yield per plant. Components of grain yield such as plant height, number of leaves per plant, panicle length, number of whorls per panicle, number of primaries per panicle, length of panicle and ear weight exhibited high genetic advance over mean coupled with high estimates of broad sense heritability values.

Nguyen et al. (1998) noticed that phenotypic coefficient of variation was higher than genotypic coefficient of variation for all the 7 characters under study in 13 sorghum genotypes. The highest PCV and GCV were obtained for dry weight of leaves. High heritability estimates
coupled with high genetic advance were observed for dry weight of leaves, plant height and 100-grain weight, indicating that these traits are controlled by additive gene action.

Amit et al. (1999) studied 34 genotypes of sorghum under two environments and noticed that estimates of genotypic coefficients of variation, heritability and genetic gain were of higher order for characters such as peduncle length, panicle weight, biological yield and harvest index.

Veerabadhiran and Kennedy (2001) studied the genetic variability in 75 genotypes of sorghum and noticed that 100-grain weight and grain yield showed high genetic and phenotypic coefficients of variation. The heritability estimates were higher for all the characters studied. The highest heritability was recorded in grain yield per plant (99.9%) followed by days to 50% flowering (96.9%). Among the characters studied 100-grain weight and grain yield exhibited highest heritability coupled with high genetic advance.

Narkhede et al. (2001) studied genetic variability for 22 yield related traits in 168 genotypes of sorghum and noticed that phenotypic coefficient of variation was higher than the genotypic coefficient of variation. However, variations of both estimates were within range, indicating the phenotypic variability is a reliable measure of genotypic variability. All the traits showed moderate to high estimates of broad sense heritability.

Tiwari et al. (2003) observed higher estimates of heritability and genetic advance for plant height, length of leaf, length of internode, days to maturity, grain yield per plant and test weight in 10 diverse genotypes of sorghum indicating contribution of additive genes in the expression of these traits.
Umakanth et al. (2004) studied range, phenotypic and genotypic coefficients of variation, heritability, genetic advance and the relationship between yield and yield components in 40 landraces and three established lines. High heritability estimates coupled with high genetic advance were observed for panicle length and 100-seed weight.

Deepalakshmi and Ganesamurthy (2007) reported high heritability accompanied with high GA as per cent of mean was observed for the characters viz., days to 50% flowering, plant height, leaves per plant, leaf length, ear head weight, number of primaries per panicle, 100 grain weight, grain mould score and single plant yield suggesting that these characters are under additive gene action and thus gives better scope for selection.

2-2 Correlation and path analysis

Correlation and path analysis studies are important in breeding programs, as they give information on direction and magnitude of association between different traits. This could be utilized to select for one character indirectly by selection for another, (Sharaan and Ghaallab,1997). The advantage of path coefficient analysis is that it permits the partitioning of the correlation coefficient into its components, one component being the path coefficient (standardized partial regression coefficient) that measures the direct effect of predictor variable upon its response variable; the second component being the indirect effect of a predictor variable on the response variable through other predictor variable (Dewey and Lu,1959). Milligan et al. (1990) stated that in plant breeding path analysis has been used to assist in identifying traits that useful as selection criteria to improve crop yield.

Bramel and Lauer (1990) and Khazzah and Miller 1992) stated that grain yield of sorghum was positively correlated with 1000 -seed weight and plant height,while negatively correlated with days to 50% flowering.
Choudhary (1992) found that grain yield was positively associated with days to flowering, panicle weight and total dry matter. Mather and Patel (1982) reported that plant height and number of leaves per plant were positively correlated with dry matter yield. Hooskstra and Ross (1982) recorded that plant height, days to 50% flowering and number of leaves in sorghum were positively correlated with grain yield and with each other in F1 generation.

Limma et al (1992) stated that there was a significant positive correlation for plant height with grain yield. Elagib (1999) observed that grain yield was positively correlated with days to 50% flowering, plant height, 1000 seed weight, while negatively correlated with tiller number per plant and stem thickness. Mohammed et al, (1999) found that the genotypic correlations were similar in size and magnitude, indicating that association between characters were mostly of genetic nature. the undesirable positive correlation between yield and days to 50% flowering.

Bittinger et al, (1981) revealed positive association between grain yield and plant height, 1000-grain weight and days to 50% flowering. Totok et al (1998) reported that genetic correlation between grain and seed weight, panicle weight and productive panicle was 1.00, 9.89 and 0.75, respectively, suggesting that indirect selection through yield components will improve grain yield. Similar results were obtained by Harer and Karad (1999), who found that grain yield was highly and positively correlated with plant height, 100-grain weight, fodder yield/plant, ear length and flag leaf area, but was negatively correlated with days to maturity.

Abraham et al.(1989) found that genotypic correlation coefficient were slightly higher than the respective phenotypic ones. Grain yield had
positive phenotypic association with days to 50% flowering, productive tillers/plant, days to maturity and 1000-grain weight.

Shukla (1966), Gomez (1987), Manuel and Palanisamy (1990) found that grain yield was significantly correlated with plant height. Liang et al (1969) stated that there was significant correlation with grain yield, also Chigwe (1984) found that 1000-grain weight was significantly correlated with yield under dry conditions in all maturity groups.

Abdalla (2011) found that yield was negatively correlated with days to 50% flowering and 100-seed weight and positively correlated with plant height, number of leaves and percent of effective tillers. He reported that, of the four characters recorded in 23 genotypes, grain number per plant was highly correlated with grain yield per plant (r = 0.7). The most important direct effect on grain yield per plant was shown by grain number per plant followed by panicle length.

Nimbalkar et al. (1988) noticed positive, highly significant correlation coefficient between grain yield per plant and panicle weight, panicle breadth, number of secondary tillers, and 1000-grain weight. Raut et al. (1992) observed that among 20 sorghum genotypes, number of leaves per plant and panicle weight had positive and significant association with yield and also a high positive direct effect on this trait. Potdukhe et al. (1994) studied 10 yield related traits in 42 sorghum genotypes and revealed that grain yield was positively and significantly correlated at the genotypic and phenotypic level with panicle length, panicle weight and 100-grain weight.

Jeyaprakash et al. (1997) correlated 65 sorghum genotypes and inferred that grain yield was significantly and positively correlated with panicle weight, panicle length and dry fodder yield. Plant height also had a positive significant association with grain yield at the genotypic level.
They also studied correlation and path coefficient analysis, and reported that grain yield was positively correlated with panicle length, panicle weight, plant height and dry fodder yield.

Griffiths (1965) showed that seed production depends directly or indirectly on the number of agronomic traits, such as plant height, foliar area, dry matter production as well as on the length and width of the flag leaves.

Rao and Patel (1996) studied correlation and path coefficient analysis in sorghum. They found a high positive direct effect of grain/panicle on grain yield. They also studied variability and correlation in F2 population and found that genotypic and phenotypic coefficient of variation was highest for grain/panicle followed by grain yield/plant.

Ezeaka and Mohamed (2006) studied association and path analysis between hill count, bloom, plant height, panicle count, 1000 seed mass, head weight, and grain yield of 30 sorghum varieties. They found significant high positive correlation between grain yield and head weight and 1000 grain mass. Partitioning of yield and yield components into direct and indirect effects revealed that head weight had the highest direct effect on grain yield while 1000 grain mass contributed indirectly to grain yield via head weight as one of the most important yield components followed by 1000 grain mass and then panicle count. Plant height has high positive phenotypic and genotypic correlation coefficient with head weight and grain yield indicating that taller plant possesses heavier head than shorter plants, probably due to greater mobilization of assimilates to the panicle in taller plants.

Evans and Wardlaw (1976) concluded that yield differences in agronomic crops are associated with kernel number and kernel weight. Janour et al. (1976) observed a positive correlation between late maturity and height and positive correlation between grain yield.
2-3 Genotype x environment interaction

Testing and evaluation of varieties aimed at identifying genotypes that consistently produce stable yields over a range of diverse environments. Knowledge from GxE studies are useful for developing strategies for testing and selection of genotypes most adapted to the target environments under which the genotypes will be grown (Ramon Rea and De Sousa-Vieira. 2002).

Allard and Bradshow (1964) stated that significant genotype x environment interactions resulted from changes in the magnitude of the different genotypes in different environments, while Chakour et al .(1990) emphasized the importance of the presence and magnitude of G x E interaction to plant breeders for making decision regarding the development and evaluation of new cultivars.

Gomez et al., (1986) investigated GxE interaction in 40 sorghum hybrids and their parents and they showed that environmental influence was the most important for the eight characters studied, while the genetic influence was the most important for only four characters. They found that 1000-grain weight, number of panicles per plot and panicle exertion exhibited no significant differences among environments, genotypes and GxE interactions, respectively. Patel et al.,(1988) stated that the genotypic effects were more important than the environmental effect for all the characters.Their F1 and F2 generations of 8x8 diallel cross evaluated for grain yield and yield components in three environments showed significant genotype x environment interaction for all characters.

Santos et al .(1995) studied the G x E in sorghum and showed that years were a significant source of variation for flowering and grain yield. Mohammed and Frances (1979) observed that G x E interaction was increased with an increase in duration of plant growth. Shivanna et al .(1992) showed that G x E interaction was significantly different
among different sorghum lines. Desai et al. (1984) observed that the GxE interaction was significant in sorghum. Faris and Araujo (1981) found that G x E interaction was highly significant. Hoveny (2001) studied the GxE interaction of 14 parents with their 40 crosses in grain sorghum and conclude that the crosses showed highly significant differences over the two seasons.

Ganga and Prasada (1971) stated that the genotype x year interaction was non-significant. Ahmed (2000) recorded that the genotype x year interaction was significant for days to 50% flowering, plant height, 100-seed weight and grain yield in grain sorghum. Hashim (2008) studied sorghum germplasm for grain yield stability over years, and reported significant differences for plant height, days to 50% flowering, number of seed per panicle, 100-seed weight and grain yield.

Kambal and Mahmoud (1978) estimated variety × environment interactions for grain yield from a study involving 16 sorghum varieties grown at three locations over 3 years period. They found that variety × year interaction was small and not significant while variety x location × year interactions were highly significant. They suggested that the years of testing could be reduced by increasing the number of test locations. Prabhakar and Patil (2002) evaluated 12 sorghum cultivars for grain yield and stable performance in medium soils. They observed significant variation among the genotypes and environments. Significant genotype × environment interaction was observed for grain yield. They noted that the highest mean yield was 1219 kg per ha and 1217 kg per ha, respectively, in RSLG227 and RSLG 262. In north Queensland (Australia) Jackson (1991), Jackson and Hogarth (1992) found genotype x location (GxL) interactions to be of greater importance than genotype x crop-years (GxC) and genotype x location x crop-years (GxLxC) interactions. They advocated testing across several locations to maximize gain and
suggested that minimal gains will be achieved from testing multiple crops within a location.

