STUDIES ON GENETIC VARIATIONS IN A SORGHUM VARIETY *(Sorghum bicolor* (L.). *Moench)* IRRADIATED WITH COBALT 60 (CO^{60})

By

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DECLARATION

I hereby declare that this dissertation has been written by me and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree.

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CERTIFICATION

This dissertation entitled "Studies on Genetics Variation in sorghum variety (*Sorghum bicolor*. (L.) Moench) irradiated with Cobalt 60 (CO^{60})" by Daniel Afang Aba meets the regulations governing the degree of Doctor of philosophy of Ahmadu Bello University, Zaria, and is approved for it's contribution to scientific knowledge and literacy presentation.

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DEDICATION

This work is dedicated to GOD,

Julie, Aluwong, Emily, Tache and Zanang.

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ABSTRACT

Genetic variability was created in a common sorghum variety SK5912 (SAM-SORG 17) using gamma-ray irradiation from Cobolt 60 (Co^{60}) source. The M_0 seeds were grown in the off-season of 1985/86. This was bulk harvested and planted as M, bulk in 1986. In 1986, 90 M_2 single seed selections were made from single plants selected based on height, yield and disease resistance. These were advanced to M_3 in 1987, out of which 34 M_4 family selections were obtained for evaluation. The 34 M_4 family selections were harvested and threshed. The seeds from each family were divided into three equal portions for evaluation. The 34 M_4 plant types were evaluated in a randomized complete block design (RCBD) for three years (1989, 1990 and 1991) in the Institute for Agricultural Research (I.A.R) farms. Data were collected on 22 characters, (i) eight (8) panicle characters, (ii) eight (8) leaf characters, and (iii) six (6) stem (culm) characters.

Coefficients of variability (C.V%) were high for panicle characters, than for leaf and stem characters. They ranged from 1.65% for days to 50% flowering to 4.15% for grain weight per spikelet. Heritability estimates were high for most panicle characters (>45%) while they were moderate for both the leaf and stem characters (<40%).

There were highly significant mean squares for all characters except for grain weight per spikelet in the combined analysis. There were high and significant correlations (r= >0.5) between the lengths of first and second leaf sheaths (r=0.689) and also the lengths of internodes (r=0.652, 0.628 and 0.634). Highly significant

but negative correlation was found between length of first leaf shealth and width of spikelet (r = -0.840) in 1991.

Variance components from the combine analyses showed that genotypic variancve was high for all characters except for percentage protein and weight of spikelet. All other characters had lower genotypic variances than their respective phenotypic and error variances.

Principal components extracted from the combine correlation matrix showed high variability in leaf and stem characters than in the panicle characters. Internode lenth and leaf sheaths length load significantly on the first factor in the individual years as well as in the combined. Ploting the first two factors of all the years *(F_1* and F_2) in a common scale showed that internode length and leaf sheath length were clustered together in one quadrant; grain weight per panicle, grain weight per spikelet, days to 50% flowering and width of spikelet where also clustered together which is indicating the close relationship between these characters.

The negative correlation between the leaf and stem characters with days to 50% flowering and some panicle characters might be suggesting that selection for shorter plants which have erect leaf could result in increase in yield and early maturing plant. However, there were low correlations between internodes length, length of leaf blade and length of leaf sheath which were highly variable with most panicle characters (yield components). It might be more effective to select directly for grain weight per panicle, length of panicle, spikelet number per panicle and grain weight per spikelet together with these photosynthetic structures for better improvement in yield in our 'plant types'.

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CHAPTER ONE

INTRODUCTION

Sorghum is a major stable food in many parts of the world. It has very extensive use as a food crop in Africa, Asia, and as a major feed grain in North America and more recently in South Africa (Pickett and Oswalt, 1971). In areas where sorghum is used as food crop the food preferences of each particular areas have imposed severe restriction of the types of grain that may be used in variety development. In India, the selection is primarily for the white, creamy white to yellow and pearly types. In Africa, the variability of preference is tremendous with the various types being the primary factor in food preferences. As a feed grain in the United States, it has been utilized as whole grian, but more extensive methods of preparation have been used such as grinding, steam rolling and other treatments. (Pickett and Oswalt, 1971).

About 40 percent of the calories from all food stuffs come from cereals in Nigeria and of this amount sorghum contributes 50 percent, with almost all the production coming from the Northern zone of the country (Oke, 1976). Sorghum is a very versatile and hardy crop that is adapted to varying environments, from the wet guinean savanna through to the vast dry sudanian savanna and semi- arid sahel zones in Nigeria. These cultivated areas in Nigeria lie between latitudes 6° 30'N and 13° 55'N of the country (Obilana, 1984).

The estimated annual production of sorghum is conservatively put at about 4 million metric tonnes (Nwasike and Aba 1986). Of this amount, 3.12 million tonnes are consumed as human food (Nwasike, 1987), while the remaining 20

percent is used for various industrial purposes, the most important being brewing (Okediobi, 1989).

In developing these various types of sorghum the breeder is always faced with the low genetic variability existing in his germplasm. To overcome this constraint, a breeder may employ breeding methods like hybridization and selection between and within populations and or the use of mutation breeding to provide the desired variability. These procedures help to broaden the genetic base of the breeding materials. Parra-Negrette *et al.* (1984), have evaluated induced mutation and hybridization methods for producing genetic variability in fifteen quantitative characters of sorghum. Their results showed large variability for plant maturity, plant height, panicle length and exertion.

Most of the sorghum produced in Nigeria comes from the four ecological zones of the country: Sahel, Sudan, Northern Guinea and Southern Guinea savannas, where the rainfall is erratic and unpredictable with periods of draughts being experienced in the Sudan and Sahel zones more frequently. This situation calls for the development of early maturing, shorter and higher yielding sorghums that are disease and insect pests resistant. The study therefore is aimed at overcoming these constraints in order to increase sorghum production for the ever-increasing population of Nigeria. It could be possible too to develop varieties that could be used for the various industrial purposes which are becoming quite challenging in terms of their demand for the various types.

The objectives of the study are:

1 To study the gentic variation in some characters of sorghum including yield components in the population or lines which arise from artificially induced mutations.

2 To study the relationship of these characters to one another which helps the breeder select characters that directly or indirectly affect the other characters and contribute to the genral improvement of the variety.

3 To study the extent to which these characters are inherited helps in deciding the selection technique that will enhance progress, during the process of improvement.

CHAPTER TWO

LITERATURE REVIEW

Mutation breeding was used to create genetic variability in plants as far back as 1930 when Gustafasson (1930) reported significant variability in many characters of a mutant wheat induced by x-rays, however, the yields remained at par with the mother variety. In the United States of America and Canada, mutation experiments were established after the second world war, with emphasis on disease resistance (Allard, 1960). Gregory (1956) reported significant higher yields in mutant progenies of peanuts than the control variety from which they were derived when irradiated with gamma-rays (Co^{60}).

Different breeders have used different crops in mutation breeding to create variability in different characters.

2.1 Panicle (Head) Characters

The panicle may be short compact or loose and open: 4 - 25cm or more long and 2 to 20cm or more wide (House, 1985). The central axis of the panicle, the rachis, may be completely hidden by the density of the panicle branches or completely exposed. The rachis differs greatly in it's shape and length, from long and thin to short and stubby. It may be striated, hairy or glabrous. Several branches are borne at each node, and these branches which vary in length may be stout or slender, rigid or flexible, hairy or almost glabrous, branched from near the base or not branched until near the tip. The panicle usually grows errect at the apex of the culm, but may be recurved.

The raceme consists of one or several spikelets. One spikelet is sessile the other pedicelate, except the terminal sessile spikelet which is accompanied by two pedicelled spikelets.

There are 1 to 4 nodes in some species, and 5 to 8 in others. Internodes vary in length, thickness, and hairiness, depending on the species. Sessile spikelets are usually green at flowering changing to shades of straw, cream, yellow, red, brown, purple or almost black at grain maturity. Pedicelled spikelets are much narrower than the sessile, usually lanceolate in shape. They are male or neuter in sex and may have rudimentary ovaries.

The seeds are spherical in shape, may vary to somewhat flattened on one side. The pericarp colour varies from red, brown, white, yellow or cream. The embryo mark varies in length from about one-half to two-thirds the length of the grain. The hilium frequently turns dark at about the time the seed reaches physiological maturity. Seed size varies from very small, less than 1gm/100 seeds, to large 5-6gm/100 seeds (House, 1985).

2.1.1 Variability in Panicle Characters

The panicle characters include percentage protein, grain weight per spikelet, grain weight per panicle, panicle length, length of spikelet, width of spikelet and days to 50% flowering.

Parra-Negrette *et al.*, (1984) used different doses of gamma-ray (Co^{60}) to induce genetic variability in sorghum. They reported significant increases in panicle length and exertion, but no significant difference in grain yield and duration of grain filling period

in the mutant lines. Naphade and Ghwaghawe (1971) reported that seeds of M156, M22576 and MCK 60 sorghums were irradiated with gamma-rays (Co^{60}) with varying doses ranging from 10,000 to 40,000R. In both the R_1 and R_2 generations, seeds of M22576 contained more protein than the other two varieties. In general, irradiation reduced the percentage protein of R_1 generation, but increased that of the R_2 in which two of the varieties had higher percentage protein resulting from 30,000R.

Mohan and Axtell (1954) and Axtell (1976) described results of a research at Purdue in which a high lysine character was induced by treatment of sorghum with chemical mutagens. They compared the lysine and protein content of 470 mutants with the normal control seeds. Among the mutants lysine increased by 10 - 30 per cent, in 83 mutants, by 30 - 50 per cent in 35 mutants, and greater than 50 per cent in the rest of the mutants compared to normal seeds. Percentage protein in the mutant seeds ranged from 7.6 to 22.1 per cent and lysine (as percent protein) from 1.37 to 4.93 per cent. Porter and Axtell (1977) used a chemical mutagen diethlsulphate, to create variability in lysine content of sorghum seeds of P721. Approximately 70% of the mutants evaluated in M_2 and M_3 generations had 1 gram of lysine as percentage of 100 gram of protein greater than 2.5.

Parra-Negretter *et al.*, (1984) evaluated mutation induction and hybridization methods for producing genetic variability in fifteen quantitative characters in sorghum. Comparisons of means and phenotypic variances of each population, represented by at least 60 individuals, showed that the means of total dry matter at anthesis were lower than the corresponding checks in D_1 M_1, D_2 M_2 and F_2 populations. The large number

of characters with means below those of their checks in M_2 population were attributable to harmful effects of irradiation. They compared the M_2 and F_2 populations using the M_2's corresponding to the parental lines involved in developing the particular F_2 populations, they showed that means of the F_2 populations exceeded those of the M_2 populations for all characters except days to bloom, days to physiologic maturity, tiller number and biological yield. The phenotypic variances of the F_2 populations were significantly lower for grain filling period, panicle length, 100 grain weight, and number of tillers per plant. A wide range of genetic variability have also been reported in barley as a result of mutagenic treatment, and these include changes in maturity, seed size, malting qualities and yield (Allard, 1960). Ishikawa (1970) obtained mutants of sorghum developed from x-ray irradiation which were earlier maturing than the original variety. Mackey (1954, and 1956) reported that a spontaneously arisen awned wheat mutant, in the scandia KK variety outyielded the parent strain in three years of testing after treatment with x-ray irradiation. Rawlings *et al*. (1958) observed that a significant increase in variability in soybean yields in the M_2 generation of the varieties Adams and Hawkeye, treated with x-rays and thermal neutrons, was largely in the negative direction, the means of the mutants were lower than those of the original variety.

