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Grain Yield Performance of Sorghum [Sorghum bicolor (L.) Moench] Genotypes and Correlation Analysis of Yield and Agronomic Traits in Ethiopia

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Abstract
A field experiment was conducted to evaluate sorghum genotypes at Fedis, Meiso, Kobo, Pawi and Humera with the objective of determining the yield performance and correlation status of yield and agronomic characteristics of released sorghum varieties. The materials used in the study consisted of eight sorghum genotypes representing the types widely grown in lowland areas. The treatments were laid out in a Randomized Complete Block Design (RCBD) and replicated three times. The combined analysis of variance revealed a significant variation among entries for most of the traits considered. From twelve characters the environment effect was highly significant for days to flowering and stand count at harvest and significant for days to maturity and thousand seed weight. Based on the mean performance of the genotypes Abishir, Gobye and Birhan gave higher mean grain yield of 2.85, 2.82 and 2.69tons ha^{-1} respectively and the lowest yield was obtained from N-13 and SRN-39 2.28 and 2.27tons ha^{-1} respectively. Grain yield was positively and significantly correlated with panicle weight and panicle exertion. Generally, this study showed the performance sorghum genotypes for their yield and correlation characteristics of traits across diverse lowland areas of Ethiopia.
Keywords: combined, correlation, sorghum, yield

1. Introduction

Sorghum serves as a staple food for more than 500 million people in the semi-arid tropics of Africa and Asia. It is also used for preparing traditional beverages. Both the grain and the stover are also used as animal feed. Furthermore, industrial use of sorghum is increasing for making sugar, starch, syrup, alcohol and molasses (Duncan, 1996). With the frequent and cyclical occurrence of drought and erratic rainfall, it could be an insurance crop to the small-scale resource-poor farmers constituting most the rural farming community in Ethiopia (Abdissa, 1997).

In Ethiopia sorghum is predominantly cultivated in lowland areas that cover nearly 66% of the total area of the country; sorghum production in this area is mainly dependent on seasonal rainfall. Sorghum production is limited mainly by water stress due to low and variable rainfall between and within the seasons (Geremew et al., 2004). In areas where there is high variability among the growing environments; genotypes will show different performance (Asfaw, 2007).

A simple correlation shows association between any two variables whether they are from or unreplicated data. Phenotypic, genotypic and environmental are the three types of simple correlations. The observable correlation which includes both genotypic and environmental effects can be obtained from the phenotypic correlation of two variables. A correlation which is resulting from the inherent association of two variables or the association due to pleiotropic gene action, linkages or effects of both is determined with genotypic correlation analysis. Furthermore, a correlation that is due to the effects of environmental influence is determined by environmental correlation (Singh, 1993).

Therefore, selection for grain yield can only be effective if desired genetic variability is present in the genetic stock. Based on this a study was conducted with the objective of determining yield performance and correlation of yield and agronomic characteristics of released sorghum varieties.

2. Materials and methods

2.1. Description of the Study Area

Field experiments were conducted at five locations which represent the dry lowland areas of Ethiopia, where sorghum is widely grown. The research was conducted at Fedis, Mieso, Kobo, Pawe and Humera, which are in the Eastern Harerghe, Western Harerghe, North Wollo, Metekel, and North Tigray zones, respectively.

Planting materials used for the experiment comprised sorghum varieties released from Melkasa and Sirinka Agricultural Research Center for low moisture stress areas of the Ethiopian lowlands in 2000, 2005 and 2007. The varieties were Gobye, Abishir, Birhan, N-13, SRN-39, Gedo, Framida and Hormat12.

The trial was laid out in a randomized complete block design (RCBD) with three replications at all study locations. The experimental plots consisted of 3 rows, each 5m in length with 75cm between and 15cm in plant-to-plant spacing. The total row number of each plot was three, all these rows were harvested. Therefore, both the total area of each plot and the three harvestable rows had a size of $11.25m^2$. Sowing was done by hand drilling. The seed rate for each plot was calculated as per the recommendation for row planting (10kg ha^{-1}). Then, thinning was done two weeks after emergence to adjust plant to plant space. Nitrogen and phosphorus fertilizers were applied in the form of Urea (46 % N) and DAP (18 % N and 46 % P_2O_5) based on the national sorghum improvement program recommendation. During planting, 100kg ha^{-1} of DAP was applied in the seed furrow. Urea was applied as top dressing at the rate of 50kg ha^{-1} at knee height stage. The field was kept free of weeds during the period of the experiment. All the other recommended agronomic management practices such as land preparation and insect pest control were applied as required following research recommendation.