Analysis of individual and combined experiments revealed highly significant differences (P=0.05) among the genotypes, environments and genotype x environment for both days to 50% flowering and plant height. Mean days to 50% bloom for each genotype at each environment (Abdalla et al. 2011). The mean squares of genotypes, seasons, locations, location x season, location x genotypes, season x genotypes and season x location x genotype interactions were highly significant (P=0.01) for grain yield. Mean grain yield ranged from 2722 to 557 kg/ha. The sorghum genotypes Edo 34-23-4, Edo 26-18 and Edo 16-dwarf gave substantially higher grain yields than commercial checks and the trial mean. Their percentage yield increase ranged from 5 to 75% over Yarwasha and from 8% to 24% over Wad Ahmed (Elzein et al., 2008).

2-4 Stability

Stable variety is defined as the mean variety that does relatively the same over a wide range of environments. Lin et al.,(1986) remarked that the concept of the stability is defined in many ways depending on how the scientist wishes to look at the problem. Eberhart and Russell (1966) defined a stable variety as that having unit regression coefficient (b=1) and the deviation not significantly different from zero. Perkins and Jinks (1968) concluded that there might be some linear relationship between performance of a particular genotype to environmental conditions. Information combining mean yield and stability statistics associated with each genotype being tested should enable researchers to determine the more appropriate genotype to be selected.

Narkhede et al (1997) studied stability performance of sorghum varieties for grain and fodder yield, they found that some of them have a
wide adaptation with respect to grain yield and one variety was most stable for fodder and possessed general stability.

Ibrahim et al (1998) studied sorghum genotypes to identify stable genotypes that perform well over a wide range of environmental conditions in the Sudan. Their combined analysis of variance over years and locations revealed highly significant main and interaction effects for genotype, year and location. The location × year effect had no relationship to recommendation with respect to genotypes, but it indicated that the ranking of locations with respect to average yield was not the same in different years. They select stable varieties as that with above mean grain yield, regression coefficient (b=1) and deviation from regression equal zero.

Abdalla et al. (2011) revealed that lines AG-8 and AG-15 were 18 and 14 days earlier in 50% flowering, than Wad Ahmed, respectively. This early maturity coupled with their high yield potentials, harness their drought tolerance and make them adaptable and stable across a wide range of environments.

Prabhakar and Patil (2002) in stability analysis they found that RSLG 262 is the most appropriate for developing rabi sorghum cultivars suitable for medium soil. Stability studies for public and private bred hybrids of kharif sorghum was made by Mruthyunjaya (2003) and he observed significant genotype × environment interaction for the seven characters studied and reported that hybrids PJH 65, Amarnath 251 and DSH 3 were well adapted to all environments as they had high mean, unit regression coefficient (bi) and also associated with non-significant deviation from regression (S2di). Karthik (2004) performed stability analysis for ten quantitative characters (plant height, number of primaries ear per head, test weight and grain yield etc.) in rabi sorghum and reported significant variation for all the characters studied. Among the
hybrids, M-312A × BRJ-62, 53A × SPV-570 and 117A × BRJ-356 were found to be stable for most of the characters.

Abdalla et al (2011) found that the genotypes, AG15 and AG8, had b values of 0.900 and 0.928, which are not significantly different from 1, that were less responsive to environmental changes and are more adaptive. However, results indicated clear differences in slopes of the regression lines between the tested lines and the checks. CAG had below average mean grain yield indicating instability, and the regression coefficient (b) exceeded unity significantly, 1.35, for Wad Ahmed.

Jowett (1972) indicated that comparison of regression coefficients of yield on environmental index shows that hybrids are more stable in terms of stability parameters. In terms of deviation from regression, the three way crosses were more stable than single cross (Patanothai and Atkins, 1974). A study on the genotype x environmental interaction for green fodder yield of sorghum revealed that a portion of interaction was accounted by the linear function of the environmental means, whereas significant portion was independent of the linear component. The genotypes CA33, C-406-8 and C-19 had not only shown high mean performance in all the environments but also better phenotypic stability and response 'bi' value (Paroda et al., 1973). Thirteen promising genotypes were evaluated by Paroda et al. (1973) in Sorghum sudanense. Mean yields of the genotypes viz., T103, 5722 and T83 were superior to check variety and stable as the deviation around the regression slope was low. In an analysis of stability of hybrids and parents, Singhania and Rao (1976) revealed that the F1 populations were not only better in respect of increased production but also showed greater stability in production over environments. Females were more stable but had low mean yields than males that were low in stability and better adapted to favorable environment.
Cheng et al. (1977) in order to select male parents from 78 combinations, grain yield showed the lowest stability and largest range of hybrid vigour. Eleven genotypes of grain sorghum including the local variety K-3 were tried under two environments over two years in Coimbatore. Mean difference between the environments and those between genotypes were highly significant. The genotype x environment component was also significant. There were distinct differences in "values among 11 varieties in the linear regressions of individual genotypes. Low S2di value coupled with high mean over environments were observed for 'Swarna' and 'S8411' and were considered as stable. Even though 'CS3541' was the' most promising variety with the highest mean, it was not stable since its 'S2di' value was high (Palanisamy et al., 1977). Jatasra and Paroda (1985) observed significant G x E interaction for ear emergence and noted that ear emergence was stable conferring the yield stability in 40 cultivars at three locations. Sharma et al. (1987) evaluated six hybrids including' three released and three advanced stage experimental hybrids for stability parameters in eight different environments. The hybrid CSH-9 gave the highest grain yield but was not stable, while, CSH-5 and CSH-6 were poor yielders, but stable in performance. Further they indicated that the hybrids SPH 196 and SPH 225 were good in grain yield and stability.

Shivanna et al. (1989) investigated yield stability of 17 new sorghum hybrids at 4 sites differing in precipitation. SB322A x S82202 was the most stable hybrid, suitable for all environments, while 2219 A x SPV 126 and 2219 A x SB 5204 were suitable for favorable environments and 2219 A x SPV 346 and 2219 A x SB 4272 were suitable for unfavorable environments. Palanisamy and Prasad (1980) reported that the mean difference between the environments and those between the genotypes were highly significant (P=0.01). The genotype x environment
component was also significant. The estimates of 'bi' showed that there were distinct differences among the eight hybrids in the linear regressions of the individual genotypes. Hybrid combinations CSH-6 and 3660 A x 1324 showed less 'S2d' values and could be considered phenotypically more stable. Of these two combinations, CSH-6 showed the least 'S2di' values coupled with high mean yield over environments and could be considered as very stable and desirable genotype which could give linear response to the improvement in environmental conditions. Shekhar et al. (1993) carried an experiment during kharif seasons of 1983-88 with five sorghum hybrids and three cultivars grown at three locations. The results showed that hybrid CSH-11 had the best stability for grain production followed by hybrid AKSH-73 (SPH-388). Among cultivars, SPV-351 had the best stability.

Patil et al. (1991) evaluated ten genotypes of sorghum (Sorghum bicolor) at five different environments during five monsoon seasons with respect to six yield and growth characters. Analysis of pooled data revealed significant genotype x environment interactions for all traits. Stability parameters indicated that the best adapted genotype was SPV 346 for all characters, RSV 6 for fodder yield and RSV 10 for 1000 grain weight. They also noticed that SPH 196 was stable and had the highest fodder yield (14.1 t/ha), grain yield (4.3 t/ha) and 1000 grain weight (25.34 g) under favorable environments. Hybrids CSH-1 and CSH-6 were stable for days to maturity and responsive to poor environments. Dale and Sauer (1992) observed that the highest grain yields were obtained with cv. Barrier (4.85 t/ha), Hylan '726 (4.74 t), success 40 W (4.73 t), S81 (4.58 t) and Buster (4.57 t) cv. DK35 produced the lowest yield (3.60 t/ha). Yields were correlated with an environmental sensitivity index. The top 13 cultivars had sensitivity indices > 1.0 and conversely
12 of the bottom 14 cultivars had sensitivity indices < 1.0. However, some hybrids (E.g., Hylan 726) were very high yielding and stable with sensitivities of about 1.00.

Shekhar et al. (1993) observed that the growth period of SPH 468 (103-105 days) was the same as that of CSH-1. Out of 26 genotypes tested by ICRISAT at 18 locations in 13 countries of semiarid tropics, SPH 468 ranked third with an over all yield of 5.28 t per ha. It showed average stability and was very responsive to crop management methods.

Wilfred and Rangaswamy (1994) studied stability parameters of 16 hybrid combinations. Hybrids IR58025Aj TNAU 88013 and V20Aj TNAU 88013 were identified as the most stable and consistent for grain yield. Muppidathi et al. (1995a) reported that the 20 grain sorghum entries (15 varieties and five hybrids) evaluated for stability of panicle characteristics in eight environments during 1985-86 showed significant genotype x environment interactions for the six characters studied (panicle length and breadth, peduncle length and girth radius, number per panicles and grain yield per panicle). All the entries were unstable for rachis number per panicle. Genotypes C0 25 and TN S533 had above average stability for grain yield and were suitable for favorable environments. CS 3541 and TNS 31 had average stability for grain yield and were suitable for a variety of environments.

Muppidathi et al. (1995b) evaluated 20 sorghum entries for stability of grain yield and seven yield components in eight environments. There was significant genotypes x environment interaction for all eight characteristics. Both linear and non-linear components were significant. In favourable environments, five genotypes were identified as superior KS 6312, CSH 5, CSH 1, Co H3 and K tall. The most stable genotype was CSH9.
Sudhakar et al. (1997) evaluated eight advanced breeding lines of fodder sorghum (*Sorghum bicolor* (L.) Moench) and variety C0 27 for five seasons starting from summer 1992. Genotypes differed in their stability for yields. High yielding genotypes FS 205 and FS 9402 had the widest adaptability and high stability. Beheshti (1997) compared ten sorghum [*Sorghum bicolor* (L.) Moench] varieties for yield and adaptability during 1989-1991. Rubino gave the best mean yield (7.82 t/ha) over three years period and was the most stable.

Narkhede et al. (1997c) evaluated seven sorghum genotypes for grain and fodder yield and noted significant genotype x environment interaction for both traits. Selection-3 and SPV 489 were stable for fodder yield.

Narkhede et al. (1998) studied 18 *kharif* sorghum hybrids for their grain and fodder yield stability during *kharif* 1995. The variance due to environment was significant for both grain and fodder yield and there was considerable interaction between cultivar and environment. The hybrid SPH 821 was the most stable for grain yield and SPH 792 was the most stable for fodder yield.

Prabhakar and Patil (2002) evaluated 12 sorghum cultivars for grain yield and stable performance in medium soils. They observed significant variation among the genotypes and environments. Significant genotype x environment interaction was observed for grain yield. They noted highest mean yield of 1219 kg per ha and 1217 kg per ha respectively in RSLG 227 and RSLG 262. By stability analysis it was revealed that RSLG 262 is the most appropriate for developing *rabi* sorghum cultivars suitable for medium soil. Stability studies for public and private bred hybrids of *kharif* sorghum was made by Mruthyunjaya (2003) he observed significant genotype x environment interaction for the seven characters studied and reported that hybrids PJH 65, Amarnath 251
and DSH 3 were well adapted to all environments as they had high mean, unit regression coefficient ($b_i$) and also associated with non-significant deviation from regression ($S^2_{di}$).