2.2 Culm (Stem) Characters

The culm or stem is made up of a series of alternating nodes and internodes. The stem is slender to very thick, measuring about 0.5cm in diameter near the base and becoming narrower at the upper end and varying in diameter from 0.5cm to 4cm. It is solid with a hard cortex and a softer pith. The nodes appear as a ring at the base of the

leaf sheath; this is the point to which the leaf is attached to the stem. A bud forms at each node, except at the node to which the flag leaf is attached. These buds, at successive nodes, arise on alternating sides of the stem. At times these buds develop into axilliary tillers; basal tillers, if any, form at the first node.

2.2.1 Variability in Culm Characters

Parra-Negrette *et al.*, (1984), used gamma-ray (Co^{60}) to creat genetic variability in sorghum. After seven cycles of selection for lower plant height, 10 mutants M_8 lines were developed, and were evaluated for agronomic characters with the parental lines for comparisons. Means of the M_8 were significantly lower than those of the parents for plant height, internode number and internode length. Goud *et al.* (1968), working with fifty true breeding lines selected from wheat mutants found that plant height was positively correlated genotypically and phenotypically with internode number and internode length, plant height and panicle length. Scossiroli *et al.* (1960) and Scossiroli and Polligrini-Scossiroli,(1962); Swaminathan, (1961) and Borojevic (1963, 1965 and 1967) studied changes in quantitative characters in wheat, after mutagenic treatment, they found that mutagenic treatments decreased the mean value and increased the variability of quantitative characters in M_2 and M_3 generations. The changes in variability occured through an increase in the genetic components of these characters. The variability which increased up to four times in M_2 and M_3 gradually decreased in later generations and stabilized around M_5.

Borojevic (1964, and 1967) made observations on the quantitative characters of beared mutants in M_7, M_8 and M_9 selected after treatment with x-rays and thermal

neutrons from awnless varieties Campodora and Mara. It was observed that the bearded mutants differed from the original variety in the mean values for some quantitative characters, such as plant height, tillering and vegetative period which were higher.

Jagathesan *et al.* (1961) and Swaminathan (1961) reported that awned mutants of wheat varieties M.P 791 and M.P. 809, out yielded the parental strains in two years of testing.

Morishima and Oka (1968) evaluated some 33 mutant lines of rice from gamma-ray irradiation and observed that, they were all identical in all the characters measured. The irradiated lines in most characters had a mean value slightly lower than that of Norin 8 the original variety. The genetic and environmental correlations between the length of panicle and first to fifth internodes length that constituted plant height showed that the organs located near to each other tended to be strongly correlated. Genetic correlations between some characters showed that leaf angle was positively correlated with the number of elongated internodes,and negatively correlated with mean internode length. Leaf angle was also found to be correlated with the fifth internode indicating that upper elongation plant types with shorter internodes would have erect leaves thus increasing light interception. Shorter internodes will also bring about resistance to lodging. Forty six ear progenies selected on the basis of short culm length, and preliminary yield tests showed that there was a general tendency for grain yield to decreased with shortening culm length. A mutant line "Fukei No. 71" with extreme straw stiffness, showed a shortening in culm length by 46 per cent: the three lower internodes were very short but the uppermost internodes and ear were approximately equal to the corresponding ones

of the original variety and thereby resistance to lodging was extremely increased. Morishima *et al.* (1967)(1) showed that those with many panicles or tillering types had larger number of shorter panicles and shorter leaves than the tall plant types (long panicle). The internode length (longer internode) had smaller number of longer internodes and more erect leaves than the internode number types (shorter internodes).

2.3 Leaf Characters

Leaves are variously distributed along the stem in sorghum; in some types they may be crowded at the base, while in others they are distributed uniformly.

Leaves are born at different angles to the stem, varying from at most vertical to horizontal. The leaf blade may be straight, or may slowly loop over, forming an arc. The tip of the leaf may even droop down. The leaves vary in length usually being shorter and smaller at the top and in the lower mid-section, they may be as long or slightly longer than those at the base of the plant. Leaves may be as long as 1m and may vary in width from 10 to 15cm (House, 1985). The plants differ in the number of leaves: in well adapted plants there are usually 14 - 17 leaves but less adapted ones may have up to 30 leaves, (House, 1985). The leaves are borne alternatively in tow ranks along the stem, and consist primarily of a sheath and a blade. The sheath is attached to the node and surrounds the internode, and frequently the node above it before the blade extends outwards. The sheaths attached to lower nodes will cover the nodes above, but those higher on the plant will not extend as far as the node above. This sheath is covered with a waxy bloom, at times the bloom is quite pronounced.

The blades are broad at the base and taper upward to a point. The margins of the leaf are smooth or scabrid, especially on the upper half. The mid-rib is prominent greenish or whitish, flattened or slightly concave on the upper surface and convex on the lower one. The blades are thicker at the base than at the tip and along the mid-rib than along the margins. When damaged, the injured spot turns red, tan or deep purple depending on the plant color.

2.3.1 Variability in Leaf Characters

Leaf characters include leaf lengths, leaf width, leaf area, and leaf sheath length and leaf number. Parra-Negrette *et al.*, (1984) evaluated sorghum lines after treatment with gamma-ray (Co^{60}) and found that after seven cycles of slection there was a significant reduction in leaf area at anthesis, but not with maturity. They concluded that the selection for seassonal adabtability and for high yielding capacity may be made simultaneously.

In order to examine the influence of leaf characters such as number, size, orientation and senescence pattern on percentage light transmission and net assimilation rate, rice varieties Taichung native 1 and Tainam 3 were treated with a wide range of mutagens including gamma-rays, ethyl-mathane-sulphonate and nitrosomethyl urea (Swaminathan, 1970). Mutants with altered leaf characteristics were isolated in M_2, M_3 and in later generations. There was considerable variations in size, number, alignment and aging pattern of leaves in the mutants. Some of these mutants had associated changes in panicle characters, such as density and fertility. Mutants with normal panicles but

altered leaf characteristics were being used in studies of light transmission and dry matter production (Swaminathan, 1970).

Even though the great stores of unexploited natural variability remaining in most agricultural species would seem to obviate any immediate need for the production of additional variability by artificial means, excluding a few cases, mutation breeding still has a place in the planned improvement of agricultural plants, provided constructive changes can be induced frequently enough to make the search for them economically competative with other methods of breeding (Allard, 1960).

CHAPTER THREE

MATERIAL AND METHODS

Genetic variability was created in sorghum "Short Kaura" with gamma-ray from cobalt source (Co^{60}). This variety is a semi-tall plant about 1.5m, braod leafed, thick stem, compact head (panicle), large grains that are yellow in color, and matures in about 125 days to 150 days. Using Genetic effective cell number, (GECN) of 2, and a mutation rate of 10^{-3}, a total of 2300 seeds were irradiated with 250Gy as outlined by Nwasike (1985). Compensating for 70 per cent viability of seeds, 65 per cent survival, and 80 per cent fertility after treatment, the total number of seeds used in M_1 were thus calculated.

$$M_1 = \frac{2300}{2 \times 0.80 \times 0.70 \times 0.65} = 3159 \ seeds$$

For plant density of 500 per m^2 in M_1 plus 10 per cent for planting control, the seeds would be

$$\frac{3159}{500} + \frac{315.9}{500} = 6.318 + 0.6318 = 6.949 = 7 \ seeds/m^2$$

Since 7 seeds/m^2 was the seeding rate and 20 seeds per row in M_2, the plot size will be 3159/7 seeds/m^2 = 451.28seeds/m^2.

Treated M_0 seeds were planted in the field during the off season 1985.

Selection: M_1 seeds were grown as bulk.

Bulk seeds were grown as M_2 population. Selection was made of single M_3 panicles or plants for family lines selection in M_3.

Individual panicles or plants selected in M_3 were planted ear-to-row for family selections. Ninety family lines were selected in M_3, these were put into ear-to-row selection in M_4, after which 34 family selections were made.

Thirty-four M_4 family selections were threshed as individual panicles and each divided into three equal portions. Each of the 34 portions served as treatment were evaluated in a randomized complete block design (RCBD) each year for three years (1989-1991) at the Institute for Agricultural Research farms. There were four replications with four row plots, each row was 6m long and the plants were spaced 25cm within the row. Prior to ridging 32Kg/ha of single superphosphate fertilizer (P_2O_5) was applied as basal dressing. Split application of nitrogen fertilizer (Urea) was done, the first 32 Kg/ha was basal, while 32 Kg/ha was applied 3 weeks after thining (top dressing).

3.1 Records of Measurement

The following characters were measured and recorded for the purpose of analysis using a sample of ten (10) plants per plot:-

1. **Percentage Protein :** Total crude percentage protein was determined using Microkjeldahl method for 20gms of seeds from each line.
2. **Grain weight per panicle**: Weight in grams of grains threshed from a single panicle was determined using a metal balance.

3. **Panicle length**: The length of the panicle was measured with a meter rule from the apex to its base where it is attached to the peduncle.

4. **Spikelet number per panicle**: All the spikelets removed from a single panicle were counted.

5. **Grain weight per spikelet**: All grains from a single spikelet were weighed using analytical balance.

6. **Days to 50% flowering**: The number of days from planting to the time when 50% of the heads in a plot start flowering were determined.

7. **Spikelet length**: The length of the spikelet measured from the spike to the end of the spikelet using a meter rule.

8. **Width of spike**: The width of the spike was measured from the rachis to the pit of the spike using a meter rule.

9. **Length of first leaf blade**: The length of the first leaf from its tip to the base where it is attache to the stalk was measured using a meter rule.

10. **Length of second leaf blade**: The length of the second leaf from its tip to the base where it is attache to the stalk using a meter rule.

11. **Length of the third leaf blade**: The length of the third leaf from its tip to the base where it is attache to the stalk using a meter rule.

12. **Length of fourth leaf blade**: The length of the fourth leaf from its tip to the base where it is attache to the stalk using a meter rule.

13. **First leaf sheath length:** The length of the first leaf sheath from the base of the flag leaf to the first node was measured using a meter rule.

14. **Second leaf sheath length**: The length between the base of the second leaf to the base of the second node was measured using a meter rule.