Data were collected from the three rows for plot based data and ten randomly sampled plants for plant-based data following the descriptors for sorghum (IBPGR/ICRISAT, 1993). Phenological data (emergence date, flowering date, and maturity date), morphological data (plant height), data on yield (g plot^{-1}), panicle exertion, panicle weight, panicle yield and stand count at harvest were collected.

The collected raw data were used to compute analysis of variance (ANVOA) following a model outlined by Gomez and Gomez (1984). Bartlett's test of homogeneity of variance was adopted for the eight parameters to determine the validity of the combined analysis of variance of the data prior to combined analysis. This analysis revealed the homogeneity of error variance. Therefore, combined analysis of variance was done to determine the effects of the genotypes, locations and their interactions. Varieties were assumed to be fixed and environment effects random. Mean separation was carried out using LSD at 5% level of significance.

2.2. Correlation and coefficient of determination

Pearson correlation between mean grain yield and other traits was estimated using Excel computer software.

3. Results and discussion

3.1. Combined Analysis of Variance

The combined ANOVA indicated that main effects due to genotypes showed highly significant (P< 0.01) difference in grain yield, panicle exertion, above ground biomass, harvest index and thousand seed weight and significant effect were in days to flowering, days to maturity, plant height and stand count at harvest. The interaction (GEI) and main effect due to location showed a non-significance difference for grain yield; however, highly significant (P< 0.01) effect was revealed in days to emergency, days to maturity, stand count and thousand seed weight and significant (P< 0.05) effect for days to flowering. The interaction effect showed that a highly significant difference in thousand seed weight and significant in days to flowering and stand count. The effect of GEI for grain yield (GY), days to emergency(DE) days to maturity (DM), plant height (PH), panicle exertion (PE), panicle weight (PW), panicle yield (PY), biomass weight (BW) and harvest index (HI) showed a non-significance difference on interaction effect (Table 1).

The significant effects of genotypes indicated that the test for yield potential was statistically significant yield potential. The presence of significant GEI showed the inconsistency in the performance of the sorghum genotypes across environments. Mosisa et al. (2001) and Akcura et al. (2005) have reported the similar result. Furthermore, Alberts (2004) also found more than two-fold increase in GEI than genotypic variation.

Non-significant effect of location on the yield of sorghum genotypes was reported by Asfaw (2007), Almeida et al. (2014), Maposa et al. (2010). The GEI_was also highly significant (P≤ 0.01), showing the difference in the response of genotypes at different environments. This result is in agreement with the findings of Almeida et al. (2014) and Asfaw (2007) who identified differential genotypic behavior in the environments. In another study, Dagnachew et al. (2014) obtained a significant genotypic effect and non-significant environmental and significant GEI effect on the yield of triticale.

Table 1. Mean squares of yield and other traits from a combined analysis of variance of eight genotypes grown at five locations.

SOV	DF	GY	DF	DM	PH	PE	PW	PY	ABM	HI	TSW
E	4	15.71^{ns}	1001.96**	20.73**	659.03ns	10.22ns	2022.7ns	2 119.66ns	2833.54ns	0.01ns	787.81**
R(E)	10	11.34^{ns}	6.05ns	2.44ns	239.25ns	9.24ns	2789.29ns	2138.27ns	730.22ns	0.06ns	2.51ns
G	7	62.45**	36.89*	10.38*	3331.88**	42.64**	8878.45*	7978.16*	2888.84**	0.31**	61.28**
GEI	28	15.74^{ns}	25.25*	5.12ns	295.40ns	10.35ns	6986.33*	4515.20ns	1050.94ns	0.03ns	25.23**
Error	70	0.14	12.72	3.62	284.2	7.00	163.55	151.00	0.45	0.007	6.6
CV		14.40	5.00	1.55	11.97	10.40	17.9	18.01	12.44	14.2	9.11