Elzein et al. (2008) found differences in slopes of the regression lines. Some regression coefficients ($b$) exceeded unity while others were less than one. The genotypes Edo 34-23-4 and Edo 26-18 which had high regression coefficients ($b_i$) of 0.934 and 0.809, and with minimum deviation from regression of 0.033 and 0.684, respectively, and also mean grain yield above the general mean of the trial; means that they have better response in unfavorable environments and therefore adaptable and predictable (high $R^2$ value). Regression coefficients greater than one and had higher ($S^2_d$) were observed for Gew 22-15 and Gew 3-2 with mean grain yield below the general mean yield, indicating that these two lines were not stable under adverse conditions but may respond better in favorable environments. The genotype Edo 16 dwarf had regression coefficient $b_i = 0.522$ and a high deviation ($S^2_d = 10.977$) and mean grain yield above the trial mean could be considered adaptable and suitable for general cultivation. The commercial variety W. Ahmed had the largest ($b_i$, 2.927) and significantly different deviation (166.548) but out-yielded the general trial mean confirming that it is only responsive to good growing conditions. Elasha et al. (2011) found that the genotypes DIA-07666, DMN 15P 1003, PAC-501 and E-1 showed slopes ($b$) of 2.67, 2.49, 2.34 and 1.18 with deviation from regression of 0.08, 0.45, 0.68 and 0.12 under irrigation respectively and a mean grain yield above the general mean of the trial; meaning that are more adaptable under irrigation, and greater mean grain yield values were obtained by PAC-501 (0.93 t/ha), PAC-537 (0.70 t/ha) and DIA-07666 (0.96 t/ha) compared to a mean grain yield of (0.56 t/h) for HD-1 and of (0.85 t/h) for Wad Ahmed; meaning that are more adaptable under rain-fed areas.
CHAPTER THREE
MATERIALS AND METHODS

3-1 Location

The experiments were conducted over three consecutive seasons (2009/2010, 2010/2011, 2011/2012) at three locations, viz. Rahad Research Farm of the Agricultural Research Corporation (ARC), Sudan, North and South Gedarif regions of the Gedarif Research Station farm.

3-2 Experimental treatments and design

Eighteen accessions of sorghum collected from Gedarif and from the gene bank (Wad Medani) were used in this study. These accessions were five released varieties (Wad-Ahmed, Tabat, Butana, Bashayer and Arffagadamak-8), and 13 local land races preferred by farmers Korakollo, Mugod, Saffra, Wad-Bako, Tetron, Faki-Mustahi, Farhoda, Gadambalia bloom, Ajeb-seido, Arafah, Gesheish, Wad-fahal and Milo).

3-3 Cultural practices

The standard cultural practices adopted for sorghum at the Rahad Research Farm were followed. Land was prepared by disc ploughing, disc-harrowing, leveling and ridging in irrigated site and by disc-harrowing in rain-fed sites.

Treatments (18 accessions) were laid out in a randomized complete block design with four replicates in the different locations and seasons. Sowing was the first week of July under irrigation and the first to the third week of July under rainfed conditions depending on the onset of rainfall. Under irrigation, the entries were sown to five rows, 5 m length on ridges; 0.8 m apart at 0.3 m intra-row spacing and thinned to two seedlings per hill. Under rainfed conditions, they were also sown to five rows 5 m length, on flat; 0.8 m apart at 0.2 m intra-row spacing and thinned to two seedlings per hill. Urea at a rate of 80 kg and 40 kg /fed
was applied under irrigation and rain-fed sites, respectively, as recommended by the (ARC). The crop was irrigated every two weeks or whenever necessary and irrigation was withheld three weeks before harvest. In irrigated and rainfed experiments, assessments were made in the central three rows of the plot discarding one row or more at each side.

3-4 Parameters measured:

3-4-1 Days to 50% flowering
The number of days from planting to the date when approximately 50% of the plants in the row were at half-bloom.

3-4-2 Plant height(cm) prior to harvest
The average of heights were taken at random from five plants for each entry measured from the soil surface (base of the plant) to the tip of the panicle in each plot.

3-4-3 Number of plants at establishment/m²
Plant count per m² was done after thinning.

3-4-4 Number of heads/m²
Taken at random from five plants per plot.

3-4-5 1000 grain weight/g
Thousand grains were taken randomly from each plot and weighed using sensitive balance.

3-4-6 Head width (cm)
The average head width, taken at random from five heads and then measured from the middle of the panicle at harvest.

3-4-7 Head length (cm)
The average head length, taken at random from five heads and measured from the base of the panicle up to the tip of the panicle at harvest.
3-4-8 Grain yield kg/ha

Grain yield was calculated from the yield per plot which was attained from harvested heads. The grain yield per plot (kg/m²) was then converted to kg/ha.

**Statistical analysis**

Data collected were analyzed by the analysis of variance procedure to examine the differences among the genotypes for all traits measured. Analysis of variance was used for each season data to test for significant differences among genotypes. Combined analysis of variance was carried out for testing the effect of environments, genotypes and their interactions. Mean for seasons was used to compute simple linear correlation coefficients between all possible combinations. The path coefficients applied due to Dewey and Lu (1959) procedure in order to partition correlation coefficients between grain yield and its components which is divided into direct and indirect effects.

**Stability analysis**

Combined analysis of data generated from different environments was used for estimation of stability parameters. These parameters include:

1-**Regression approach of Eberhart and Russel(1966).**

In this approach, genotype means from individual environments are regressed on the environmental means. Genotypes which have regression coefficient larger than one are regarded to be more adapted to favorable environments, and those which have regression coefficient smaller than one are regarded to be more adapted to unfavorable environments. Genotypes which show small values of deviation from regression ($s^2d$) are claimed to have high yield stability

2-**The Additive main Effect and Multiplicative Interaction (AMMI) analysis** was carried out to show the stability and pattern of adaptation of sorghum lines to the environment. AMMI analysis fits additive effects
due to genotypes (G) and environments (E) by the usual additive analysis of variance procedure and then fits multiplicative effects for genotype-environment interaction (GE) by principle components analysis (PCA). The IRRISTAT software was used to conduct the AMMI analysis (IRRI, 2005) according to (Gauch and Zobel, 1988 and Nachit et al., 1992) the equation of AMMI model is:

\[ y_{ij} = \mu + g_i + e_j + \sum_{n=1}^{n} \lambda_n \alpha_{in} \gamma_{jm} R_{ij} \]

where:

- \( y_{ij} \) is the grain yield of the \( i^{th} \) genotype in the \( j^{th} \) environment
- \( \mu \) is the grand mean
- \( g_i \) is the deviation of the genotype mean from the grand mean
- \( e_j \) is the deviation of the environment mean from grand mean
- \( \lambda_n \) is the eigenvalue of the \( n^{th} \) IPCA
- \( \alpha_{in} \) and \( \gamma_{jm} \) are the genotype and environmental interaction principle components eigenvectors (\( IPCA_g \) and \( IPCA_e \), respectively) for axis \( n \); \( n \) is the number of IPCA retained in the model; and \( R_{ij} \) is the residual.

Environmental and genotype PCA score are expressed as unit vector time the square root of \( \lambda_n \). The multiplicative part of the model is obtained by PCA (\( \alpha_{in} \) and \( \gamma_{jm} \)). The principal advantage of the AMMI is that the interaction can be modeled by only one or two PCA-axes.

To analyze genotype-environment interaction and adaptation graphically, AMMI bi-plot with the PCA1 scores was plotted against the mean yield (main effect). Genotype or environments that appear almost on a perpendicular line have similar means and those that fall almost on a horizontal line have similar interaction patterns. Genotype (or environments) with large positive or negative have high interactions, whereas genotypes (or environments) with (principle component
analysis) PCA1 score near zero have small interactions. To further explain the GE and adaptation a biplot between the PCA1 score PCA2 score was drawn. The AMMI expected yield of any genotype and environmental combination can be calculated from the biplot as indicated by Zobel et al., 1988. The interaction part is simply the genotype PCA1 score time the environmental PCA1 score. Genotype and environment with PC1 score of the same sign produce positive interaction effects, whereas combinations of PC1 score of opposite signs have negative interactions.
Table 1. Monthly means of rainfall (mm) data recorded during season 2009, 2010, and 2011 at North (NG) and South Gedarif (SG).

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>No rain</td>
<td>No rain</td>
<td>39.4</td>
<td>No rain</td>
<td>No rain</td>
<td>No rain</td>
</tr>
<tr>
<td>June</td>
<td>49</td>
<td>76</td>
<td>73.8</td>
<td>172</td>
<td>77</td>
<td>No rain</td>
</tr>
<tr>
<td>July</td>
<td>179</td>
<td>266</td>
<td>101.9</td>
<td>291</td>
<td>261</td>
<td>92</td>
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<tr>
<td>Aug</td>
<td>127</td>
<td>177</td>
<td>132.2</td>
<td>212</td>
<td>284</td>
<td>176.6</td>
</tr>
<tr>
<td>Sept</td>
<td>152</td>
<td>94</td>
<td>132.2</td>
<td>33</td>
<td>181</td>
<td>25.7</td>
</tr>
<tr>
<td>Oct</td>
<td>55</td>
<td>35</td>
<td>19.4</td>
<td>No rain</td>
<td>17</td>
<td>No rain</td>
</tr>
<tr>
<td>Total</td>
<td>530</td>
<td>648</td>
<td>498</td>
<td>708</td>
<td>820</td>
<td>294.3</td>
</tr>
</tbody>
</table>
CHAPTER FOUR
RESULTS AND DISCUSSION

4-1 Genotype x Environment interaction (GxE)

Mean yield across environments is an adequate indicator of genotypic performance only in the absence of genotype by environment (GE) interaction. GE is a differential genotypic response across environments. Most often GE complicates breeding, testing and selection of superior genotypes. It is important for plant breeders to identify specific genotypes adapted or stable to environment(s), thereby achieving quick genetic gain through screening of genotypes for high adaptation and stability under varying environmental conditions prior to their release as cultivars (Ariyo, 1989; Flores, et al., 1998; Showemimo, et al. 2000; Mustapha et al., 2001; Yan and Kang, 2003).

The combined analysis of variance showed highly significant differences among seasons (S) for all the traits studied with the exception of head length (Table 2). It also showed that differences among locations were highly significant for all traits under study. Differences among genotypes were highly significant for all traits with the exception of number of plants/m2 and head length. The interaction effect of genotype x location were highly significant for most traits except number of plants/m2 and number of heads/m2 and this may be due to the genetic factors.