15. **Third leaf sheath length:** The length between the base of the third leaf base to the third node was measured using a meter rule.

16. **Fourth leaf sheath length**: The length between the base of the fourth leaf to the fourth node was measured using a meter rule.

17. **First internode length**: The length between the base of the peduncle to the first node was measured using a meter rule.

18. **Second internode length**: The length between the first node to the second node was measured using a meter rule.

19. **Third internode length:** The length between the second and third nodes was measured using a meter rule.

20. **Fourth internode length:** The length between the third and fourth nodes was measured using a meter rule.

21. **Fifth internode length**: The length between the fourth and fifth nodes was measured using a meter rule.

22. **Leaf angle**: The angle between the fifth leaf and the stem was measured using a protractor.

3.2 Statistical Analysis

The statistical model used for the combined analysis of variance (ANOVA) was:-

where $$Y_{ijk} = \mu + E_i + R_{i(j)} + G_k + (GE)_{ik} + eijk$$

μ = Overall mean.

Ei = The effect of the ith year; i = 1, 2, 3.

$R_{i(j)}$ = The effect of the jth replication in the ith year; j = 1, 2, 3, 4.

Gk = The effect of the kth line (entry);

K = 1,2,3 34

$(GE)_{ik}$ = The interaction effect between the kth line in the ith year. And

eijk , NID $(0, \sigma^2)$

Analysis of variance was computed for all the characters from each experiment. The analysis for each character was done using plot means. Both lines and years were treated as fixed effects. The form of analysis of variance with expected means squares which were used for the estimation of genetic components is shown in Table 1.

Table 1: Form of ANOVA With Expected Mean Squares (EMS) in One Year for Each Character

Sources of variation	D.f	MS	EMS
Replications	(r-1)		
Entries (lines)	(g-1)	Mg	
Error	(r-1)(g-1)	Me	$\sigma_e^2 + r\sigma_g^2$

r = number of replications

g = number of entries (lines)

σ^2_e = error variance

σ^2_g = total genetic variance among the entries (lines)

M subscript: The observed mean squares of the subscript effect. For each year of experiment, components of variance were estimated from the mean square for each character by using the observed mean square, thus:-

$$\sigma_e^2 = Me \text{ and}$$

$$\sigma_g^2 = \frac{Mg - Me}{r}$$

A combined analysis of variance for the three experiments in three years for each character is expected to provide a more valid estimate of variance components including the genotype x year interaction.

Table 2: Form of ANOVA With Expected Mean Squares (EMS) in Three Years for Each Character

Sources of variation	D.f	MS	EMS
Years	(y-1)		
Reps/Years	y(r-1)		
Entries (lines)	(g-1)	Mg	$\sigma_e^2 + r\sigma_{gy}^2 + r\ y\ \sigma_g^2$
Entries x Years	(g-1)(y-1)	Mgy	$\sigma_e^2 + r\sigma_{gy}^2$
Error	y(g-1)(r-1)	Me	σ_e^2

σ_{gy}^2 = *Genotype x year interaction variance*

The components of variance and their standard errors were estimated from the expected mean squares using observed mean square values of each character thus; (Lukhele, 1982).

$$\sigma_e^2 = Me \text{ with } S.E = \sqrt{\frac{2(Me)}{d.f + 2}}$$

$$\sigma_g^2 = \frac{M_g - M_{gy}}{ry} \text{ with } S.E \sqrt{\left(\frac{1}{r}\right)^2 \frac{2(Mgy)^2}{df + 2} + \frac{2(Me)^2}{df + 2}}$$

The phenotypic variance among the entries was estimated as:

$$\sigma_{ph}^2 = \frac{\sigma_g^2 + \sigma_e^2}{r=4} \text{ for one year}$$

$$\sigma_{ph}^2 = \frac{\sigma_e^2}{ry=12} + \sigma_{gy}^2 + \sigma_g^2 \text{ for three years}$$

To determine if the variations among entries (lines) and their interaction with the years were significantly different from zero, F tests were used for both single and combined ANOVA as follows:

$F = \frac{Mg}{Me}$ with $(g-1)$, $y(r-1)(g-1)$ d.f for one year

$F = \frac{Mg}{Me}$ with $(g-1)$, $y(r-1)(g-1)$ d.f and

$F = \frac{Mgy}{Me}$ with $(g-1)(y-1)$, $y(r-1)(g-1)$ d.f for the three years.

According to Mode and Robinson (1959), the expectations of mean products in the analysis of variance, have the same form as the expected mean squares for the

analysis of variance, and therefore the procedure for analysis of covariance are analoguos to those for analysis of variance. Table 3 shows the form of analysis of variance and covariance of pairs of characters (x and y) with their expected mean cross-products in three years.

Table 3: Form of Analysis of Variance and Covariance with Observed and Expected Mean Products for Two Characters (x and y) in Three Years.

Sources of variation	D.f	Trait x	Trait y	Mean product	Expected mean product
Entries	(g-1)	Mgx	Mgy	Mgxgy	σxy + rσgy x gyy+ ryσgxgy
Entries x years	(g-1)(yl-1)	Mgyx	Mgyy	Mgx x gy	σxy + rσgy x gyy
Pooled error	y(r-1)(g-1)	Mex	Mey	Mexey	σxy

Correlation coefficients were calculated using the formula by Singh and Chaudhar (1977):

$$r.(x_1x_2) = \frac{cov\ x_1x_2}{\sqrt{v(x_1).v(x_2)}}$$

Where:

$r(x_1x_2)$ = the correlation between characters x_1 and x_2

$Cov(x_1x_2)$ = the covariance between characters x_1 and x_2

$V(x_1)$ = the variance of character x_1 and

$V(x_2)$ = the variance of character x_2

Heritability

The effectiveness of selection for a trait depends on the relative importance of genetic and non-genetic factors in the expression of phenotypic differences among genotypes in a population, a concept refered to as heritability. Estimates of broad sense heritability were made from family means using variance components as given by the formula:

$$h^2 = \frac{\sigma_g^2}{\sigma_{ph}^2}$$

Yearly response index, used for estimating the magnitude of yearly difference as compared to mean values of the characters, were estimated using the formula.

$$R = \frac{x_2 - x_1}{x_2 + x_1}, \frac{x_2 - x_3}{x_2 + x_3}, \frac{x_3 - x_1}{x_3 + x_1}$$

where x1, x2 and x3 stand for means of the character in 1989, 1990 and 1991 respectively (Morishima *et al.*, 1967)(II).

3.3 Principal Component Analysis

Principal component analysis is used in this study because it is a relatively new method of analysis that helps in determining components that account for variation in a reduced data set derived from a large number of variables in the data. It is applied more in statistical analysis as opposed to common-factor analysis because they differ in terms of the amount and kinds of variability of the variables being analysed.

Principal component analysis is a relatively straight forward method of transforming a given set of variables into a new set of composite variables or principal components that are orthagonal (uncorrelated) to each other: it is simply to find the best linear combination of variables that would account for more of the variance in the data as a whole than any other linear combination of variables. In that case therefore, the first principal component, may be viewed as the single best summary of linear relationships exhibited in the data. The second component is defined as the second (or next) best linear combination of variables, under the condition that the second component is orthogonal to the first component, the second one must account for the proportion of the variance not accounted for by the first one. Thus, the second component may be defined as the linear combination of variables that account for the most residual variance after the effect of the first component is removed from the data. Subsequent components are defined similarly until all the variances in the data are exhausted. Unless at least one variable is perfectly determined by the rest of the variables in the data, the principal-component solution requires as many components as there are variables (Norma *et al.*, 1975).

To test for the significance of the loadings, But Bunks (1947) have shown that, as one progresses from the first factor to higher factors, the acceptable value for a loading to be judged significant should increase (it should get harder for coefficients to reach significance). Apart from that, the gradual intrusion of unique variances into the later also makes it harder to achieve significance. They therefore deviced a formula, which has the merit of allowing not only for the sample size but also the number of tests

correlated and number of factors extracted up to and including the one under examination. The formula is as follows:-

$$\textit{Standard error} = \textit{standard error of a loading of a correlation} = \sqrt{\frac{n}{n+1-r}}$$

where

n = number of variables in the analysis.

r = number of factor, that is the factor number during extraction.

The technique attempts to summarize all the correlations between a number of variates by expressing them in terms of a lesser number of variates called components (factors) Smith and King (1962). The eigenvalues (latent roots) and vectors (factors vectors) required were obtained with a standand computer programme (SPSS).

There are two criteria that can be used in deciding the number of factors to be retained as being important in principal component analysis.

The first is Kaisers (1960) criterion which states that only factors (components) having eigenvalues (latents roots) equal to or greater than one (1) are considered as common factors (Richard *et al.*, 1980).

The second criterion is Cattel (1966) test, in this case, a graph of eigenvalues against the factor numbers is plotted, and the resulting curve is used to judge the cut-off point, which is usually the point at which the graph tends to flatten out along the horizontal axes. In this present study the first criterion is used, and so only factors that had eigenvalues equal to or greater than one (1) were retained as common factors. This is the same as the minimum eigenvalue criterion (MINEGEN CRITERION), which also

ensures that only factors accounting for at least the amount of total variance of a single variable (tests) will be treated as being significant (Norman *et al.*, (1975). This multivariate analysis of variance is particularly useful when the hypothesis to be tested or investigated in a research study is concerned with traits or characters that are too complex or too broad in scope to be measured satisfactorily by a simple test. It also assigns weights (loadings) that will maximized the variability between groups of traits relative to the variability within the groups.

In this study Kaisers cretarion (1960) was used in deciding the number of factors to be retained in the analysis.

To calculate the percentage variance from the latent root (eigen value) the following formular was used (Dennis, 1978):-

$$\frac{\text{Latent root}}{\text{Number of tests}} \times 100 = \text{percentage variance}$$

Rotation: The ultimate goal in any rotation is to obtain some theoretical meaningful factors, and if possible the simplest factor structure (Norman *et al.*, 1975). To achieve such a simple structure, Thurstone (1947) tried to establish some rules of thumb which have been summerized by Harman (1967) below:

1. Each row of the factor matrix should have atleast one zero loading (not significant).
2. If there are n common factors being used in the rotation, there should be atleast n zero loadings in each factor.

3. For every pair of factors there should be several variables with zero loadings in one factor but having at the same time significant loadings in the other.

4. For every pair of factors a large proportion of the loadings should have zero values in both factors where there are four (4) or more factors.

5. For every pair of factors there should only be a small proportion of loadings with significant values in both factors.

CHAPTER FOUR

RESULTS

The mean values, coefficients of variation and standard error of all the 22 characters studied are presented in Table 4. These characters were classified into three groups namely:

(a) The panicle characters consisting of, grain weight per panicle, spikelet number per panicle, grain weight per spikelet, spikelet length, spikelet width, percentage protein and days to 50% flowering.