Sou.=source of variation, GY = Grain yield (ton ha^{-1}); DF = days to flowering; DM = Days to maturity; PH =plant height(cm); PE = panicle exertion; PW =panicle weight(g); PY=panicle yield(g); ABM= above biomass weight (ton ha^{-1}) HI = harvest index (%); TSW=thousand seed weight(gm). ns = non-significant, * = significant (p ≤ 0.05), ** significant (p≤ 0.01)

3.2. Genotypes Mean Performance

The relative performance of varieties based on mean grain yield and other agronomic traits over locations are presented in Table 2. The result showed that as for grain yield, days to maturity, plant height, panicle exertion, panicle weight, panicle yield, above ground biomass and harvest index, days to flowering and thousand seed weight do not have an interaction effect; however, for these traits, the genetic effect was significant. Therefore, based on these traits, varieties could be compared to their over location mean performance.

In addition to yielding performance of the genotypes, growth and morphological parameters contributing to the yield performance were suggested as a selection criterion in the development of drought tolerance sorghum genotypes (Henzell et al., 1992). To this effect comparison of the mean values of varieties and their components was accomplished for various phenological and growth parameters. The actual mean values showed variation among entries for plant height, days to maturity, panicle exertion, panicle yield, above ground biomass and harvest index many of which appear to be under strong genetic control although environment could have marked effect.

The high panicle weight and yield contributed for better yield of sorghum under conditions where the tests were conducted. Results of some previous studies have shown that these traits have marked contribution to the improved performance of cultivars grown under drought stress condition (Saeed et al., 1986).

Similarly, mean thousand seed weight was significantly different among genotypes with the values ranging from 25.8 to 31.92g. In areas where post-flowering drought is the major impediments of production thousand seed weight is the most seriously hampered trait unless the genotype has any of the mechanisms that tolerate this effect (Blum et al., 1989). Previous reports have shown that higher thousand seed weight with the presence of stay-green trait (Van Oosterom et al., 1996) and early flowering (Blum, 1970) under the stated condition.

Table 2. Mean performance of eight genotypes for different traits at five locations

Genotypes	GY	DE	DF	DM	SCH	PH	PE	PW	PY	TSW	ABM	HI
Gobye	2.82	6.66	68.93	122.40	51.26	122.72	26.86	96.33	83.93	25.8	7.50	0.42
Abishir	2.85	6.80	72.73	122.53	48.66	133.18	26.86	99.27	84.80	29.16	5.40	0.67
Birhan	2.69	6.66	70.73	122.86	55.20	143.36	25.26	90.87	81.53	29.68	4.70	0.62
N-13	2.28	6.66	72.06	124.13	47.66	129.37	22.36	98.60	81.53	28.10	5.60	0.49
SRN-39	2.27	6.66	69.60	121.40	46.93	137.57	23.50	105.33	86.87	26.66	2.90	0.85
Gedo	2.46	6.53	73.66	121.40	50.93	162.07	26.06	98.33	85.67	26.35	6.20	0.45
Framida	2.64	6.86	70.86	122.86	48.33	134.46	26.80	105.07	88.40	27.98	6.40	0.51
Hormat12	2.68	6.53	71.33	122.2	50.26	163.81	26.03	104.93	90.13	31.92	4.90	0.65
$\bar{x}$	2.60	6.67	71.24	122.70	49.9	140.8	25.4	99.84	85.36	28.2	5.42	0.58
CV	14.40	4.24	4.21	1.50	13.92	10.88	9.98	12.8	14.4	8.56	12.44	14.2
LSD	2.29	NS	2.6	1.39	5.15	12.28	1.93	9.25	NS	1.87	4.20	0.46

GY = Grain yield (ton ha^{-1}); DE = Days to emergency (days); DF = days to flowering (days); DM = Days to maturity (days); PH = plant height (cm); SCH= Stand count at harvest (in number); PE = panicle exertion (cm); PW =panicle weight (g); PY=panicle yield (g); ABM= Above ground biomass (ton ha^{-1}),HI = harvest index (%); TSW=thousand seed weight (g); LSD = Least Significant Differnce - at 5% probability level.