The significance of genotype x environment indicated that genotypes responded differently to environment and some are environment specific, also this finding indicated the importance of these components in affecting the phenotypic performance of the evaluated sorghum genotypes. Similar results were reported by Abdalla et al. (2009), who found that the mean squares of genotypes, environments and
Table 2. Mean squares for seasons, locations, genotypes, and their interactions for 18 sorghum genotypes combined over three seasons and three locations, grown at North Gedarif, South Gedarif, and Rahad Research farm (RRF) during seasons 2009, 2010, and 2011.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Season (S)</th>
<th>Location (L)</th>
<th>Genotype (G)</th>
<th>L X G</th>
<th>S X G</th>
<th>S X L X G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days to 50% flowering</td>
<td>2068**</td>
<td>7091**</td>
<td>1274**</td>
<td>126**</td>
<td>245*</td>
<td>141**</td>
</tr>
<tr>
<td>Plant height (cm)</td>
<td>19500**</td>
<td>246696**</td>
<td>1323**</td>
<td>2057**</td>
<td>2333**</td>
<td>1775**</td>
</tr>
<tr>
<td>Number of plants/m²</td>
<td>55**</td>
<td>909**</td>
<td>7.84 ns</td>
<td>9.60 ns</td>
<td>9.11 ns</td>
<td>7.93 ns</td>
</tr>
<tr>
<td>Numbers of heads/m²</td>
<td>83.9**</td>
<td>4096**</td>
<td>28.7**</td>
<td>7.67 ns</td>
<td>13.3**</td>
<td>10.30*</td>
</tr>
<tr>
<td>Head length (cm)</td>
<td>573 ns</td>
<td>15.5**</td>
<td>29834 ns</td>
<td>18.84**</td>
<td>56.23**</td>
<td>22.83**</td>
</tr>
<tr>
<td>Head width (cm)</td>
<td>74.8**</td>
<td>75.2**</td>
<td>2.5**</td>
<td>1.8**</td>
<td>1.13 ns</td>
<td>1.5**</td>
</tr>
<tr>
<td>1000-SW/g</td>
<td>660**</td>
<td>7251**</td>
<td>423**</td>
<td>113**</td>
<td>55**</td>
<td>46**</td>
</tr>
<tr>
<td>Grain yield (kg/ha)</td>
<td>24873664**</td>
<td>7349446**</td>
<td>166993**</td>
<td>165846**</td>
<td>165846**</td>
<td>143870**</td>
</tr>
</tbody>
</table>

*, ** Significant at 0.05, and 0.01 of probability levels respectively, ns = not significant.
genotypes x environments interactions are highly significant (P=0.01). Also Elasha et al. (2011) found significant differences between environments, genotypes and environment x genotype.

Genotypes significantly interacted with seasons for almost all traits except number of plants/m² and head width and this may be due to the genetic factors. However the significant interactions of genotype with seasons shown by all of the characters studied reflect their instability over seasons. Similar results were reported by Shivanna et al. (1992); Santos et al. (1995); Tadesse et al. (1995). The second degree interaction of season x location x genotype was significant for all traits except for number of plants/m². Kambal and Mahmoud (1978) reported that variety x year interaction was small and not significant, while the variety x location and variety x location x year interaction were highly significant in sorghum crop. The current findings indicated that there is a wide range of genetic variability among tested genotypes, which could be attributed to both genetic and environmental factors and their interactions. Similar results were reported by Hashim, (2008), Tadesse and Ejeta (2008), and Bello et al. (2007) who studied genetic variability in sorghum and reported significant differences among cultivars for days to 50% flowering, plant height, 100- seed weight and grain yield.

Shinde and Jagadshwar (1986). in F1 and F2 generations of 8x8 diallel cross evaluated for grain yield and yield components in three environments showed significant genotype x environment interaction for all traits studied.

From present study, and from the basis of the importance of genotype x environment interactions as shown we can conclude that, sorghum genotypes show differential responses, when grown under different environments, suggesting that these genotypes should be tested
over a number of environment (years and locations) to assure the selection of the suitable genotype or genotypes for each location.

4-2 Mean performance

4-2-1 Days to 50% flowering

This trait is used as an earliness index. It showed significant differences among genotypes under the three seasons and three locations (Tables 2 and 3). It showed the highest general mean at the Rahad location (73,79 and 80 days) in 2009, 2010 and 2011 seasons, respectively, and the lowest general mean at North Gedarif (68,70 and 63 days) in 2009, 2010 and 2011 season, respectively. This could be attributed to the irrigation supplements given to the crop in Rahad location. Southern Gedarif had higher rain than North Gedarif. In general, the crop flowers early under rain-fed conditions forced by the drought prevalence in September.

Across locations, the range for days to 50% flowering was 59 (Milo) to 83 (Wad Ahmed) in 2009, from 60 (Gesheish) to 88 (Faki Mustahi and Tetron) in 2010, and from 59 (AG-8) to 74 (Tetron) in 2011.

This trait is usually used as an indicator to maturity because identifying early and medium maturing genotypes is important for choosing genotype to suit the different growing environments (irrigation and rain fed). Hence, from these findings the early maturing genotypes were Milo, Gesheish and AG-8, an indication that these lines would fit quite well in short rainy seasons, which were suitable for North Gedarif environment, while the late maturing ones were Tabat, Wad Ahmed, Faki Mustahi and Tetron which were suitable to grow under Rahad and South Gedarif environments (Table 3). These findings were in agreement with Abdalla et al. (2009), who reported that lines AG-8 and AG-15 were 18 day and 14 day earlier in days to 50% flowering than wad-Ahmed. Elzein et al. (2008) found a wide range of variability in days to 50% flowering.
Table 3a. Rank and means of days to 50% flowering for 18 Sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2009.

<table>
<thead>
<tr>
<th>Genotype no.</th>
<th>Rank</th>
<th>Means</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NG</td>
<td>SG</td>
<td>RH</td>
</tr>
<tr>
<td>1</td>
<td>13</td>
<td>12</td>
<td>8</td>
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<td>2</td>
<td>2</td>
<td>2</td>
<td>15</td>
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<td>3</td>
<td>14</td>
<td>13</td>
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<td>5</td>
<td>7</td>
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<td>10</td>
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<tr>
<td>9</td>
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<tr>
<td>10</td>
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<td>14</td>
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<td>15</td>
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<tr>
<td>18</td>
<td>18</td>
<td>17</td>
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</tr>
</tbody>
</table>

Mean | 68  | 70  | 73  | 70 |

CV%  | 2.80 | 11.00 | 3.40 | 6.80 |

SE±  | 0.97 | 3.85 | 1.24 | 1.39 |

*,** Significant at 0.05 and 0.01 probability levels, respectively.

1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadambialah bloom, 9-Ajob seido, 10-Araba, 11-AG-8, 12-Butana, 13-Bashaiyer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
Table 3b. Rank and means of days to 50% flowering for 18 sorghum genotypes grown at North Gedarif (NG), south Gedrif (SG), and Rahad (RH), season 2010.

<table>
<thead>
<tr>
<th>Genotype no.</th>
<th>Rank</th>
<th>Means</th>
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<td></td>
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<td>NG SG RH Combined NG SG RH combined</td>
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<td>14</td>
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<td>2.10</td>
<td>2.80</td>
</tr>
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<td></td>
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<td>1.21</td>
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<td>0.60</td>
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**,** Significant at 0.05 and 0.01 probability levels, respectively.

1-Karakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustah, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajeb seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashaiyer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
Table 3 c. Rank and means of days to 50% flowering for 18 sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2011.

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<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV%</td>
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</tr>
<tr>
<td>SE±</td>
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</table>

* ** Significant at 0.05 and 0.01 probability level, respectively.

1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajob seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashayer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
Development of short, medium genotypes is important for any plant breeding program, because these genotypes were suitable for mechanical harvesting and for resistance to lodging. Plant height showed significant differences (at \( p=0.05 \) or \( p=0.01 \)) among genotypes under the three seasons and three locations (Tables 2 and 4) with the exception for Rahad in season 2010. The highest general mean were observed in Rahad location (198, 207 cm and 142 cm) in season 2009, 2010 and 2011, respectively, and the lowest general mean at North Gedarif (124, 147 cm and 92 cm) in season 2009, 2010 and 2011, respectively. This is due to the irrigation water given to the crop at Rahad location and also the rainfall at south Gedarif was higher than at North Gedarif.

Across locations, the range for plant height was 112.02 (Tabat) to 189 (Wad Baku) in 2009, from 137 (Butana) to 216 (Tetron) in 2010, from 97 (Bashaiyer and AG-8) to 139 (Tetron) in 2011. Thus, in this study the short genotypes were Tabat, Butana, Bashaiyer and AG-8, while the tall genotypes were Wad Baku and Tetron (Table 4). From these results tall genotypes such as Wad Baku and Tetron are not appropriate for drought areas such as North Gedarif, because they were susceptible to lodging, while Butana and Bashaiyer were suitable to grow under North Gedarif condition. These findings were in agreement with Elasha et al (2011), who found significant differences (\( P<0.01 \)) between the entries in their plant height. Plant height within the irrigated sites during the first season ranged from 119-259 cm and from 102-275 cm during the second season. During both seasons, DMN 15P-10031, DIA-07666 were the shortest entries, while GW-13 and GW-65 the tallest. Also Bushara (1999), who recorded highly significant differences in plant height among hybrids of grain sorghum.
Table 4a. Rank and means of plant height for 18 Sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2009.

<table>
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*,** Significant at 0.05 and 0.01 probability level, respectively.
1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajeb seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashaiyer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
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<td>SE±</td>
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**, ** Significant at 0.05 and 0.01 probability levels, respectively.

1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajeb seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashaiyer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
Table 4 c. Rank and means of Plant height(cm) for 18 sorghum genotypes grown at North Gedarif (NG), south Gedarif (SG), and Rahad (RH), season 2011.

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Mean

<table>
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</table>

*,**, Significant at 0.05 and 0.01 probability level, respectively.
1-Korakollo ,2-Mugod, 3-Safra, 4-Wad-Baku ,5-Tetron, 6-Faki-Mustahi ,7-Farhoda, 8-Gadambaliah bloom, 9-Ajeb seido ,10-Arafa, 11-AG-8 ,12-Butana, 13-Bashaiyer, 14-Tabat ,15-W-Ahmed ,16-Gesheish ,17-Wa d-Fahal, and 18-Milo.
4-2-3 Number of plants at establishment/m²

This trait is very important in determining grain yield. Optimum plant population during crop establishment is expected to result in high grain yield.

Significant differences (at p=0.05 or p=0.01) among genotypes were observed for this trait under three seasons and three locations (Table 2 and 5) with the exception for season 2009. The highest general mean were observed in Rahad location (16, 13 and 9 plants/m²) in season 2009, 2010, and 2011, respectively, and the lowest general mean was observed at North Gedarif (9, 10 and 7 plants/m²) in season 2009, 2010, and 2011, respectively. Differences between the two locations were due to varying moisture level.

Across locations, the range for number of plants/m² was 11 (Milo) to 14 (Tetron) in 2009, from 9 (Wad Fahal) to 12 (Wad Ahmed and Ajeb seido) in season 2010, and from 8 (Arafa) to 12 (Wad Baku) in season 2011 (Table 5). From this study genotypes Milo, Wad Fahal and Arafa relatively had optimum plant population. This could be attributed to genotype ability to withstand unfavorable condition and/or growth environment at crop establishment.
Table 5a. Rank and means of numbers of plant at establishment/m2 grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2009.