(b) Leaf characters consisting of length of first leaf blade, length of second leaf blade, length of third leaf blade and length of fourth leaf blade, length of 1st leaf sheath, length of second leaf sheath, length of third leaf sheath and length of fourth leaf sheath.

(c) Stem characters consisting of length of first internode, length of second internode, length of third internode, length of fourth internode and length of firth internode and leaf angle in degrees.

The coefficients of variations ranged from 1.65 percent for days to 50 percent flowering in 1989 to 48.15 percent for grain weight/spikelet for panicle characters.

For length of leaf blades the coefficients of variations ranged from 4.40 percent for length of third leaf blade in 1991 to 18.52 percent for length of first leaf blade in 1990 (Table 4).

For length of leaf sheath, the coefficients of variations ranged from 13.74 percent for fourth leaf in 1991 to 25.79 percent

Table 4: Mean, Standard error and coefficient of variation in percent (C.V.%) for individual and the combined years for 22 characters

Character	1989			1990			1991			Combined		
	Mean	S.E.	C.V.%	Mean	S.E.	C.V.%	Mean	S.E.	C.V.%	Mean	S.E.	C.V.%
I. Panicle characters												
Protein content %	9.82	±0.54	7.85	10.01	±0.469	6.64	10.24	±0.491	6.80	10.02	±0.500	7.06
Grain weight per panicle (kg)	64.00	±16.98	37.52	68.10	±16.81	34.91	64.84	±13.70	29.89	65.65	±16..25	35.01
Length of panicle (cm)	32.79	±2.49	10.77	30.47	±2.134	9.91	29.42	±1.965	9.45	30.89	±2.239	10.25
Spikelet number per panicle	121.69	±19.14	22.25	113.60	±17.00	21.16	104.58	±10.97	14.84	113.29	±16.277	20.32
Grain weight per spikelet (gm)	1.12	±0.38	48.15	1.71	±0.448	37.03	1.94	±0.512	37.47	1.59	±0.463	41.28
Days to 50% flowering	105.95	±1.24	1.65	119.84	±2.628	3.10	110.29	±1.45	1.86	112.63	±1.88	2.38
Length of spikelet (cm)	7.60	±1.15	21.37	8.16	±0.88	15.29	7.89	±0.987	17.78	7.87	±1.022	18.38
Width of spikelet (cm)	0.24	±0.04	22.98	0.25	±0.031	21.73	0.24	±0.038	23.15	0.24	±0.038	27.60
II. Leaf characters												
Length of first leaf blade (cm)	46.60	±5.84	17.72	54.52	±7.19	18.52	39.64	±2.114	7.54	47.85	±2.11	17.23
Length of second leaf blade (cm)	53.76	±4.20	11.05	59.52	±6.144	14.60	53.61	±1.889	4.92	55.63	±1.88	11.12
Length of third leaf blade (cm)	61.14	±4.14	9.57	61.87	±5.805	13.27	60.66	±1.885	4.40	61.22	±1.885	9.25
Length of fourth leaf blade (cm)	66.21	±5.21	11.1	65.88	±6.743	14.93	68.05	±3.90	8.11	65.05	±3.90	11.56
Length of first leaf sheath (cm)	35.84	±6.06	15.64	14.89	±1.827	17.37	29.26	±3.02	14.61	36.66	±3.02	16.99
Length of second leaf sheath (cm)	22.78	±3.96	22.39	14.01	±2.19	22.14	16.99	±1.77	14.76	17.90	±1.77	22.35
Length of third leaf sheath (cm)	19.70	±3.61	20.34	14.18	±2.28	22.75	15.39	±1.488	14.60	16.42	±1.588	21.72
Length of fourth leaf sheath (cm)	18.03	±2.83	19.59	16.11	±2.938	25.79	15.26	±1.48	13.74	16.47	±1.482	72.19
III. Stem characters												
Length of first internode (cm)	11.15	±2.50	29.80	9.79	±1.63	23.61	10.89	±1.92	24.94	10.61	±1.92	28.95
Length of second internode (cm)	10.03	±1.83	25.77	9.24	±1.606	24.60	10.51	±1.374	18.51	9.92	±1.374	23.90
Length of third internode (cm)	9.95	±1.74	24.72	9.40	±1.876	28.23	10.21	±0.956	13.25	9.86	±0.95	23.24
Length of fourth internode (cm)	10.82	±1.94	25.38	9.54	±2.08	30.87	10.56	±1.186	15.88	10.31	±1.18	24.88
Length of firth internode (cm)	10.94	±1.57	20.32	10.07	±2.02	78.43	10.72	±1.11	14.67	10.58	±1.81	21.23
Leaf angle in degrees	31.30	±6.06	27.37	43.05	±8.48	27.87	62.29	±9.60	21.85	45.54	±1.11	86.23

for the same character in 1990.

For lengths of internode the coefficients of variations ranged from 13.25 percent for length of third internode in 1991 to 86.23 percent for leaf angle in 1991. This gives the highest range of variability among the three groups of characters.

For the combined analysis, the C.V% ranged from 2.38% for days to 50% flowering to 41.28% for grain weight/spikelet, 9.25 percent for third leaf blade to 17.23 percent for first leaf blade, 16.99 percent for first leaf sheath to 72.19 percent for fourth leaf sheath and from 21.23 percent for fifth internode to 86.23 percent for leaf angle. Again large variations were observed with the internode lengths than all other characters.

The means for most characters were similar for the three years except for the lengths of leaf sheaths which were higher in 1989 than in 1990 and 1991 and internode lengths which were higher in 1991 than in 1989 and 1990.

For all the leaf characters the lowest coefficients of variations were in 1991, while they were highest in 1990 except for length of second leaf sheath. In the stem (culm) characters the coefficients of variations were lowest in 1991 and highest in 1990, except for length of first and second internodes that were lower in 1990.

The mean square values for the 22 characters in the individual years and the three years combined are shown in Tables 5 and 6, respectively. In 1989, all the characters had highly significant (P=0.01) mean squares except for grain weight per spikelet and

Table 5. Mean squares for 22 characters of 35 plant types of sorghum in 1989, 1990 and 1991.

Sources of variation	Df	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Reps	3												1989										
Entries	34	4.33**	922.0**	33.4**	1011.5*	0.45**	40.9**	6.3**	0.004	74.5**	50.5**	96.6**	121.9**	114.9**	87.9**	48.6**	32.9**	28.6**	37.9**	43.9**	49.4**	55.3**	92.4**
Error	139	0.59	976.8	12.5	7333.3	0.29	3.1	2.6	0.003	68.2	35.3	34.2	54.2	31.4	26.0	16.1	12.5	11.0	6.7	6.0	7.5	4.9	73.4
Reps	3												1990										
Entries	34	6.4**	762.6**	41.2**	1157.2*	0.7	34.3**	10.5**	0.003	131.4**	111.1**	74.9**	97.4**	19.3**	18.1	14.7**	43.6**	13.5**	16.5**	14.6**	12.9**	10 8**	116.5**
Error	139	0.4	565.76	9.1	578.0	0.4	13.8	1.6	0.002	103.5	75.5	67.4	90.9	6.7	9.6	10.4	17.3	5.3	5.2	7.0	8.7	8.2	144.1
Reps	3												1991										
Entries	34	6.3**	831.8**	9.3**	582.5**	0.7**	7.2**	3.6**	0.002	42.1**	128.4**	162.2**	83.0**	36.8**	41.7**	21.1**	11.2**	18.1**	3.9**	3.1**	4.7**	5.1**	231.4**
Error	139	0.4	376.6	7.7	376.6	0.5	4.2	1.9	0.003	8.9	7.1	7.1	30.4	18.3	6.3	5.1	4.4	7.4	3.7	1 8	2.8	2.5	184.4

*, ** significant at 5% and 1% probability. respectively.

I
1. Protein percent
2 Grain weight per plant
3 Length of panicle
4 Spikelet number per panicle
5 Grain weight per spikelet
6 Days to 50% flowering
7 Length of spikelet
8 Width of spikelet

II
9 Length of first leaf blade
10 Length of second leaf blade
11 Length of third leaf blade
12 Length of fourth leaf blade
13 Length of first leaf sheath
14 Length of second leaf sheath
15 Length of third leaf sheath
16 Length of fourth leaf sheath

III
17 Length of firstt internode
18 Length of second internode
19 Length of third internode
20 Length of fourth internode
21 Length of fifth internode
22 Leaf angle in degrees.

Table 6. Mean squares for 22 characters of 34 plant types of sorghum for the combined years (1989, 1990 and 1991)

Sources of variation	Df	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Reps x yr																							
Entries	34	76.0**	1024.8*	44.6**	1311.3	0.66	7071.7*	13.9**	0.005	81.1**	134.1**	130.2**	149.3**	95.9**	79.7**	34.9**	32.2**	30.2**	35.6**	35.2**	32.6**	38.9**	188.9**
Ent x yr	68	4.8**	745.8**	19.7**	719.9**	0.64**	33.1**	3.2**	0.003	83.5**	77.9**	106.8**	76.6**	37.5**	34.0**	24.7	23.3**	14.9**	11.5**	13.2**	17.3**	16.1**	126.7**
Error	312	0.5	528.3	10.0	529.9	0.4	7.1	2.1	0.003	65.7	65.7	36.4	58.3	20.5	16.1	12.1	14.0	9.3	5.6	5.2	6.6	5.2	142.8
Total	419																						

*, ** significant at 5% and 1% probability, respectively.

I
1. Protein percent
2 Grain weight per plant
3 Length of panicle
4 Spikelet number per panicle
5 Grain weight per spikelet
6 Days to 50% flowering

II
7 Length of spikelet
8 Width of spikelet
9 Length at 1st leaf blade
10 Length at 2nd leaf blade
11 Length at 3rd leaf blade
12 Length at 4th leaf blade
13 Length at 1st leaf sheath
14 Length at 2nd leaf sheath
15 Length at 3rd leaf sheath
16 Length at 3rd leaf sheath

III
17 Length at 1st internode
18 Length at 2nd internode
19 Length at 3rd internode
20 Length at 4th internode
21 Length of 5th internode
22 Leaf angle in degrees.

width of spikelet, this may be due to measurement difficulties for these characters resulting in little difference between the values which had non-significant mean squares. A similar trend was observed for the mean squares of the characters in 1990 and 1991 where we had highly significant (P=0.01) mean squares for all the characters except for grain weight per spikelet and width of spikelet which had non-significant mean squares in the two years. The same reason for non-significance of the mean square of this characters as given earlier above. The combined analysis of variance in Table 6 shows highly significant differences between years for all characters except for grain weight per spikelet, width of spikelet and spikelet number per panicle. This follows a similar trend for the individual years results (Table 5). There were highly significant genotype x year interaction mean squares for all characters except width of spikelet which showed a non-significant interaction.