The interaction effect for days to flowering, stand count at harvest, panicle weight and thousand seed weight were significant, which indicates the performance of varieties for these traits varied from location to location. The single location result showed that all the four parameters had significant (days to flowering at Meiso, Pawe and Humra), stand count at harvest at pawe, panicle weight at Pawi and Kobo and thousand seed weight at Meiso, Pawe, Fedis and Humera genotypic effect. This indicates that genotypes respond differently to environmental variables, which is a common phenomenon in the semi-arid tropics (Haussmman et al., 1999).

Gobye, Abishir, Birhan, Hormat and Framida genotypes showed highest yield performance when compared to others based on the overall mean performance (Table.2). The mean yield performance of these genotypes was above the grand mean. The mean performance of days to flowering of Gobye, Birhan, and Framida showed that below the grand mean, the rest genotypes showed above the grand mean. The mean performance of days to maturity of Abshir, Birhan, N-13 and Framida was above the grand mean and the other four genotypes the mean performance was below the grand mean. The stand count mean performance of these varieties was (Gobye, Birhan, Gedo and Hormat) above the grand mean.

Three genotypes (N-13, SRN-39 and Gedo) showed lowest mean performance compared to the other genotypes and also less than grand means. The mean performance of plant height of these varieties was (Birhan, Gedo, and Hormat) scored above the grand mean and five genotypes showed the least mean performance (Gobye, Abshir, N-13, SRN-39 and Framida). Gedo and Hormat were highly significant in plant height. The panicle exertion mean performance of Gobye, Abshir, Gedo, Framida and Hormat genotypes showed that above the grand mean. varieties (Birhan, N-13, and SRN-39) showed the lowest panicle exertion mean performance. The panicle weights mean performance of Gobye, Abshir, Birhan, N-13 and Gedo genotypes showed that lowest mean, below the grand mean.

Mean performance of panicle yield of genotypes SRN-39, Gedo, Framida, and Hormat showed that above the grand mean.Genotypes Gobye, Abshir, Birhan and N-13 showed that lowest panicle yield.

Days to flowering and maturity are the most important attributes that need to be considered in selecting genotypes for drought affected areas. In this study number of days to flowering ranged from 68.93 to 73.66. The data for individual location analysis also showed similar patterns of the result.

From the eight genotypes, the highest mean plant height was recorded from N-13 which was 124.13cm.

Similarly, the number of days to maturity ranged from 121.4 to 124.13. Based on the mean performance varieties, Abshir, Gobye, Birehan, Hormat and Framida were statistically significant.

Based on the result obtained grain yield was varied from 2.85 to 2.27 tons ha^{-1} (Table 2). There was significant variation in yield in few among experiments, despite all being grown under non-limiting water and nutrient conditions. The results for experiments were well below the expectation of a potential yield of sorghum, however, it was similar with the result of Hammer et al. (1996).

The test genotypes exhibited significant differences in certain environments for grain yield. The lowest average yield (2.27tons ha^{-1}) was recorded from SRN-39 and the highest yield (2.85 tons ha^{-1}) was recorded from Abishir within genotype and the lowest and highest environmental mean yield recorded (2.5 and 2.73tons ha^{-1}) from Kobo and Meiso, respectively.

Taking the mean general yield as the first parameter for the assessment of the genotypes, Abishir, Gobye, Birhan, Gedo and Hormat gave the best yield, with the mean yield greater than 2.6tons ha^{-1} (Table 2), N-13 gave the lowest yield.

3.3. Correlation between Phenological Traits and Yield Components

Simple linear correlation coefficients were calculated among twelve characters to see the interrelationship between any two characters. The correlation between and among the various phenological and growth parameters and the yield components was strong and significant while some others have a weak association (Table 3). Within the growth and phenological parameters, days to emergence was shown to be negatively and significantly correlated with thousand seed weight, Days to flowering was positively and significantly correlated with plant height (r=0.27). This is a common phenomenon in sorghum where long maturing varieties have longer plant height and higher biomass in general. They have a longer active growth cycle that they continue to grow and produce higher biomass if growth substances are not limiting (Omanya et al., 1997; Haussmann *et al.*, 1999). Plant height was also positively correlated with other components of a height such as a panicle exertion and with days to maturity which agrees with established facts.