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</tbody>
</table>

| Mean         | 9    | 11    | 16   | 12       |
| CV%          | 13.9 | 19.1  | 32.8 | 27.90    |
| SE±          | 0.6  | 1.1   | 2.7  | 0.99     |

* ** Significant at 0.05 and 0.01 of probability levels, respectively.

1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajeb seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashaayer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
Table 5b. Rank and means of Numbers of plants at establishment/m² for 18 sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2010.

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**NS** Significant at 0.05 and 0.01 probability, respectively.

1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajeb seido, 10-Araf, 11-AG-8, 12-Butana, 13-Bashaiyer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
Table 5 c. Rank and means of Numbers of plant at establishment/m2 for 18 sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2011.

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*,** Significant at 0.05 and 0.01 probability levels, respectively.
1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farahoda, 8-Gadambaliah bloom, 9-Ajeb seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashaiyer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
4-2-4 Number of heads/m2

This character is an indicator for high grain yield. Good crop establishment will result in increasing number of heads/m2 which lead to an increase in grain yield. This trait showed highly significant differences among the genotypes in the three seasons and the three locations (Table 2 and 6) the highest general mean was observed for Rahad location (16,15, and 9 head) in season 2009, 2010, and 2011, respectively, and there are tillers in plants at Rahad season 2010. And the lowest general mean was observed at North Gedarif (4,8, and 4 heads) in season 2009, 2010, and 2011, respectively.

Across locations, the range for numbers of heads/m2 was from 6 (Wad Fahal, Mugod, Tabat) to 11 (Wad Ahmed) in season 2009, from 8 (Wad Fahal) to 13 (Wad Baku) in season 2010, from 5 (Arafa and Faki Mustahli) to 9 (Korakollo) in season 2011, respectively (Table 6). In this study the highest numbers of heads/m2 were obtained by the genotypes Wad Ahmed, Wad Baku, and Korakollo, while the lowest number of heads/m2 were obtained by the genotypes Wad Fahal and Arafa. This is because Wad Fahal and Arafa are late in maturity and some plant failed to produce heads due to moisture stress.

4-2-5 Head length (cm)

This trait may be important in increasing grain yield. This trait showed highly significant differences among genotypes under three seasons and locations (Tables 2 and 7), the highest general mean was observed in Rahad location (17, 18, and 16 cm) in season 2009, 2010, and 2011, respectively, and the lowest general mean was exhibited by the North Gedarif location (18, 19 and 13 cm) in season 2009, 2010, and 2011, respectively. This is because all genotypes are tall and late maturing and they produce small head size under drought spell conditions in North Gedarif compared to the Rahad environments.
Across locations, the range for this trait ranged from 13 cm (Mugod and Wad Baku) to 24 (Faki Mustahi) in season 2009, from 12 (Mugod) to 27 (Tetron) in season 2010, from 12 (Safra and Farhoda) to 18 (Tabat) in season 2011. In this study the longest heads were obtained by the genotypes Faki Mustahi, Tetron, and Tabat, while the shortest heads length were obtained by the genotypes Mugod and Safra (Table 7). This result agree with Elasha et al (2011), who found that During both seasons at the irrigated and the rainfed sites, there were significant differences (P< 0.01) between the entries in their panicle length.
Table 6a. Rank and means of numbers of heads/m² for 18 Sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2009.

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Mean: 4 | 4 | 16 | 8

CV%: 50.8 | 37.2 | 20.0 | 29.60

SE±: 1.0 | 0.6 | 1.6 | 0.67

*.* *Significant at 0.05 and 0.01 probability levels, respectively.
1-Korakollo ,2-Mugod ,3-Safra, 4-Wad-Baku, 5-Tetron ,6-Faki-Mustahi, 7-Farhoda ,8-Gadambaliah bloom, 9-Ajeb seido ,10-Arafa ,11-AG-8, 12-Butana, 13-Bashaiyer, 14-Tabat, 15-W-Ahmed ,16-Gesheish, 17-Wad-Fahal, and 18-Milo.
Table 6b. Rank and means of numbers of heads/m² for 18 sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2010.

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* ** Significant at 0.05 and 0.01 probability levels, respectively.

1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajeb seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashaiyer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
Table 6 c. Rank and means of Numbers of heads/m² for 18 sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), an Rahad (RH), season 2011.

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*, ** Significant at 0.05 and 0.01 probability levels, respectively.

1-Korakollo, 2-Mugod ,3-Safra ,4-Wad-Baku, 5-Tetron ,6-Faki-Mustahi ,7-Farhoda ,8-Gadambaliah bloom, 9-Ajeb seido, 10-Arafa, 11-AG-8 ,12-Butana ,13-Bashaiyer ,14-Tabat ,15-W-Ahmed ,16-Gesheish ,17-Wad-Fahal, and 18-Milo.
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*, ** Significant at 0.05 and 0.01 of probability levels, respectively.

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Table 7b. Rank and means of head length (cm) for 18 sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2010.

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| * **Significant at 0.05 and 0.01 probability levels, respectively. 
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Table 7c. Rank and means of head length(cm) for 18 sorghum genotypes grown at North Gedarif(NG), South Gedarif(SG), and Rahad(RH), season 2011.

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*, ** Significant at 0.05 and 0.01 probability levels, respectively.

1-Korakollo , 2-Mugod, 3-Safra , 4-Wad-Baku, 5-Tetron , 6-Faki-Mustahi , 7-Farhoda , 8-Gadambaliah bloom , 9-Ajeb seido , 10-Arafa, 11-AG-8 , 12-Butana , 13-Bashaiyer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
4-2-6 Head width (cm)

This trait showed highly significant differences among the genotypes over the three seasons and locations except for Rahad season 2010 and 2011 (Table 2 and 8). The highest general mean was observed in Rahad location (4, 6, and 4 cm) in three seasons, respectively, while the lowest general mean was exhibited by the North Gedarif (3, 4, and 3 cm) in season 2009, 2010, and 2011, respectively.

Across locations the range for head width varied from 3 (Faki Mustahi) to 4 (Wad Fahal), from 4 (Faki Mustahi) to 6 (Butana and Gesheish), from 3 (Bashaiyer) to 4 (Mugod) in seasons 2009, 2010, and 2011, respectively (Table 8). From this study genotype Mugod had largest head width coupled with longest head length, this means that tall, late maturing genotypes are not suitable for drought areas such as North Gedarif but suitable for South Gedarif and Rahad environments.

4-2-7 1000 seed weight/g

This trait is very important in determining grain yield. This study showed highly significant differences between genotypes under the three seasons and three locations, with the exception of South Gedarif in season 2011 (Tables 2 and 9). The highest general mean for this trait at Rahad location was (30, 38, and 32 g) in season 2009, 2010, and 2011, respectively, while the lowest general mean at North Gedarif was (21, 24, and 20 g) in season 2009, 2010, and 2011, respectively. This is due to the irrigation water at Rahad location, and also attributed to the high rainfall at South Gedarif compared to the North Gedarif.

Across locations the range for 1000 -seed weight/g varied from 18 (Butana) to 36 (Mugod), from 25 (Tetron and Wad Ahmed) to 42 (Wad Fahal), from 21 (Wad Ahmed) to 31 (Wad Fahal) in season 2009, 2010, and 2011, respectively. Hence, in this study the highest 1000 seed weight/g was exhibited by the genotypes Butan, Tetron and Wad Ahmed.
Table 8a. Rank and means of head width (cm) for 18 Sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2009.

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Mean: 3.3, 2.8, 3.89, 3.34
CV%: 24.3, 23.2, 18.8, 21.90
SE±: 0.4, 0.32, 0.37, 0.21

* ** Significant at 0.05 and 0.01 probability levels, respectively.

Table 8b Rank and means of head width (cm) for 18 sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2010.

| Genotype no. | Rank | Mean | | | |
|--------------|------|------|---|---|---|-------------------|---|---|---|---|
|              | NG   | SG   | RH | Combined | NG | SG | RH | Combined |
| 1            | 4    | 8    | 9  | 6        | 5  | 5  | 6  | 5        |
| 2            | 15   | 9    | 13 | 12       | 4  | 5  | 6  | 5        |
| 3            | 2    | 5    | 6  | 3        | 5  | 6  | 6  | 6        |
| 4            | 1    | 13   | 17 | 9        | 5  | 5  | 5  | 5        |
| 5            | 7    | 15   | 18 | 17       | 5  | 5  | 5  | 5        |
| 6            | 13   | 18   | 16 | 18       | 4  | 4  | 5  | 4        |
| 7            | 3    | 7    | 15 | 7        | 5  | 6  | 5  | 5        |
| 8            | 14   | 10   | 14 | 13       | 4  | 5  | 5  | 5        |
| 9            | 11   | 14   | 5  | 10       | 4  | 5  | 6  | 5        |
| 10           | 16   | 11   | 12 | 14       | 4  | 5  | 6  | 5        |
| 11           | 5    | 4    | 8  | 4        | 5  | 6  | 6  | 5        |
| 12           | 6    | 1    | 1  | 1        | 5  | 7  | 8  | 6        |
| 13           | 17   | 12   | 11 | 15       | 3  | 5  | 6  | 5        |
| 14           | 18   | 17   | 3  | 16       | 3  | 4  | 6  | 5        |
| 15           | 12   | 6    | 10 | 8        | 4  | 6  | 6  | 5        |
| 16           | 10   | 16   | 4  | 11       | 5  | 4  | 6  | 5        |
| 17           | 9    | 2    | 2  | 2        | 5  | 6  | 7  | 6        |
| 18           | 8    | 3    | 7  | 5        | 5  | 5  | 6  | 5        |
| Mean         |      |      |    |          | 4  | 5  | 6  | 5        |
| CV%          |      |      |    |          | 28.3 | 22.8 | 18 | 22.60    |
| SE±          |      |      |    |          | 0.6  | 0.6 | 0.51 | 0.33     |

** Significant at 0.05 and 0.01 probability level, respectively.
1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajeb seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashaiyer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
Table 8 c. Rank and means of Head width(cm) for 18 sorghum genotypes grown at Gedarif(NG), South Gedarif(SG), and Rahad(RH), season 2011.

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<th>Genotype no.</th>
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</tbody>
</table>

Mean: 3 4 4 3
CV%: 22 16.9 23.9 4.38
SE±: 0.26 0.3 0.5 0.21

* ** Significant at 0.05 and 0.01 probability levels, respectively.
1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farahoda, 8-Gadambaliah bloom, 9-Ajeb seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashaayer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
Table 9a. Rank and means of 1000 seed weight/g for 18 Sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2009.

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Mean 21 24 30 25

CV% 19.9 11.6 9.8 13.50

SE± 2.1 1.4 1.5 0.98

*, ** Significant at 0.05 and 0.01 probability levels, respectively.

1-Korakollo, 2-Mugod, 3-Safra,, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajeb seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashaiyer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18 Milo.
Table 9b. Rank and means of 1000 seed weight/g for 18 sorghum genotypes grown at North Gedarif (NG), south Gedarif (SG), and Rahad (RH), season 2010.