Estimates of variance components were calculated for all the characters using the analysis of variance for each year and for the three years combined (Tables 7,8,9, and 10). Genetic variances (σ^2g) for all the characters were lower than their error variances (σ^2e) in 1989 except for percentage proteinu, days to 50% flowering, lengths of second, third, fourth, fifth internodes and leaf angle which were higher than their error variances (Table 7). In 1990 all the genetic variances (σ^2g) for all characters were lower than their error variances (σ^2e) except for percentage protein and length of spikelet which were higher than their error variances (Table 8).

Table 7: The genotypic (σ^2g), phenotypic (σ^2ph), error variance (σ^2e) and heritability (h^2) estimates of 22 characters of sorghum plant types grown 1989.

Character	σ^2g	σ^2ph	σ^2e	h^2(%)
I.				
Protein percent	1.76	2.35	0.59	74.89
Grain weight/plant	124.14	1100.94	976.8	11.28
Length of panicle	8.68	21.18	12.5	40.98
Spikelet number/panicle	195.33	928.63	733.3	21.03
Grain weight/spikelet	0.058	0.35	0.29	16.57
Days to 50% flowering	6.49	9.59	3.10	67.67
Length of spikelet	2.48	5.08	2.60	48.82
Width of spikelet	0.0004	0.004	0.003	11.76
II.				
Length of first leaf blade	3.85	72.05	68.20	5.34
Length of second leaf blade	23.87	59.17	35.30	40.34
Length of third leaf blade	23.45	57.65	34.20	40.67
Length of fourth leaf blade	22.75	56.95	54.20	39.94
Length of first leaf sheath	18.39	49.79	31.40	36.93
Length of second leaf sheath	15.93	41.93	26.00	37.99
Length of third leaf sheath	5.72	21.82	16.10	26.21
Length of fourth leaf sheath	4.54	17.04	12.5	26.64
III.				
Length of first leaf internode	5.22	16.22	11.0	32.18
Length of second leaf internode	7.49	14.19	6.70	52.78
Length of third leaf internode	7.48	13.48	6.00	55.48
Length of fourth leaf internode	6.57	49.27	7.50	13.33
Length of fifth leaf internode	8.45	13.35	4.90	63.29
Leaf angle in degrees	11.54	84.94	73.40	13.58

Table 8: The genotypic (σ^2g), phenotypic (σ^2ph), error variance (σ^2e) and heritability (h^2) estimates of 22 characters of sorghum plant types grown 1990.

Character	σ^2g	σ^2ph	σ^2e	h^2(%)
I.				
Protein percent	1.50	1.90	0.40	78.94
Grain weight/plant	49.34	614.10	565.76	8.03
Length of panicle	8.03	17.13	9.10	46.87
Spikelet number/panicle	144.79	722.79	578.00	20.03
Grain weight/spikelet	0.10	0.50	0.40	20.70
Days of 50% flowering	5.11	18.90	13.80	27.03
Length of spikelet	2.23	3.83	1.6	58.22
Width of spikelet	0.0001	0.003	0.003	3.33
II.				
Length of first leaf blade	6.99	110.49	103.50	6.32
Length of second leaf blade	8.90	84.40	75.50	10.54
Length of third leaf blade	4.40	71.80	67.40	6.12
Length of fourth leaf blade	1.62	92.52	90.90	1.75
Length of first leaf sheath	3.14	9.84	6.70	31.91
Length of second leaf sheath	2.12	11.72	9.60	18.08
Length of third leaf sheath	1.09	11.49	10.40	9.48
Length of fourth leaf sheath	4.34	21.64	17.30	20.05
III.				
Length of first leaf internode	2.04	7.34	5.30	27.79
Length of second leaf internode	2.85	8.05	5.20	35.40
Length of third leaf internode	1.88	8.08	7.00	21.17
Length of fourth leaf internode	1.08	9.78	8.70	11.04
Length of fifth leaf internode	0.65	8.85	8.20	7.34
Leaf angle in degrees	6.88	150.98	144.10	4.55

Table 9: The genotypic (σ^2g), phenotypic (σ^2ph), error variance (σ^2e) and heritability (h^2) estimates of 22 characters of sorghum plant types grown 1991.

Character	σ^2g	σ^2ph	σ^2e	h^2(%)
I.				
Protein percent	1.46	1.86	0.40	78.49
Grain weight/plant	114.05	490.65	376.60	23.24
Length of panicle	0.39	8.09	7.70	4.82
Spikelet number/panicle	85.34	461.91	376.6	18.47
Grain weight/spikelet	0.04	0.54	0.50	74.07
Days of 50% flowering	0.74	4.94	4.20	14.97
Length of spikelet	0.42	2.32	1.90	18.10
Width of spikelet	0.004	0.003	0.003	13.33
II.				
Length of first leaf blade	8.30	17.20	8.90	48.25
Length of second leaf blade	30.30	37.40	7.10	81.01
Length of third leaf blade	38.76	45.86	7.10	84.51
Length of fourth leaf blade	13.15	43.55	30.40	30.19
Length of first leaf sheath	4.63	22.93	18.30	20.11
Length of second leaf sheath	8.85	15.15	6.30	58.41
Length of third leaf sheath	4.01	9.11	5.10	44.01
Length of fourth leaf sheath	1.70	6.10	4.40	27.86
III.				
Length of first leaf internode	2.67	10.07	7.40	26.51
Length of second leaf internode	0.05	3.75	3.70	1.33
Length of third leaf internode	0.32	2.12	1.80	15.09
Length of fourth leaf internode	0.48	3.28	2.80	14.63
Length of fifth leaf internode	0.66	3.16	2.50	20.88
Leaf angle in degrees	11.75	196.15	184.40	5.99

Table 10: The genotypic (σ^2g), phenotypic (σ^2ph), error variance (σ^2e) and heritability (h^2) estimates of 22 characters of sorghum plant types grown in three years (1989, 1990 and 1991) combined.

Character	σ^2g	σ^2ph	σ^2e	σ^2gy	$h^2(\%)$
Protein percent (%)	1.76	2.26	0.50	1.06	77.88
Grain weight/plant	124.14	652.39	528.30	54.391	19.03
Length of panicle	8.68	18.68	10.00	2.40	46.31
Spikelet number/panicle	195.33	725.28	529.90	47.48	26.69
Grain weight/spikelet	0.058	0.49	0.40	0.05	11.84
Days of 50% flowering	6.49	13.60	7.10	6.49	47.72
Length of spikelet	2.48	4.57	2.10	0.28	54.27
Width of spikelet	0.0004	0.003	0.003	0.003	11.76
Length of first leaf blade	3.85	69.56	65.70	4.44	5.50
Length of second leaf blade	23.87	89.57	65.70	9.84	26.64
Length of third leaf blade	23.45	59.80	36.4	17.61	39.21
Length of fourth leaf blade	22.75	81.01	58.30	4.57	28.08
Length of first leaf sheath	18.39	39.39	20.50	4.23	47.91
Length of second leaf sheath	15.93	31.97	16.10	4.49	49.82
Length of third leaf sheath	5.72	17.83	12.10	3.15	32.08
Length of fourth leaf sheath	4.54	18.56	14.00	2.31	24.46
Length of first leaf internode	5.22	14.53	9.30	1.41	35.92
Length of second leaf internode	7.49	13.12	5.60	1.45	57.08
Length of third leaf internode	7.48	12.72	5.24	1.99	58.81
Length of fourth leaf internode	6.57	13.25	6.60	2.67	49.96
Length of fifth leaf internode	8.45	13.65	5.20	2.73	61.90
Leaf angle in degrees	11.54	154.33	126.70	-4.27	7.47

In 1991 all the characters had lower genetic variances (σ^2g) than their error variances (σ^2e) except for percentage protein, lengths of second and third leaf blades and length of second leaf sheath which were higher (Table 9). In general the genotypic (σ^2g), phenotypic (σ^2ph) and error variances (σ^2e) were high for grain weight per panicle in all the years with leaf angle becoming high in 1990 and 1991.

Variance components from the combine analysis (Table 10) shows that all the genotypic variances (σ^2g) were lower than their respective error variances (σ^2e) except for percentage protein, length of spikelet, lengths of second, third and fifth internodes. Genotype x year variances (σ^2gy) were lower than the phenotypic variances (σ^2ph).

4.1 Heritability

Broad sense heritability estimates were computed for all characters since they had positive O^2g, using the components of variance estimates from the individual as well as for the combined analysis of variance. Heritability from the combined analysis (Table 10) showed that percentage protein which has almost the lowest variance components for O^2g, O^2ph, and O^2e has the highest heritability value of 77.88%, while length of 1st leaf blade has the lowest heritability value of 5.5%. For the individual years the heritability estimates ranged from 5.34% for 1st leaf blade to 74.89% for percentage protein in 1989; for 1990 the heritabilities ranged from 1.75% for length of fourth leaf blade to 78.94% for

Table 11: The values of yearly response index (R) for 22 characters compared with coefficient of variability in percent (C.V%) for the 3 years (1989, 1990 and 1991).

	1989		1990		1991	
	R	C.V.(%)	R	C.V.(%)	R	C.V.(%)
I.						
Protein percent	0.96	7.85	1.14	6.64	2.09	7.06
Grain weight/plant	3.11	37.52	-2.45	34.91	0.65	35.01
Length of panicle	-3.67	10.77	-1.75	9.91	-5.43	10.25
Spikelet number/panicle	-3.44	22.25	-4.13	21.16	-7.56	20.32
Grain weight/spikelet	17.12	48.15	6.30	37.03	26.80	41.28
Days of 50% flowering	-6.15	1.65	-4.15	3.10	2.60	2.32
Length of spikelet	3.55	21.37	-1.87	15.29	1.68	18.38
Width of spikelet	2.04	22.98	-2.04	21.73	0.00	22.60
II.						
Length of first leaf blade	8.20	17.72	-16.16	18.52	-8.07	17.23
Length of second leaf blade	5.08	11.05	-5.22	14.60	-0.14	11.17
Length of third leaf blade	0.59	9.57	-0.99	13.27	-0.40	9.85
Length of fourth leaf blade	-1.79	11.12	3.16	14.93	1.37	11.56
Length of first leaf sheath	-41.30	15.64	32.59	17.37	-10.11	16.99
Length of second leaf sheath	-23.84	22.39	9.61	22.14	-14.58	22.35
Length of third leaf sheath	-16.30	20.34	4.09	22.75	-12.28	21.19
Length of fourth leaf sheath	-5.62	19.59	-2.77	25.79	-8.32	22.74
III.						
Length of first leaf internode	-6.50	29.80	5.32	23.61	-1.18	28.76
Length of second leaf internode	-4.10	25.77	6.43	24.60	2.34	23.90
Length of third leaf internode	-2.89	24.72	4.13	28.23	1.29	23.24
Length of fourth leaf internode	-6.29	25.38	5.08	30.87	-1.22	24.88
Length of fifth leaf internode	-4.14	20.32	13.13	28.43	-1.02	21.56
Leaf angle in degrees	15.80	27.37	18.27	27.87	33.11	26.23

percentage protein, while in 1991 the heritabilities ranged from 1.38% for length of second internode to 84.51% for length of third leaf blade. This result tends to suggest that most of the leaf and stem characters are heritable while panicle characters have low heritability estimates, which may make them difficult to be selected for.