Among the yield components, grain yield and stand count at harvest, panicle exertion, panicle weight panicle yield were significantly and positively correlated. Similarly, Biomass yield was also correlated with panicle exertion and grain yield significantly and positively (Table 3). This result is in close agreement with previous findings by Alam et al. (2001) and Gul et al. (2005) where grain yield was reported to have been strongly associated with the major yield components as well with total biomass and harvest index. Many of these yield components, however, are regulated by different genetic mechanisms indicating that grain yield is a function of a multiple of factors.

Above ground, biomass was significantly and negatively associated with harvest index while stand count has no notable association with harvest index. Moreover, associations between panicle weight and panicle yield, panicle weight and grain yield, panicle yield, and grain yield and stand count and grain yield were highly significant. Whereas thousand kernel weight showed a negative association with stand count and panicle weight.

The correlation between the various phenological and/or growth parameters and yield components also yielded interesting results. Days to flowering, days to maturity and plant height were shown to have a negative correlation with the major yield components including grain yield, panicle yield, panicle weight and above ground biomass even though the association with some of the traits was weaker and not significant. The same traits, however, had positive and highly significant (only days to maturity) correlation with thousand seed weight and above ground biomass (only positively correlated with days to maturity but not significant). The later association concurs with the common knowledge that extended maturity positively contributes to biomass and also panicle weight which is a component of the total biomass (Jan-orn *et al.*, 1976). However, the negative relationship of these phenological characters to the other yield components, under normal conditions, is contrary to established facts. But there may be situations when results of this nature could prevail. Optimal growth conditions during early stages of development may allow plants to develop larger sink size (panicle weight) and thus the biomass. But when this is followed by acute terminal stress, especially the late maturing varieties fail to fill the sink ending up with lower panicle yield, and low kernel weight because of shriveled seeds (Blum et al., 1989; Patel et al., 1994).

The insignificant and negative association of maturity, days to flowering and plant height with harvest index clearly depicts this likely fact. Haussmann et al. (1999) reported similar result from a related work conducted in semi-arid environments of Kenya and Mali. Panicle weight and panicle yield also had a negative relationship with thousand seed weight and panicle weight and above ground biomass negatively correlated with harvest index and positive association with panicle weight and thousand seed weight for the same reason. Whereas, days to emergence appear to have a negative association with any of yield components except grain and panicle yield significant with thousand seed weight, however, with days to flowering, plant height and stand count positive association was recorded. This indicates that early vigor positively contributes to plant fecundity by stimulating the initiation of productive tillers. This has the important agronomic implication that maintenance of plant early vigor either by manipulating growing environments or through a selection of appropriate cultivars would contribute to increased yield.

From the combined analysis, grain yield showed significant (P≤0.05) positive phenotypic correlations with panicle weight (r=0.18) and panicle yield (r=0.20) (Table 3). A similar result was reported by Ezeaku and Mohammed (2006), who found positive phenotypic correlation coefficients of grain yield with panicle weight and panicle yield. Therefore, the positive association of grain yield with these traits suggested that the possibility of simultaneous improvement of grain yield through an indirect selection of these positively correlated traits.

Table 3. Correlation coefficients among the traits measured from eight genotypes tested at five locations.

	DE	DF	DM	PH	SCH	PE	PW	PY	GY	ABM	HI
DF	0.024^{NS}										
DM	-0.14^{NS}	0.15^{NS}									
PH	0.06^{NS}	0.27*	0.08^{NS}								
SCH	0.09^{NS}	0.08^{NS}	-0.08^{NS}	0.06^{NS}							
PE	-0.07^{NS}	0.02^{NS}	0.08^{NS}	0.001^{NS}	-0.10^{NS}						
PW	-0.03^{NS}	0.06^{NS}	-0.05^{NS}	0.08^{NS}	0.02^{NS}	0.08^{NS}					
PY	0.02^{NS}	0.05^{NS}	-0.13^{NS}	0.17^{NS}	0.05^{NS}	-0.03^{NS}	0.86**				
GY	-0.07^{NS}	-0.01^{NS}	-0.082^{NS}	-0.07^{NS}	0.21**	0.29*	0.18**	0.20**			
ABM	-0.02^{NS}	-0.08^{NS}	0.13^{NS}	-0.13^{NS}	0.15^{NS}	0.18**	-0.04^{NS}	-0.13^{NS}	0.03*		
HI	-0.01^{NS}	-0.02^{NS}	-0.06^{NS}	-0.002^{NS}	-0.15^{NS}	-0.12^{NS}	-0.04^{NS}	0.02^{NS}	0.13^{NS}	-0.75*	
TSW	-0.56*	0.12^{NS}	0.2**	0.032^{NS}	-0.11^{NS}	0.07^{NS}	-0.002^{NS}	-0.02^{NS}	0.09^{NS}	-0.06^{NS}	0.07^{NS}