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| Mean        | 24    | 30    | 38.12 | 31         |
| CV%         | 16.9  | 9.4   | 18.7  | 16.30      |
| SE±         | 2.05  | 1.42  | 3.56  | 1.45       |

* ** Significant at 0.05 and 0.01 probability levels, respectively.

1-Korakollo , 2-Mugod , 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi ,7-Farhoda, 8-Gadambaliah bloom, 9-Ajob seido ,10-Arafa, 11-AG-8, 12-Butana, 13-Bashaiyer, 14-Tabat ,15-W-Ahmed ,16-Gesheish, 17-Wad-Fahal, and 18-Milo.
Table 9c. Rank and means of 1000 seed weight/g for 18 sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2011.

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<th>Genotype no.</th>
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</table>

Mean                  | 20   | 23   | 32   | 25       |
CV%                    | 12.7 | 15.5 | 8.3  | 24.2     |
SE±                    | 1.26 | 1.8  | 1.31 | 0.85     |

*, **Significant at .05 and .01 probability levels, respectively
1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajeb Seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashair, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
1000 -seed weight/g were obtained by the genotypes Butana, Tetron, and Wad Ahmed (Table 9). These findings agree with Geremew (1993), who recorded a wide range of variability in 1000 seed weight. From these findings genotypes Mugod and Wad Fahal had large seed size compared to the genotypes Butana, Wad Ahmed and Tetron those having medium seed size, in addition to that tall late maturing genotypes with large to medium seed size such as Tetron are not suitable to grow under North Gedarif conditions because it needs a dequate water. But genotypes that have large seed size it reflect their ability to transmit their large seed size to its off spring if we interred them in crossing programs.

4-2-8 Grain yield (kg/ha)

Grain yield showed highly significant differences in the three seasons and locations (Tables 2 and 10) The highest general mean for this trait was shown at Rahad (738, 2818 and 1131 kg/ha) in seasons 2009, 2010 and 2011 respectively. In season 2011 the lowest general mean at Rahad location is due to the water logging. The lowest general mean for this trait obtained at North Gedarif at season 2011, and this is attributed to the low and poor distribution of rainfall.

Across locations, the range for this trait was from 225 kg (Farhoda) to 735 kg (Butana) in season 2009, from 1408 kg (Faki Mustahi) to 2572 kg (Wad Ahmed) in season 2010, from 862 kg (Faki Mustahi) to 2545 kg (Mugod) in season 2011, respectively. Hence, in this study the highest grain yield kg/ha were exhibited by the genotypes Butana, Wad Ahmed, and Mugod, while the lowest grain yield were obtained by the genotypes Farhoda and Faki Mustahi (Table 10). This study indicated that Butana was early maturing and short genotype which is suitable for North Gedarif condition, while medium or tall genotypes
Table 10a. Rank and means of grain yield (kg/ha) for 18 Sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2009.

<table>
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<th>Genotype no.</th>
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Mean 343 271 738 450

CV% 22.7 34.5 44.7 45.00

SE± 16.36 19.65 69.33 24.63

**, ** significant at 0.05 and 0.01 probability levels, respectively.

1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajob seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashaiyer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-W-Fahal, and 18-Milo.
Table 10b. Rank and means of grain yield (kg/ha) for 18 sorghum genotypes grown at North Gedarif (NG), south Gedarif (SG), and Rahad (RH), season 2010.

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**,** significant at 0.05 and 0.01 probability levels, respectively.

1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustah, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajeb seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashayer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
Table 10 c. Rank and means of grain yield (kg/ha) for 18 sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2011.

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Mean: 469, 2895, 1131, 1498
CV%: 10.7, 21.3, 54.4, 33.60
SE±: 10.52, 129.3, 29.4, 61.07

* *= Significant at .05 and .01 probability levels, respectively
1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadamhaliab bloom, 9- Ajeb Seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashair, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Milo.
that are late maturing coupled with high grain yield such as Mugod and Wad Ahmed were suitable for growing under irrigation and high rainfall. Grain yield showed highly significant differences across seasons (Table 11) the highest general mean for this trait was obtained at Rahad location (1563 kg/ha), while the lowest general mean was observed at North Gedarif (803 kg/ha), the range for this trait from 409 kg (Wad Fahal) to 1129 kg (Arafa), from 916 kg (Faki mustahi) to 2572 kg (Mugod), and from 1060 kg (Wad Baku) to 2120 kg (Wad Ahmed) for North Gedarif, South Gedarif and Rahad, respectively. Hence, in this study the highest grain yields (kg/ha) were exhibited by the genotypes Mugod at South Gedarif and Wad Ahmed in Rahad location, while the lowest grain yield were obtained by the genotypes Wad Fahal, Faki Mustahi and Wad Baku at North Gedarif, South Gedarif and Rahad, respectively. This is because all of them are tall and late maturing genotypes and they produce small seed size under drought spell conditions. From this finding, genotype Tetron was late maturing, tall, with medium seed size and high grain yield, genotype Gesheish was early maturing and has low yield, while genotype Mugod is medium maturing, having medium height with big seed size and high yielding, while Faki Mustahi late maturing genotype with small seed size and has low yield.

Across seasons and locations, there are highly significant differences among the genotypes for this trait, the range for this trait was from 846 kg (Faki Mustahi) to 1510 kg (Mugod), with over all mean of 1302 kg (Table 11). These findings indicated that the highest grain yield were exhibited by the genotype Mugod (1510 kg/ha), followed by the genotypes Bashaiyer (1503 kg/ha), Wad Ahmed (1471 kg/ha), Gadambalia bloom (1428 kg/ha), Safra (1401 kg/ha), and Tetron (1323 kg/ha). The lowest grain yield was obtained by the genotypes Faki-Mustahi.
Table 11. Grain yield combined over seasons, and over seasons and locations for 18 sorghum genotypes grown at North Gedarif (NG), South Gedarif (SG), and Rahad (RH), season 2009, 2010 and 2011.

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<th>Rank</th>
<th>Rank</th>
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Mean: 803, CV%: 28.3, SE±: 27.46

*, **: significant at 0.05, and 0.01 of probability level respectively. 1-Korakollo, 2-Mugod, 3-Safra, 4-Wad-Baku, 5-Tetron, 6-Faki-Mustahi, 7-Farhoda, 8-Gadambaliah bloom, 9-Ajab seido, 10-Arafa, 11-AG-8, 12-Butana, 13-Bashaayer, 14-Tabat, 15-W-Ahmed, 16-Gesheish, 17-Wad-Fahal, and 18-Millo
(846 kg/ha), Gesheish (1194 kg/ha), Wad Baku (1225 kg/ha), and Wad-fahal (1230 kg/ha).

4-3 Simple linear correlation coefficients:

Correlation and path analysis studies are important in plant breeding programs, as they give information on direction and magnitude of association between different traits. This could be utilized to select for one character indirectly by selection for another one (Sharaan and Ghalab, 1997). Simple linear correlation coefficients among various pairs of eight characters of sorghum genotypes are presented in (Table 12).

Grain yield was positively, and highly significant correlated with head width (0.65**) , number of heads/m2 (0.46**) , and 1000-seeds weight (0.32*). It was positively and non-significantly correlated with days to 50% flowering. Similar results were reported by Bittinger et al. (1981) and Elagib (1999) who reported that grain yield was positively correlated with days to 50% flowering, and 1000-grain weight. Also positive association between grain yield and days to 50% flowering was reported by many authors Liang et al. (1969) in sorghum, Umakanth et al. (2001) found that correlation coefficient were moderate to high for days to anthesis, plant height, 1000-seed weight, number of plants/m2 and number of heads/m2. Liang et al. (1969) found that 1000-grain weight was significantly correlated with grain yield. Shukla (1966) and Chigwe (1984) found that 1000-seed weight was significantly correlated with grain yield under dry conditions in all maturity groups.

Hadjichrislodoulu (1990) and Krishnasamy (1986) found that, days to 50% flowering showed significant positive correlation with plant height in some hybrids. And not in all hybrids, also positive correlation was reported by Rana et al. (1984) who found that there is association between fodder yield and days to 50% flowering.
Table 12. Simple linear correlation coefficients among various pairs of 8 characters of sorghum genotypes combined over three seasons (2009, 2010, 2011) and three locations (North Gedarif, South Gedarif, and Rahad).

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<th>#H/m2</th>
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<td></td>
</tr>
<tr>
<td>GY</td>
<td>0.13</td>
<td>-0.04</td>
<td>-0.59*</td>
<td>0.46**</td>
<td>-0.02</td>
<td>0.65**</td>
<td>0.32*</td>
<td></td>
</tr>
</tbody>
</table>

* ** Significant at 0.05 and 0.01 probability levels, respectively

50%F: days to 50% flowering, PH: Plant height, #P/E = number of plants/establishment, #H/m2: Numbers of heads/m2, HL: head length, HW: Head width, 1000SW, GY: Grain yield (kg/ha)
Grain yield was significantly and negatively correlated with number of plants at establishment/m2, but negatively and non significantly correlated with head length and plant height.

Plant height was positively and highly significantly correlated with 1000-seed weight (0.48**), head width (43**), number of heads/m2 (0.40**), and number of plants/m2 (0.35**). These results indicated that selection for these traits may be effective in improvement of grain yield. In addition, these findings indicated that tall plant possess heavier head weight than the short plants.

1000-seed weight was positively, and highly significantly correlated with head width (0.59**) and plant height (0.48**), but positively and nonsignificantly correlated with number of heads/m2 and days to 50% flowering. 1000-seed weight was negatively correlated with number of plants/m2 and head length. Significant and positive correlation of 1000-seed weight with plant height were reported by many authors (Ezeaku and Mohamed, 2006).

Correlation coefficients, as indicators of the degree of relationship between different attributes, are useful in determining those characters which are highly associated with grain yield and consequently, can be used as indicator in selection for yield. In the present study, most of the studied characters were positively correlated with yield and could play significant role in the assessment of grain yield. Hence in this study head width, number of heads/m2 and 1000-grain weight had strong correlation with grain yield (0.65**, 0.46**, and (0.32*), respectively, while it was negatively correlated with plant height, number of plants/m2, and head length.

The positive and significant association of grain yield with head width and number of heads/m2 was mainly due to their positive direct
effect with negligible indirect effects through other characters. This suggested the direct use of these two characters as selection criteria.

4-4 Path coefficient analysis

Path coefficient analysis is important in breeding programs. It has been used to assist in identifying traits that could be useful as selection criteria to improve crop yields. All the measured agronomic traits were analyzed by path coefficient model to determine their direct and indirect effects on grain yield. The results of the path coefficient analysis are presented in Table 13. The relatively large, positive and significant simple linear correlation coefficient between grain yield and number of heads/m² was 0.46**. The positive direct effect of number of heads/m² on grain yield was the highest (0.47). The highest positive direct effect on grain yield was exhibited by head width (0.33). Its indirect effect through number of heads/m² is large while too small through the other characteristics. This suggested the use of this character as selection criterion for improvement of grain yield is quite possible. Its indirect effects on grain yield were negligible through the other traits.