4.2 Yearly Response Index (R)

For estimating the magnitude of yearly differences as compared to mean values of the characters, an index of yearly response, was set up and the values were computed for each character. This index may be compared with the coefficient of variation, and is useful for comparing how the characters response to yearly differences. The yearly response index (R) and coefficient of variation values are given in Table 11. Percentage protein, grain weight/spikelet and leaf angle showed positive response index values (R) in all the years while length of fourth leaf sheath had negative response index values in all the years. There were positive response index values for twelve characters in 1990, and ten characters in 1991, while we had negative response index values for ten characters in 1990, and twelve characters in 1991. Positive response index indicates an increase in the mean of the characters from one year to the other, while a negative response index suggests a reduction in the mean of characters from one year to the other (Table 11).

4.3 Correlations Coefficients

In 1989, high and significant ($p=0.05$) correlations were found between length of spikelet and length of panicle ($r=0.651$); length of second leaf sheath and first leaf sheath ($r=0.676$), length of third leaf sheath and first leaf sheath ($r=0.636$), length of fourth leaf sheath and first

leaf sheath (r=0.640), also length of second internode and first internode (r=0.668), length of fourth and fifth internodes and second internode (r=0.699, r=0.620). Highly significant (p=0.01) correlations were found between length of third leaf sheath and second leaf sheath (r=0.755), length of third internode and second internode (r=0.751), length of fourth and fifth internodes and third internode (r=0.812, r=0.76) length of fourth internode and fifth internode (r=0.771).

In 1990, high and significant (p=0.05) correlations were found between length of spikelet and length of panicle (r=0.624), length of second leaf blade and first leaf blade (r=0.692) length third leaf blade and second leaf blade (r=0.672) length of fourth leaf blade and third leaf blade (r=0.652). Highly significant correlations were found between third leaf and fourth leaf sheaths with second leaf sheath (r=0.869 and 0.753), fourth leaf sheath and third leaf sheath (r=0.796) and also length of second internode and first internode (r=0.707).

Highly significant (p=0.01) but negative correlation was found between second leaf sheath and grain weight/panicle (r=-0.840) in 1991.

Table 12: Phenotypic correlation coefficients between 22 characters in sorghum plant types grown in 1989.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	-1.000	-0.065	0.060	0.046	-0.078	-0.095	0.038	-0.142	-0.040	-0.071	-0.081	-0.173	-0.107	-0.088	-0.114	-0.108	-0.045	-0.159	-0.121	-0.104	-0.169	0.089
2	-0.065	1.000	0.213	0.231	0.489	0.091	0.022	0.130	-0.026	-0.016	-0.100	-0.44	-0.067	-0.024	-0.006	-0.026	-0.070	-0.078	-0.086	-0.133	-0.104	0.031
3	0.061		1.000	-0.055	0.216	0.159	0.615*	0.040	-0.100	0.090	0.201	0.163	0.141	0.065	0.047	0.128	0.220	0.295	0.288	0.315	0.322	0.151
4	0.046			1.000	0.035	-0.040	-0.093	0.070	0.016	-0.119	0.013	-0.065	-0.207	-0.185	-0.192	-0.148	-0.169	-0.195	-0.174	-0.187	-0.258	0.056
5	0.078				1.000	0.077	0.228	0.042	-0.141	-0.097	-0.047	-0.106	-0.051	-0.018	-0.005	0.001	-0.056	-0.014	0.008	0.011	0.004	0.081
6	-0.095					1.000	0.050	-0.179	-0.116	-0.173	0.129	-0.060	0.083	0.009	0.044	0.061	0.019	0.065	0.109	0.140	0.166	0.078
7	0.038						1.000	0.011	-0.021	0.197	0.151	0.200	0.204	0.171	0.125	0.113	0.252	0.365	0.324	0.330	0.408	0.035
8	-0.141							1.000	0.060	0.195	-0.025	0.105	-0.037	0.019	-0.014	-0.040	-0.073	-0.027	-0.041	-0.051	-0.085	-0.026
9	-0.040								1.000	0.348	0.114	0.228	0.029	0.016	0.092	0.139	-0.124	-0.049	-0.142	-0.127	-0.091	0.030
10	-0.071									1.000	0.238	0.500	0.160	0.133	0.179	0.076	0.144	0.165	0.123	0.143	0.178	0.009
11	-0.187										1.000	0.427	0.235	0.192	0.142	0.131	0.015	0.055	0.090	0.143	0.232	-0.053
12	-0.173											1.000	0.382	0.306	0.320	0.275	0.242	0.420	0.361	0.357	0.434	-0.051
13	-0.107												1.000	0.676*	0.636*	0.532	0.268	0.367	0.463	0.397	0.502	-0.029
14	-0.088													1.000	0.790**	0.640*	0.180	0.302	0.454	0.427	0.499	-0.110
15	-0.114														1.000	0.755**	0.163	0.278	0.389	0.349	0.455	-0.069
16	-0.108															1.000	0.078	0.198	0.342	0.324	0.413	-0.103
17	-0.045																1.000	0.668*	0.563	0.559	0.389	0.059
18	-0.159																	1.000	0.751**	0.699*	0.620*	-0.029
19	-0.121																		1.000	0.815**	0.761**	-0.008
20	-0.104																			1.000	0.771**	-0.036
21	-0.169																				1.000	0.040
22	0.089																					1.000

*, ** Significant at 5% and 1% propability, respectively.

I
1. Protein percent
2 Grain weight per plant
3 Length of panicle
4 Spikelet number per panicle
5 Grain weight per spikelet
6 Days to 50% flowering
7 Length of spikelet
8 Width of spikelet

II
9 Length of first leaf blade
10 Length of second leaf blade
11 Length of third leaf blade
12 Length of fourth leaf blade
13 Length of first leaf sheath
14 Length of second leaf sheath
15 Length of third leaf sheath
16 Length of fourth leaf sheath

III
17 Length of firstt internode
18 Length of second internode
19 Length of third internode
20 Length of fourth internode
21 Length of fifth internode
22 Leaf angle in degrees.

Table 13: Phenotypic correlation coefficients between 22 characters of sorghum plant types grown in 1990.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	1.000	-0.165	-345.0	-0.271	-0.107	-0.041	0.359	0.010	-0.119	0.005	0.007	0.110	0.005	0.107	0.084	0.060	0.203	0.110	0.135	0.098	0.098	-0.040
2	-0.165	1.000	-0.060	0.257	0.311	0.046	-0.066	0.037	0.207	0.154	0.101	0.015	-0.028	-0.087	-0.154	-0.081	0.091	0.021	0.079	0.068	-0.021	0.001
3	0.345		1.000	-0.062	0.037	-0.135	0.624*	0.163	-0.037	0.177	0.231	0.306	0.376	0.170	0.180	0.222	0.348	0.264	0.249	0.125	0.161	0.044
4	-0.271			1.000	0.011	0.152	-0.303	0.205	0.152	0.121	0.075	0.086	-0.216	-0.146	-0.152	-0.192	-0.269	-0.286	-0.095	-0.329	-0.232	-0.198
5	-0.107				1.000	0.064	0.030	0.147	0.192	0.225	0.186	0.123	-0.038	-0.020	-0.090	-0.082	0.085	-0.001	0.077	0.164	0.078	0.068
6	-0.041					1.000	-0.156	0.019	0.061	-0.120	-0.121	-0.053	-0.173	-0.165	-0.169	-0.125	-0.159	-0.180	0.003	-0.176	-0.147	-0.031
7	0.359						1.000	0.127	0.025	0.152	0.096	0.095	0.447	0.286	0.299	0.389	0.331	0.380	0.288	0.202	0.228	0.022
8	0.010							1.000	0.167	0.212	0.060	0.091	0.129	0.026	-0.011	-0.015	0.043	0.071	0.048	-0.060	-0.056	-0.078
9	-0.119								1.000	0.692*	0.456	0.104	0.051	0.095	0.092	0.074	0.020	0.030	0.074	0.122	0.048	-0.078
10	0.004									1.000	0.672*	0.414	0.248	0.208	0.232	0.169	0.181	0.186	0.176	0.183	0.082	0.107
11	0.007										1.000	0.652*	0.262	0.188	0.158	0.057	0.091	0.077	0.121	0.143	-0.000	0.337
12	0.110											1.000	0.250	0.105	0.116	0.017	0.129	0.086	0.054	0.026	-0.100	0.323
13	0.005												1.000	0.597	0.538	0.552	0.550	0.530	0.411	0.309	0.331	0.125
14	0.107												1.000	0.869**	0.753**	0.372	353	0.335	0.353	0.221	0.122	
15	0.084												1.000	0.796**	0.310	0.350	0.297	0.297	0.268	0.168		
16	0.060												1.000	0.358	0.311	0.301	0.378	0.348	0.106			
17	0.203												1.000	0.707**	0.512	0.455	0.422	0.025				
18	0.110												1.000	0.586	0.493	0.426	0.144					
19	0.135												1.000	0.482	0.440	0.180						
20	0.076												1.000	0.507	0.180							
21	0.098												1.000	0.171								
22	-0.040												1.000									

*, ** Significant at 5% and 1% propability, respectively.

I
1. Protein percent
2 Grain weight per plant
3 Length of panicle
4 Spikelet number per panicle
5 Grain weight per spikelet
6 Days to 50% flowering
7 Length of spikelet
8 Width of spikelet

II
9 Length of first leaf blade
10 Length of second leaf blade
11 Length of third leaf blade
12 Length of fourth leaf blade
13 Length of first leaf sheath
14 Length of second leaf sheath
15 Length of third leaf sheath
16 Length of fourth leaf sheath

III
17 Length of firstt internode
18 Length of second internode
19 Length of third internode
20 Length of fourth internode
21 Length of fifth internode
22 Leaf angle in degrees.