*, **: Significant at 5% and 1% probability level. DE=days to emergence, DF=days to flowering, DM= Days to maturity, PH=plant height (cm), SCH=stand count at harvest, PE=panicle exertion (cm), PW=panicle weight (g), PY=Panicle yield (g), TSW=1000 seed weight (g), GY=grain yield (ton/ha), HI=harvest index (%)

Summary and Conclusion

The result of the study showed that the mean yield in overall location there was a significant difference among genotypes. The combined analysis of variance indicated that Abishir, Gobye and Birhan were the top three high yielding genotypes with their respective mean grain yield of 2.85, 2.82 and 2.69 tons' ha^{-1}, respectively. The lowest yield obtained from N-13 and SRN-39 with respective mean grain yield 2.28 and 2.27 tons' ha^{-1}. Grain yield was positively and significantly correlated with panicle exertion and above ground biomass. Furthermore, it was also highly and significantly correlated with stand count at harvest, panicle yield, and panicle weight. Generally, in the present study, the yielding performance of released sorghum genotypes was identified. In addition, positive and significant association was observed between grain yield and other traits. In future, it would be better to conduct additional study to determine the strength of association of the traits.

4. References

Abdissa, G. (1997). Enterprise budget and financial performance analysis of sorghum (Sorghum bicolor L.) Seed production at Bako research center. pp. 175-187.Proceedings of The Eight Annual Conference Crop Science Society of Ethiopia, (CSSE), Addis Abeba, Ethiopia, 26-27 February 1997

Akcura, M., Yaya, Y. and Taner, S. (2005). Genotype-environment interaction and phenotypic stability analysis for grain yield of durum wheat in the Central Anatolian region. Turk Journal of Agriculture, 29: 369-375.

Alam, S., Ali A., Qamar, I.A, Arshad, M., and Sheikh, S. (2001). Correlation of economically important traits in Sorghum bicolor varieties. Online J of Biolog. Science. 1 (5):330-331.

Alberts, M.J.A., 2004. Comparison of statistical methods to describe genotype x environment interaction and yield stability in multi-location maize trials. M. Sc. Thesis, University of the Free State. 96 pp.

Almeida, F.J.E., Tardin, F.D., Daher, R.F., Barbe, T.C., Paula, C.M., Cardoso, M.J. and Godinho, V.P.C. (2014). Stability and adaptability of grain sorghum hybrids in the off-season.Genetic and Molecular Research, DOI http://dx.doi.org/10.4238/. A head of print.

Asfaw, A. (2007). Assessment of yield stability in sorghum. African Crop Science Journal, 15 (2): 83 – 92.

Blum, A. (1970). Effects of plant density and growth duration on sorghum yield under limited water supply. Agron. J. 62:333-336.

Blum, A., Mayer, J., and Golan, G. (1989). Agronomic and physiological assessments of genotypic variation for drought resistance in sorghum. Aust. J. Agric. Res., 40: 49-61

Crossa, J. (1990). Statistical analysis of multiplication trials. Advances in Agronomy, 44: 55-85.

Dagnachew Lule, Kassahun Tesfaye, and Girma Mengistu. (2014). Genotype by environment interaction and grain yield stability analysis for advanced triticale (x. triticosecale wittmack) genotypes in western Oromia, Ethiopia. Ethiopia Journal of Science, 37(1):63–68.

Ducan, R.R. (1996). Breeding and improvement of forage sorghums for the tropics. Adv. Agron. 57: 161-185.

Ezeaku. I.E and Mohammed S.G. (2006). Character association and path analysis in grain sorghum. African Journal of Biotechnology 5(14):1337-1340.

Geremew, Gemechu., Asfaw Adugna., Taye Tadese, Tesefaye Teferra., Ketema Belete., and Hilemichael, Habte.