The relatively small, negative simple linear correlation between grain yield and head length (-0.02), such association is explained via the negative direct effect of head length on grain yield (-0.12), so it is difficult to recommend this character as selection criterion for yield (Table 13).

Head width highly significantly and positively correlated with grain yield (0.65**) (Table 13), such strong association is explained via the high positively direct effect of head width on grain yield (0.33), low negative indirect effect were observed via plant height, head length, and 1000-seed weight, also it had low positive indirect effect on grain yield via number of plants/m², number of heads/m² and days to 50% flowering (Table 13).
Table 13. Path coefficient analysis of direct (in bold) and indirect effect of 8 characters on sorghum grain yield of 18 genotypes grown season s 2009, 2010, 2011 at North Gedarif, South Gedarif and Rahad.

<table>
<thead>
<tr>
<th></th>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>X5</th>
<th>X6</th>
<th>X7</th>
<th>Rij</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>0.23</td>
<td>-0.07</td>
<td>-0.02</td>
<td>0.01</td>
<td>-0.04</td>
<td>0.04</td>
<td>-0.00</td>
<td>0.14</td>
</tr>
<tr>
<td>X2</td>
<td>0.07</td>
<td>-0.24</td>
<td>-0.17</td>
<td>0.19</td>
<td>-0.03</td>
<td>0.14</td>
<td>-0.00</td>
<td>-0.04</td>
</tr>
<tr>
<td>X3</td>
<td>0.01</td>
<td>-0.08</td>
<td>-0.50</td>
<td>0.09</td>
<td>-0.02</td>
<td>-0.09</td>
<td>0.00</td>
<td>-0.59**</td>
</tr>
<tr>
<td>X4</td>
<td>-0.00</td>
<td>-0.09</td>
<td>-0.09</td>
<td>0.47</td>
<td>-0.02</td>
<td>0.20</td>
<td>-0.00</td>
<td>0.46**</td>
</tr>
<tr>
<td>X5</td>
<td>0.08</td>
<td>-0.07</td>
<td>-0.08</td>
<td>0.08</td>
<td>-0.12</td>
<td>0.07</td>
<td>0.00</td>
<td>-0.02</td>
</tr>
<tr>
<td>X6</td>
<td>0.01</td>
<td>-0.10</td>
<td>0.13</td>
<td>0.29</td>
<td>-0.03</td>
<td>0.33</td>
<td>-0.00</td>
<td>0.65**</td>
</tr>
<tr>
<td>X7</td>
<td>0.05</td>
<td>-0.11</td>
<td>0.07</td>
<td>0.12</td>
<td>0.00</td>
<td>0.19</td>
<td>-0.01</td>
<td>0.32*</td>
</tr>
</tbody>
</table>

X1: Days to 50% flowering, X2: Plant height, X3: Number of plants at establishment/m^2, X4: Number of heads/m^2, X5: Head length, X6: Head width, X7: 1000 SW (g).

*.*, **: Significant at P=0.5 and 0.01 level of probability.
rij= Simple linear correlation coefficient.
In this study, correlation and path analysis may measure two different aspects. Hence, the study of correlation alone does not give accurate indications of yield association. For example, in this study correlation between days to 50% flowering and grain yield was very small (0.13), this means that this character had no importance in influencing grain yield, but the path analysis expressed days to 50% flowering as important trait influencing yield.

From present study, the direct effect of the tested traits on grain yield indicated that among yield components head width and number of heads/m2 had the highest correlation coefficient with grain yield. These traits also showed a positive direct effect on grain yield and therefore, these characters may be considered as selection criteria for developing high yielding sorghum genotypes.

4-5 Grain yield stability:

Evaluation of varieties and hybrids of any breeding program aims at identifying genotypes that consistently produce stable yields over a range of diverse environments. The mean grain yields of sorghum genotypes ranged from 846 kg/ha as minimum to the 1510 kg/ha as maximum, with an average of 1302 kg/ha. Seven genotypes recorded higher yield than the mean of all genotypes (Table 14). These genotypes were Mugod, Safra, Tetron, Gadambalia bloom, Wad Ahmed, Butana and Bashayer. The genotype Mugod, ranked first for mean grain yield and also out yielded all the checks. Genotypic stability of grain yield over various environments is the most desirable property of genotype to be released as a variety for wide adaptation.

Estimates of stability parameters should be measured only if the variance due to G x E is significant, in the current study such condition is fulfilled since the mean square for genotypes x locations is significant.
(Table 2) giving the reasons to investigate various stability parameters. Two stability methods have been used as stability measurements.

**Eberhart and Russel's stability model (1966)**

The deviation from regression is used to assess unpredictable part of variability of any genotype with respect to environment that could not be predicted by the regression. It is a measure of reliability of the linear regression, Eberhart and Russel (1966) defined the stable genotype as one with $b_i = 1$, $S^2d = 0$ and higher than the overall mean grain yield.

From Table (14), the results were showing clear differences in slopes of the regression lines between tested genotypes and checks. Some regression coefficients ($b_i$) exceeded unity while others were less than one. According to Eberhart and Russel (1966), the regression coefficient (slope) ranged from 0.59 for (AG-8) to 1.5 for Mugod (Table 14). From this study seven highest yielding genotypes, Tetron (1323 kg/ha), Butana (1333 kg/ha), Safra (1401 kg/ha), Gadambalia bloom (1428 kg/ha), Wad-Ahmed (1471 kg/ha), Bashaiyer (1503 kg/ha), and Mugod (1510 kg/ha), recorded grain yield higher than the general mean of the trials. From (Table 14) genotypes with $b_i > 1$ and mean grain yield greater than the general mean, these were Mugod, Safra, Tetron, W-Ahmed and Gadambalia bloom indicating that they were more responsive to environmental changes and therefore suitable for favorable environments of irrigation condition (Rahad) and high rain fall conditions (South Gedarif). These findings agreed with Elasha et al. (2011) who studied stability and adaptability of seven hybrids and three open pollinated varieties under twelve environments. He found that the genotypes DIA-07666, DMN 15P 1003, PAC-501 and E-1 showed slopes ($b_i$) of 2.67, 2.49, 2.34 and 1.18 with deviation from regression of 0.08, 0.45, 0.68 and 0.12 under irrigation respectively, and a mean grain yield above the general mean of the traits meaning those are more adaptable under
Table 14. Stability parameters for grain yield (kg/ha) of 18 sorghum genotypes tested at North Gedarif, South Gedarif, and Rahad during 2009, 2010, and 2011 growing seasons.

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>Yield (kg/ha)</th>
<th>Bi</th>
<th>S²d</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Korakollo</td>
<td>1272</td>
<td>1.07</td>
<td>4.7</td>
</tr>
<tr>
<td>2- Mugod</td>
<td>1510</td>
<td>1.58</td>
<td>11.4</td>
</tr>
<tr>
<td>3- Safra</td>
<td>1401</td>
<td>1.16</td>
<td>5.5</td>
</tr>
<tr>
<td>4- Wad Baku</td>
<td>1225</td>
<td>0.96</td>
<td>2.3</td>
</tr>
<tr>
<td>5- Tetron</td>
<td>1323</td>
<td>1.14</td>
<td>9</td>
</tr>
<tr>
<td>6- Faki Mustahi</td>
<td>846</td>
<td>0.75</td>
<td>2.3</td>
</tr>
<tr>
<td>7- Farhoda</td>
<td>1252</td>
<td>1.01</td>
<td>1.0</td>
</tr>
<tr>
<td>8- Gadambalia bloom</td>
<td>1428</td>
<td>1.18</td>
<td>5.7</td>
</tr>
<tr>
<td>9- Ajeb seido</td>
<td>1261</td>
<td>0.83</td>
<td>2.8</td>
</tr>
<tr>
<td>10- Arefa</td>
<td>1298</td>
<td>0.73</td>
<td>3.3</td>
</tr>
<tr>
<td>11- AG-8</td>
<td>1214</td>
<td>0.59</td>
<td>1.4</td>
</tr>
<tr>
<td>12- Butana</td>
<td>1333</td>
<td>0.97</td>
<td>1.2</td>
</tr>
<tr>
<td>13- Bashayier</td>
<td>1503</td>
<td>0.94</td>
<td>8.4</td>
</tr>
<tr>
<td>14- Tabat</td>
<td>1299</td>
<td>1.16</td>
<td>2.5</td>
</tr>
<tr>
<td>15- Wad Ahmed</td>
<td>1471</td>
<td>1.26</td>
<td>3.2</td>
</tr>
<tr>
<td>16- Gesheish</td>
<td>1194</td>
<td>0.92</td>
<td>5.5</td>
</tr>
<tr>
<td>17- Wad Fahal</td>
<td>1230</td>
<td>0.95</td>
<td>6.6</td>
</tr>
<tr>
<td>18- Milo</td>
<td>1286</td>
<td>0.72</td>
<td>3.5</td>
</tr>
<tr>
<td>Mean</td>
<td>1302</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
irrigation conditions.

Genotypes with (bi) close to 1.0 but low yielding (below the general mean) and so quite stable with relatively small S²d were Korakollo, Wad Baku, Farhoda, Gesheish, and Wad Fahal (1272, 1225, 1252, 1194 and 1230kg/ha respectively). This means that these genotypes have better response under unfavorable environments and are therefore stable and adaptable, same findings were reported by Abdalla et al. (2009) who studied stability and adaptability in some sorghum lines grown under nine environments. He found that Genotypes, AG15 and AG8 have b values of 0.900 and 0.928, respectively, The Genotypes, AG15 and AG-8 also have mean grain yield of 894.35 and 862.32 kg/fed respectively, and Wad Ahmed has 862 kg/fed which are above the overall mean of 777.73 kg/fed of the trials, while CAG has a mean of 543kg/fed, which is lower than the overall mean. This means that both genotypes have better response in unfavorable environments and are therefore adaptable stable and predictable (high R² value) than the two checks. Same results were also reported by Elzein et al. (2008) who studied stability and adaptability in some sorghum lines he found that Regression coefficients greater than one and had higher(S²d) were observed for Gew 22-15 and Gew 3-2 with mean grain yield below the general mean yield, indicating that these two lines were not stable under adverse conditions but may respond better in favorable environments.

The third group are genotypes with bi = 1 with S²d close to zero and low yielders (below general mean) as genotype Farhoda (1252 kg/ha). These findings indicated that this genotype is more responsive under all environments. From these findings, the most stable genotypes with lowest deviation were Farhoda rank first, and followed by the genotypes AG-8, Wad Baku, Faki Mustahi, and Ajob seido respectively. The most stable genotypes as indicated by this stability
parameter were Mugod, Gadambalia bloom, Safra, Wad Ahmed and Tetron when the mean yield, regression coefficient and the deviation from regression were considered together.

**The additive main and multiplicative interactions (AMMI) analysis model**:

The parametric approach such as mean yield over environments, genotypic coefficient of variability, the ecovalence, Shukla stability variance (interaction variance) and Eberhart and Russell's stability parameters (regression coefficient or slope and deviation from regression) give only the individual aspect of stability but cannot provide an overall picture of the responses. So it is difficult to reconcile all of these assessments into a unified conclusion because genotype response to environments is multivariate consequently, non parametric approach (multivariate) has been proposed to overcome problems associated with parametric approach (Lin et al, 1986).