Table 14: Phenotypic correlation coefficients between 22 characters in sorghum plant types grown in 1991.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	1.000	0.064	-0.064	0.039	0.053	-0.231	0.157	-0.056	-0.214	0.172	0.008	-0.029	0.058	-0.031	0.046	0.005	0.092	0.125	0.229	-0.020	0.226	-0.092
2	0.064	1.000	0.094	0.372	0.288	-0.304	0.009	0.004	0.013	0.005	-0.039	0.027	0.025	-0.170	-0.069	-0.040	-0.034	0.049	-0.015	-0.042	-0.012	-0.047
3	-0.126		1.000	0.101	-0.023	0.056	0.098	-0.108	-0.013	-0.080	0.069	0.089	0.027	0.086	-0.045	-0.009	0.077	-0.054	-0.003	0.020	0.009	-0.050
4	0.039			1.000	0.079	-0.046	0.029	-0.104	0.069	-0.106	-0.198	-0.102	-0.158	-0.032	-0.311	-0.236	-0.201	-0.006	0.089	0.220	-0.054	0.121
5	0.053				1.000	-0.406	0.169	0.005	-0.027	0.158	-0.051	0.262	0.197	-0.84**	-0.064	-0.065	-0.081	-0.019	-0.071	-0.170	-0.024	-0.082
6	-0.231					1.000	-0.146	-0.103	0.004	-0.099	0.048	-0.151	-0.234	0.007	-0.033	0.054	-0.226	-0.121	0.129	0.005	-0.072	0.074
7	0.157						1.000	0.055	0.035	0.075	0.095	0.236	0.213	0.132	-0.050	0.104	0.155	0.083	0.148	0.047	0.150	-0.012
8	-0.056							1.000	0.039	-0.042	0.072	0.104	-0.001	0.010	0.005	0.069	0.142	0.236	0.101	-0.023	0.115	-0.030
9	-0.214								1.000	0.249	0.301	0.097	-0.046	0.006	-0.088	-0.051	-0.105	-0.038	-0.146	-0.042	-0.124	-0.016
10	0.172									1.000	0.515	0.408	0.007	-0.155	0.008	0.160	-0.123	-0.032	-0.071	-0.181	0.020	0.027
11	0.008										1.000	0.344	0.117	0.155	0.103	0.160	0.102	0.018	0.065	-0.209	0.135	-0.057
12	-0.029											1.000	-0.013	0.083	-0.143	0.085	0.020	0.062	0.010	0.057	0.217	-0.046
13	0.058												1.000	0.255	0.142	0.018	0.197	0.140	0.141	-0.055	0.273	-0.247
14	-0.031													1.000	0.267	0.120	0.135	-0.021	-0.043	0.054	0.140	-0.195
15	0.046												1.000	0.518	0.042	0.064	0.027	-0.058	0.111	-0.075		
16	0.005													1.000	-0.051	0.078	0.040	-0.028	0.062	-0.159		
17	0.092														1.000	0.411	0.217	0.085	0.231	0.097		
18	0.125															1.000	0.474	0.169	0.364	-0.026		
19	0.229																1.000	0.176	0.394	-0.001		
20	-0.020																	1.000	0.180	-0.016		
21	0.226																		1.000	0.023		
22	-0.092																			1.000		

*, ** Significant at 5% and 1% propability, respectively.

I
1. Protein percent
2 Grain weight per plant
3 *Length of panicle*
4 Spikelet number per panicle
5 Grain weight per spikelet
6 *Days to 50% flowering*
7 Length of spikelet
8 Width of spikelet

II
9 Length of first leaf blade
10 Length of second leaf blade
11 Length of third leaf blade
12 Length of fourth leaf blade
13 Length of first leaf sheath
14 Length of second leaf sheath
15 Length of third leaf sheath
16 Length of fourth leaf sheath

III
17 Length of firstt internode
18 Length of second internode
19 Length of third internode
20 Length of fourth internode
21 Length of fifth internode
22 Leaf angle in degrees.

Table 15: Phenotypic correlation coefficients between 22 characters in sorghum plant types combined over three (3) years, 1989, 1990 and 1991.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	1.000	-0.056	0.065	-0.104	0.021	-0.023	0.197	-0.060	-0.110	0.027	-0.024	-0.004	-0.040	-0.056	-0.046	-0.037	0.062	0.008	0.040	-0.023	0.004	0 071
2	-0.056	1.000	0.068	0.260	0.328	0.023	0.068	0.064	0.096	0.092	-0.001	-0.015	-0 076	-0.097	-0.088	-0.057	-0.28	-0.030	-0.023	-0.058	-0 065	-0 004
3	0.065		1.000	0 067	-0.092	-0.146	0.441	0.038	0.008	0.057	0.174	0.174	0.225	0.235	0.208	0.223	0.191	0.198	0.212	0.209	0.219	-0 208
4	-0.104			1.000	-0.083	-0.042	-0.155	0.068	0.130	-0.002	-0.004	-0.035	-0.036	-0.015	-0.076	-0.101	-0.184	-0.200	-0.115	-0 158	-0.199	-0 202
5	0.021				1.000	0.183	0.155	0.064	-0.033	0.140	0.035	0.101	-0.161	-0.235	-0.228	-0.154	-0.052	0.001	0.018	-0.011	-0.005	0.298
6	-0.023					1.000	0.068	-0.006	0.331	0.226	0.040	-0.161	-0.733**	-0.474	-0.380	-0.127	-0.187	-0.140	-0.045	-0.146	-0.097	0 115
7	0.197						1.000	0.068	0.050	0.175	0.118	0.144	0.026	0.085	0.073	0.207	0.218	0.290	0.261	0.205	0 273	0.039
8	-0.060							1.000	0.097	0.138	0.038	0.089	-0.029	-0.004	-0.022	-0.011	0.015	0.052	0.009	-0.052	-0.040	-0.031
9	-0.119								1.000	0.566	0.279	-0.003	-0.344	-0.103	-0.025	0.105	-0.132	-0.112	-0.107	-0.092	-0.083	-0.260
10	0.027									1.000	0.501	0.334	-0.219	-0.083	0.020	0.107	0.017	0.064	0.065	0.033	0.056	-0.005
11	-0.024										1.000	0.481	0.060	0.125	0.109	0.096	0.050	0.042	0.084	0.066	0.112	0.039
12	-0.004											1.000	0.240	0.196	0.155	0.098	0.168	0.252	0.201	0.197	0.203	0.146
13	-0.040												1.000	0.689*	0.577	0.305	0.293	0.289	0.277	0.289	0.318	-0.135
14	-0.056												1.000	0.784**	0.568	0.252	0.258	0.330	0.367	0.363	-0.257	
15	-0.046													1.000	0.716**	0.212	0.247	0.294	0.302	0.349	-0.215	
16	-0.037														1.000	0.153	0.206	0.266	0.303	0.336	-0 180	
17	0.062															1.000	0.624*	0.485	0.454	0.373	0.037	
18	0.008																1.000	0.673*	0.581	0.536	0.079	
19	0.040																	1.000	0.652*	0.628*	0.074	
20	0.023																		1.000	0.634*	0.023	
21	0.004																			1.000	0.041	
22	0.070																				1.000	

*, ** Significant at 5% and 1% propability, respectively.

I
1. Protein percent
2 Grain weight per plant
3 Length of panicle
4 Spikelet number per panicle
5 Grain weight per spikelet
6 Days to 50% flowering
7 Length of spikelet
8 Width of spikelet

II
9 Length of first leaf blade
10 Length of second leaf blade
11 Length of third leaf blade
12 Length of fourth leaf blade
13 Length of first leaf sheath
14 Length of second leaf sheath
15 Length of third leaf sheath
16 Length of fourth leaf sheath

III
17 Length of firstt internode
18 Length of second internode
19 Length of third internode
20 Length of fourth internode
21 Length of fifth internode
22 Leaf angle in degrees.

High and significant (p=0.05) correlations were found between length of first and second leaf sheaths (r=0.689), length of first internode and second internode (r=0.624), length of third internode and second internode (r=0.673), lengths of fourth and fifth internodes with third internode (r=0.652, r=0.628), length of fifth internode and fourth internode (r=0.634). Highly significant (p=0.01) correlations were found between length of third leaf sheath and second leaf sheath (r=0.784), length of fourth leaf sheath and third leaf sheath (r=0.716) and highly significant but negative correlation was found between length of first leaf sheath and width of spikelet (r=-0.733) when combined data (1989, 1990, and 1991) were used in the estimates of correlation coefficients.

In general most of the correlations were positive and significant between the leaf characters and those of the stem characters, while there were significant correlations between length of leaf sheaths with those of the length of internodes. There were low and in some cases negative correlations between leaf and stem characters with those of the panicle.

4.4 Principal Components Extracted from the Correlation Matrix in Year 1 (1989)

The principal components (factors) extracted from the correlation matrix in 1989 using the maximum eigen value criterion are given in Table 16. The first factor (F1) is a bipolar factor since it contains both positive and negative loadings on the variables (tests) it is also a general factor since more than half of the tests load significantly. Length of spikelet, length of

Table 16: Principal component (F) for the year 1989.

Tests	F1	F2	F3	F4	F5	F6	C^2
Protein content (%)	0.186	0.109	-0.110	0.004	0.262	0.789	0.672
Grain weight/plant	-0.08	0.281	0.635	0.379	-0.262	-0.004	0.704
Length of panicle	-0.386	0.533	0.374	0.046	0.311	0.125	0.687
Spikelet no./panicle	-0.299	0.085	0.243	0.062	-0.028	-0.189	0.192
Grain weight/spikelet	0.011	0.391	0.432	0.501	-0.104	-0.110	0.913
Days of 50% flowering	0.129	0.307	-0.220	0.240	0.536	-0.434	0.642
Length of spikelet	0.459	0.455	0.405	0.005	0.168	0.198	0.649
Width of spikelet	-0.031	-0.090	0.424	-0.151	-0.448	-0.136	0.431
Length of first leaf blade	-0.002	-0.460	0.346	-0.324	0.137	0.158	0.480
Length of second leaf blade	0.305	-0.250	0.4467	-0.527	-0.011	0.115	0.664
Length of third leaf blade	0.298	-0.187	0.273	-0.204	0.556	-0.334	0.661
Length of fourth leaf blade	0.579	-0.236	0.316	-0.410	0.073	-0.151	0.686
Length of first leaf sheath	0.707	-0.260	0.018	0.254	0.053	0.053	0.649
Length of second leaf sheath	0.698	-0.402	0.001	0.365	-0.063	0.107	0.800
Length of third leaf sheath	0.671	-0.471	0.036	0.392	-0.037	0.128	0.843
Length of fourth leaf sheath	0.594	0.439	0.040	0.417	0.042	0.101	0.733
Length of first internode	0.563	0.553	-0.224	-0.285	-.223	0.105	0.634
Length of second internode	0.749	0.308	-0.147	-0.253	-0.219	-0.034	0.791
Length of third internode	0.826	0.245	-0.203	-0.062	10.165	-0.031	0.816
Length of fourth internode	0.810	0.257	-0.205	-0.104	-0.091	-0.058	0.786
Length of fifth internode	0.846	0.135	-0.099	-0.015	0.062	-0.071	0.753
Leaf angle in degrees	-0.039	0.253	0.086	-0.027	0.277	0.285	0.310
Eigen value	5.746	2.243	1.879	1.7589	1.3185	1.1683	=14.114
% Variance	26.12	10.19	8.53	7.99	5.99	5.31	=64.15

*C^2 = Communality.

third and fourth leaf blades, lengths of first, second, third and fourth leaf sheaths and lengths of first, second, third, fourth and fifth internodes have significant loadings (SELd<0.417). All other characters (mostly panicle characters) have low non-significant loadings (SELd > 0.417), with five (5) of them being negative. The value 0.417 is actually the level of significant of the standard error of the loading (SELd).