(2004). Development of sorghum varieties and hybrids for dryland areas of Ethiopia. Uganda Journal of Agricultural Science,9:594-605.

Gomez, K.A. and. Gomez, A.A. (1984). Statistical procedures for agricultural research. 2nd end. John Wiley and Sons Inc., New York

Gul, I., Saruhan, V., Basbag, M. (2005). Determination of yield and yield components and relationship among the components of grain sorghum cultivars grown as main crop. Asian Journal of Plant Sciences. 4: 613-618.

Hammer, G.L., Chapman, S.C. and Muchow, R.C. (1996). Modelling sorghum in Australia: The state of the science and its role in the pursuit of improved practices. p. 43– 61. In M.A. Foale, R.G. Henzell, and J.F. Kneipp (ed.) Proc. Australian Sorghum Conf., 3rd, Tamworth, NSW, Australia. 20–22 Feb. 1996. Occasional Publ.93. Australian Institute of Agricultural Science., Melbourne, VIC.

Haussmann, B.I.G., Obilana, A.B., Ayiech, P.O., Blum, A., Schipprack, W., and Geiger, H.H. (1999). Quantitative genetic parameters of sorghum (Sorghum bicolor (L) Moench) grown in semi-arid areas of Kenya. Euphytica 105:109-118.

Henzell, R.G., Brengman, R.L., Fletcher, D.S., and McCosker. (1992). Relationship between yield and non-senescence (stay-green) in some grain sorghum hybrids grown under terminal dought stress. P.355-358. In: Foale, M.A., Henzell, R.G, and Vance, P.N. (eds.). Proceedings of the Second Australian Sorghum Conference, Gatton, Feb 4-6, 1992. Australian Institute of Agricultural Science, Melbourne, Occasional Publication no.68.

IBPGR and ICRISAT (International Board of Plant Genetic Resources and International Crop Research Institute for Semi-Arid Tropics). (1993). Descriptors for sorghum [Sorghum bicolor (L.) Moench]. IBPGR, Rome, Italy and ICRISAT, Patancheru, India 1-26.

Jan-orn,J., Gardner, C.O and Ross, W.M. (1976). Quantitative genetic studies of the NPZR random mating grain sorghum population. Crop Sci. 16:489-496.

Mahajan RC, Wadikar PB, Pole, SP, Dhuppe MV (2011). Variability, Correlation and Path Analysis Studies in Sorghum. Res. J. Agric. Sci. 2(1): 101-103.

Maposa, D., Mudimu, E. and Ngwenya, O. A. (2010). Multivariate analysis of variance (MANOVA) of the performance of sorghum lines in different agro-ecological regions of Zimbabwe. African Journal of Agricultural Research, 5(3): 196-203.

Mosisa, W., Habtamu, Z., Girma, T., Benti, T., Legesse, W., Wonde, A., Aschalew, G. and Hadji, T. (2001). Yield stability of Maize (Zea mays L.) genotypes across locations. pp.139-142. Integrated Approaches to Higher Maize Productivity in the new millennium. Proceedings of the seventh Eastern and Southern Africa Regional Maize Conference. In: Friesen, D.K and Palmer, A.F.E (Eds.), February 5-11, 2001. Nairobi, Kenya.

Patel, D. V., Makne, V. G., and Patil, R.R. (1994). Interrelationship and path coefficient studies in sweet stalk sorghum. J. Maharashtra Agric. Univ., 19:40-41.

Saeed, M., Francis, C. A., and Clegg, M. D. (1986). Yield component analysis in grain sorghum. Crop Sci. 26:561-567.

Singh, B.D. (1993). Plant Breeding. 5th Edition, Kalyani Publishers, Rajender Nagar, Ludhiana, India, 110-111.

Van Oosteriom, E.J., R. Jayachandram, and F.R. Bidininger. (1996). Diallel analysis of the stay green traits and its components in sorghum. Crop Sci. 36:549-555.

Vergas M.J., Crossa, F.A. Eeuwijk, M. van Ramirez, E. and Sayre, K. (1999). Using partial least squares regression, factorial regression, and AMMI models for interpreting genotype x environment interaction. Crop Science, 39: 955-967.