Multivariate analysis such as AMMI analysis groups genotype or environments in a qualitative manner according to their similarity of performance rather than quantitative manner of the stability parameters. AMMI analysis involves the clustering analysis to classify genotypes under the most adapted sites for them depending on the AMMI principle components scores (Gaush and Zobel, 1988; Nachit et al. 1992).

The combined analysis of variance according to the AMMI model is presented in Table (15). The partitioning of GE interaction through AMMI model analysis revealed that the four multiplicative terms (PCA1, PCA2, PCA3, and PCA4) were significant and were captured 56.7, 19.3, 10.1, and 7.2% of variation due to GE interaction sum of squares, respectively. Together they accounted for 93.3% of GE interaction sum of squares. However, most of the variation was explained
Table 15. AMMI analysis of variance of the significant effects of genotypes (G), and environment (E) and genotype-environment interaction (GE) on grain yield (kg/ha) and the partitioning of the GE into AMMI scores.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment (E)</td>
<td>8</td>
<td>0.25367E+0.8</td>
<td>0.317095E+0.7</td>
<td>100</td>
</tr>
<tr>
<td>Genotypes (G)</td>
<td>17</td>
<td>706700</td>
<td>41570.6</td>
<td></td>
</tr>
<tr>
<td>GE 1</td>
<td>136</td>
<td>0.604554E+0.7</td>
<td>44452.5</td>
<td>100</td>
</tr>
<tr>
<td>PCA1</td>
<td>24</td>
<td>0.342852E+0.7</td>
<td>142855***</td>
<td>56.7</td>
</tr>
<tr>
<td>PCA2</td>
<td>22</td>
<td>0.116852E+0.7</td>
<td>53114.5***</td>
<td>19.3</td>
</tr>
<tr>
<td>PCA3</td>
<td>20</td>
<td>615978</td>
<td>30798.9**</td>
<td>10.1</td>
</tr>
<tr>
<td>PCA4</td>
<td>18</td>
<td>392181</td>
<td>21787.8**</td>
<td>07.2</td>
</tr>
<tr>
<td>Residual</td>
<td>52</td>
<td>440344</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DF, degree of freedom; SS, sum of square; MS, mean square, and Efficiency%, percentage of GE sum of squares.

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
by the first principle components (PCA1), According to the Crossa et al. (1990). AMMI with two, three or four PCA1 axes is the best predictive model. Similarly, in the present study, the AMMI analysis further revealed that the first two interaction principle component axes (PCA1 & PCA2) explained 76% of the GxE sum of squares, this was in agreement with Sneller et al., (1997), who suggested that GxE pattern is collected in the first principal components of analysis.

Variation among the studied genotypes for grain yield and their reactions to the environments were determined (Table 16), the highest average yield was obtained in E-7 followed by the E-9 (representing Rahad environment), whereas E-1 (representing North Gedarif environment) had obtained the lowest grain yield. E-7 exhibited the largest absolute PCA1 score (i.e. had the highest interaction effect), whereas the smallest score was shown by the E-4 (representing South Gedarif environment) (i.e. had the least interaction effects) based on AMMI biplot G and E having PCA values close to zero have small interaction effects, whereas those having large positive or negative PCA absolute values largely contribute to GE interaction. Hence, E-7 was the most interactive, while E-4 was the least interactive among the nine environments.
Table 16. PCA1 and PCA2 scores for the nine growing environments of sorghum genotypes.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>113.8</td>
<td>3.51928</td>
<td>6.33557</td>
</tr>
<tr>
<td>E2</td>
<td>144.3</td>
<td>3.39088</td>
<td>6.43972</td>
</tr>
<tr>
<td>E3</td>
<td>310.3</td>
<td>5.28205</td>
<td>-4.16294</td>
</tr>
<tr>
<td>E4</td>
<td>631.2</td>
<td>-3.50394</td>
<td>4.74171</td>
</tr>
<tr>
<td>E5</td>
<td>671.1</td>
<td>5.81292</td>
<td>17.75241</td>
</tr>
<tr>
<td>E6</td>
<td>475.3</td>
<td>7.83628</td>
<td>-1.66849</td>
</tr>
<tr>
<td>E7</td>
<td>1215.9</td>
<td>-39.053</td>
<td>-5.03838</td>
</tr>
<tr>
<td>E8</td>
<td>191.4</td>
<td>4.84558</td>
<td>0.39725</td>
</tr>
<tr>
<td>E9</td>
<td>1184.2</td>
<td>11.86991</td>
<td>-24.7968</td>
</tr>
</tbody>
</table>

E1,E2,E3 (North Gedarif ),E4,E5,E6 (South Gedarif),E7,E8,E9 (Rahad)
AMMI cross site analysis:

To analyze genotype-environment interaction and adaptation graphically, AMMI bi-plot was used with the PCA, score plotted against the mean yields (main effects) a graphical display of the GE interaction of PCA1 and their effects (yields) is useful for revealing favorable pattern in genotypes response across environments (Crossa et al.1990). The AMMI bi-plot of mean on yield explained large proportion of the treatment sum of squares. The PCA scores, negative or positive, more specific or adaptive genotype to certain environments. The more PCA score approximate to zero, is the more stable or adapted genotype over all environments. Accordingly, the genotypes Mugod, Safra, Tetron, Gadambalia bloom, Butana, and Bashaiyer revealed good stability across environments and high grain yields, this indicated that these genotypes Butana, and Bashaiyer were stable over all environments, while the genotypes W-Ahmed, Tabat, Mugod, and Safra were adapted for specific environments. W-Ahmed and Tabat for favorable environment, while Mugod and Safra were adapted for specific environment (South Gedarif environments). Genotype Mugod exhibited high yield in the environment 6 which represent South Gedarif environment, followed by the genotypes Gadambalia bloom, Safra, and genotype Tetron, respectively. (Fig 1).

AMMI bi-plot of the first two principal component axes (PCA1 and PCA2):

To further explain the GE and stability, a bi-plot between the PCA1 and PCA2 scores were given in (Fig2). AMMI bi-plot of the first two principle component axes is a powerful way of detecting important score of GE effects (Zobel et al.1988). This analysis represents stability of the genotypes across environments in terms of principle component analysis. It is used to identify broadly adapted genotypes that offer stable performance across sites, as well as genotypes that perform well under
specific conditions. In this study, the first two principal component axes (PCA1 And PCA2) in bi-plot analysis explained a large proportion of the variation 76% of the total GE sum of squares (Table 15). On this AMMI bi-plot, genotypes and environment having PCA values close to zero (near the origin) have small interaction effects, whereas those having large positive or negative PCA values (distant from zero) largely contribute to GE interaction (Yau, 1995). Hence the genotypes Butana, Farhoda, Faki-Mustahi, Bashaiyer, Gadambalia bloom, Safra, and Wad baku were the most interactive, while the genotypes W-Ahmed, Tabat, Wad Fahal, and Gesheish were the least interactive. On the other hand, environment E-9 and E-6 appeared at far distance from the origin (large PCA score), hence they had large interaction effects, whereas E-2 had small interaction effects (Fig 2). Genotypes Tabat, W-Ahmed, and Wad Fahal were more stable and responsive for good environments (Rahad environment), while the genotypes Mugod, Safra, and Tetron were responsive and suitable for South Gedarif environment. Hence in this investigation, visual observations of AMMI bi-plot analysis enable to identify genotypes and testing environments that exhibited major sources of GE interaction as well as those that were stable similar results were reported by Sneller et al (1997). AMMI model is more effective in partitioning interaction SS than the linear regression techniques resulting in increased precision equivalent to the number of replication by a factor of two to five. Such gain may be used to reduce cost by reducing the number of replications, to include more treatments in the experiment or to improve efficiency in selecting the best genotypes. In this study, comparing the effectiveness of joint regression and AMMI analysis for analyzing GE interaction, it was found that PCA1 in AMMI accounted for the GE sum of squares by 56.7%, while regression analysis accounted for GE sum of squares by 21.9%. Hence, AMMI analysis was superior.
to regression techniques in accounting for GE sum of squares and more effective in partitioning the interaction sum of squares, from this study the genotypes Mugod, Wad-Ahmed, Gadambalia bloom, Safra, and Tetron were more stable and high yielding genotypes under high rainfall of South Gedarif and Rahad condition.

From these two models of stability used in this study, it was found that the genotypes (Mugod, Wad-Ahmed, Tabat, Gadambalia bloom, Safra and Tetron) were high yielding and stable under favorable environment, and it could be grown under high rainfall and Rahad conditions others (Wad Baku, Farhoda, Gesheish and Wad Fahal) quite stable under unfavorable conditions, and it could be grown under low rain fall conditions of North Gedarif. This study failed to identify genotype(s) stable across the nine environments.
Fig. 1. The AMMI biplot of the main and the PCA1 effects of both genotypes and environments on grain yield of 18 sorghum genotypes grown in nine environments. Genotypes are indicated by triangles while environments are represented by circles.
Fig. 2. The AMMI biplot of the PCA1 and PCA2 axes for grain yield of 18 sorghum genotypes grown in nine environments. Genotypes are indicated by triangle while environments are represented by circles.
CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5-1 CONCLUSIONS

From this study it could be concluded that:

1- A wide range of genetic variability was observed among sorghum genotypes for most of the characters studied.

2- The significant environments, genotypes, and genotype x environment component of interaction indicated wide differences between the environments and differential genotypic behavior in the environments, suggesting that these genotypes should be tested over a number of environments (years and locations) to assure the selection of the suitable genotype or genotypes for each environment.

3- Simple linear correlation and path coefficient analysis indicated that head width and numbers of heads/m² could be used as potential selection criteria in breeding program for developing high yielding sorghum genotypes.

4- AMMI and pattern analysis have higher efficiency for stability studies compared to regression analysis, PCA1 and PCA2 in AMMI accounted for the GE sum of squares by 56.7%, 19.3%, together they accounted 76%, while regression model accounted for the GE sum of squares by 21.9%. Hence, AMMI analysis was superior to regression techniques in accounting for GE sum of squares and more effective in partitioning the interaction sum of squares. Furthermore, this method generates new information which cannot be estimated by regression method.
5-2 RECOMMENDATIONS

1- Genotypes Mugod, Tabat, Wad-Ahmed, Gadambalia bloom, Safra and Tetron were high yielding and stable under favorable environment, and it could be grown under high rainfall and Rahad irrigation conditions, others Wad Baku, Farhoda, Gesheish and Wad Fahal were quite stable under unfavorable conditions, and could be grown under low rainfall conditions of North Gedarif.

2- The other genotypes could be used in breeding program for further evaluation and testing for other studies.

3- It would be better to use AMMI for interpretation of sorghum grain yield for multi-locations trials. This is because AMMI analysis was found superior to regression techniques and more effective in partitioning the interaction sum of squares.
REFERENCES