In the second factor (F2), four characters gave significant loadings, these include length of panicle length of spikelet and length of fourth leaf sheath and length of first internode. This factor is a group factor since only a few tests grouped together have significant loadings. The remaining characters are non- significant with eight (8) being negative, so it is also a bipolar factor. In order to see if these variables played any significant role in contributing to yield of the plant the communality (C^2) that is, the sum of squares of the loadings, were computed using the principal component analysis method. This is because extracting the common variance makes it necessary that the communalities be less than 1. The factor loading for test 1 when squared and added gives the following: $(0.186)^2 + (0.109)^2 + (-0.110)^2 + (0.004)^2 + (0.262)^2 + (0.789)^2 = 0.672$. Therefore, the unique variance which is the difference between the total variance and the cummunalities is equal to 1 - 0.672=0.328. This figure of 0.328 indicates the amount of unreliability of the tests, and by implication therefore suggests that the test for this character is reliable. The communality for test 1 through test 22 are high except for tests 4,8,9 and 22 indicating that the tests for these characters were highly reliable. The latent root (eigen value) given at the bottom of each factor is the extracted variance. The value decreases in each of the subsequent factors, because as suggested earlier, the factor procedure extracts the maximum possible variance for each factor in turn. Also the sum of the latent roots is

identical to the sum of the comunalities. For the twenty (22) tests each having a total variance of 1 the maximum possible variance is 22. The actual variance extracted from factor 1 is 5.746. This figure can be expressed in form of percentage variance.

For example, the percentage variance is 26.12% for factor 1. The percentage variance decreases with subsequent factors, and the higher the percentage variance the more substantial could we claim that the terms with significant loading have some property in common. The total extrated percentage variance for the first 6 factors is 64.15%. This is the variance attributable to interelatedness of the variables. For this study, the Kaisers (1960) criterion was used for the number of factors to be retained and the Burt-Banks (1947) criterion for the level of significance of a factor was used. Factor three (F3), has significant loadings on grain weight per spikelet, length and width of spikelet, grain weight/panicle and length of first leaf blade. The rest of the characters have negative values. The fourth (F4) factor has significant loadings on grain weight per spikelet and length of fourth leaf sheath. Other characters have non-significant loadings with eleven (11) being negative.

The fifth factor (F5) has significant loadings on days to 50% flowering and length of third leaf blade. Eleven characters have negetive loadings while the rest are non-significant.

The last factor is the sixth (F6) which has a eigen value equal to or greater than one (1) using Kaiser's (1967) criterion. There was significant loading only on percentage protein. All other characters have non-significant loadings, with eleven (11) of them giving negative values. This factor is a case of a unique factor since only one tests loads significantly on it.

The total eigen values (latent roots) is 14.40, this gives a variance of 64.15 percent. The communalities (C^2) which are the sum of squares of all the loadings of a test (variable) across

the factors ranged from 0.192 for spikelet number/panicle to 0.913 for grain weight per spikelet. The variances accounted for by each factor are given below their eigen values. In general, all the factors are bipolar with the first being a general factor while the last (F6) is a unique factor.

4.5 Principal Components Extracted From the Correlation Matrix in Year II (1990)

Table 17 shows that six factors have also been retained by the minimum eigen value criterion similar to that of 1989. The first factor (F1) has significant loadings on length of panicle, length of spikelet, lengths of first, second, third and fourth leaf sheaths, and lengths of first, second, third, fourth and fifth internodes. Other characters are non-significant with three of them being negative. In the second factor (F2) spikelet number

Table 17: Principal component (F) for the year 1990.

Tests	F1	F2	F3	F4	F5	F6	C^2
Prtein percent (%)	0.238	-0.211	-0.232	0.561	0.029	-0.209	0.541
Grain weight/plant	-0.029	0.376	0.499	-0.076	0.173	0.188	0.462
Length of panicle	0.392	0.059	-0.242	0.591	0.208	0.105	0.892
Spikelet No./panicle	-0.338	0.437	-0.033	-0.192	0.402	0.334	0.616
Grain weight/spikelet	0.072	0.399	0.430	0.075	0.012	0.071	0.360
Days of 50% flowering	-0.272	0.018	0.095	-0.019	0.099	0.547	0.393
Length of spikelet	0.588	-0.122	-0.185	0.437	0.251	-0.086	0.657
Width of spikelet	0.084	0.296	0.030	0.172	0.533	0.167	0.515
Length of first leaf blade	0.181	0.661	-0.120	-0.231	0.201	-0.461	0.790
Length of second leaf blade	0.412	0.753	-0.030	-0.051	0.053	-0.268	0.816
Length of third leaf blade	0.353	0.756	-0.189	0.074	0.315	-0.048	0.839
Length of fourth leaf blade	0.276	0.572	-0.323	0.284	-0.337	0.257	0.767
Length of first leaf sheath	0.771	-0.015	-0.124	-0.061	0.105	0.196	0.664
Length of second leaf sheath	0.725	-0.088	-0.302	-0.446	0.093	0.088	0.924
Length of third leaf sheath	0.705	0.109	-0.375	-0.469	0.049	0.056	0.875
Length of fourth leaf sheath	0.709	-0.194	0.250	-0.441	0.131	0.041	0.789
Length of first leaf internode	0.711	-0.123	0.310	0.177	0.098	0.065	0.661
Length of second leaf internode	0.710	0.148	0.338	0.138	0.016	0.064	0.663
Length of third leaf internode	0.631	-0.058	0.384	0.059	0.030	0.233	0.607
Length of fourth leaf internode	0.617	-0.086	0.434	-0.092	-0.203	-0.164	0.653
Length of fifth leaf internode	0.544	-0.220	-0.409	-0.036	-0.105	-0.119	0.538
Leaf angle in degrees	0.255	0.148	-0.024	-0.002	-0.716	0.313	0.889
Eigen value	5.517	2.720	1.769	1.739	1.464	1.146	=14.357
% Variance	25.08	12.37	8.04	7.91	6.66	5.21	=65.26
Common var.	38.42	18.95	12.32	12.11	10.197	7.98	99.77

*C^2 = Communality.

per panicle, lengths of first, second, third and fourth leaf blades load significantly, all other characters are non- significant with nine (9) of them having negative values. The third factor (F3) has significant loadings on grain weight per panicle, grain weight per spikelet, length of fourth and fifth internode. The rest of the characters were not significant with thirteen (13) having negative loadings.

In the fourth factor (F4), percentage protein,length of spikelet, and length of panicle have significant loadings, while the other characters are non-significant with twelve being negative.

In the fifth factor (F5), spikelet number/panicle, width of spikelet gave significant loadings, while all the other characters were non-significant with five (5) of them having negative values. In the sixth factor (F6), significant loading is given by only days to 50% flowering which signifies a case of a unique factor, similar to that of the first year (1989). The total eigenvalue is 14.36, which accounts for a total variance of 65.26 percent which is higher than that obtained in 1989. The communalities (C^2) ranged from 0.36 for grain weight/spikelet to 0.92 for length of second leaf sheath. The variances accounted for by the individual factors are given below their eigen values. Generally all the factors are bipolar with the first one being a general factor while the others are group factors with the sixth factor being a unique one. These results are similar to those of 1989.

4.6 Principal Components Extracted From the Correlation Matrix in the Third Year III (1991)

In 1991, nine principal components were retained by the minimum eigen value criterion, that is, three factors higher than that of the first two years, (1989 and 1990). The first factor (F1) has significant loadings on six characters, these include length of spikelet, length of first

leaf sheath, lengths of first, second, third and fifth internodes. This becomes a group factor as opposed to general factors in the two previous years. The other characters have non-significant loadings, with six of them being negative. In the second factor (F2), length of first, second, third and fourth leaf blades gave significant loadings, while the remaining characters are non-significant, with eleven (11) having negative loadings. The third factor (F3) has grain weight per panicle, spikelet number per panicle and spikelet number per panicle loading significantly, the other characters had non-significant loadings with six having negetive values, this is similar to the first factor (F1). Factor four (F4) has significant loading on only one character, days to 50% flowering, this is another case of a unique factor, all the other characters show non-significant loadings, out of which six (6) were negative. The fifth factor (F5) loads significantly on length of panicle and length of second leaf sheath, all other characters have non-significant loadings with nine (9) being negative.

In the sixth factor (F6) two of the characters gave significant loadings. The rest of the characters were not significant with twelve (12) of them being negative.

Table 18: Principal components (F) for the year 1991.

Traits	F1	F2	F3	F4	F5	F6	F7	F8	F9	C^2
Protein percent(%)	0.344	-0.123	0.214	0.131	-0.305	-0.306	-0.327	0.116	-0.183	0.531
Grain weight/plant	-0.012	-0.101	0.607	-0.231	0.029	-0.152	0.416	0.237	0.277	0.753
Length of panicle	-0.040	0.031	0.056	0.016	0.613	-0.099	0.015	-0.074	0.510	0.658
Spikelet No./panicle	-0.280	-0.301	0.529	0.118	0.312	-0.260	0.211	0.181	-0.002	0.705
Grain weight/spikelet	0.140	0.265	0.605	-0.366	-0.052	0.073	-0.012	-0.164	-0.002	0.624
Days of 50% flowering	-0.823	-0.084	-0.544	0.405	0.169	-0.213	-0.079	0.088	0.020	0.660
Length of spikelet	0.418	0.071	0.233	0.022	0.282	-0.007	-0.184	-0.318	0.040	0.451
Width of sopikelet	0.277	-0.035	-0.008	0.141	-0.216	0.417	0.461	-0.084	-0.128	0.708
Length of first leaf blade	-0.093	0.425	0.075	0.351	0.182	0.263	0.236	0.392	-0.143	0.651
Length of second leaf blade	0.208	0.592	0.173	0.301	-0.217	-0.282	-0.075	0.058	-0.061	0.653
Length of third leaf blade	0.379	0.603	-0.117	0.370	0.082	-0.018	-0.049	0.283	0.144	0.743
Length of fourth leaf blade	0.364	0.451	0.276	0.326	0.178	0.003	0.027	-0.442	-0.126	0.762
Length of first leaf sheath	0.516	0.019	0.040	-0.381	0.221	0.218	-0.267	0.283	0.006	0.660
Length of second leaf sheath	0.319	0.016	-0.326	-0.207	0.539	0.152	-0.089	0.035	-0.086	0.573
Length of third leaf sheath	0.313	0.123	-0.530	-0.417	-0.101	-0.224	0.259	0.006	0.199	0.734
Length of fourth leaf sheath	0.292	0.294	-0.430	-0.225	-0.040	-0.351	0.451	-0.223	0.061	0.790
Length of first leaf internode	0.519	-0.301	-0.033	0.080	-0.178	0.430	-0.114	-0.017	0.241	0.655
Length of second leaf internode	0.579	-0.383	0.063	0.224	-0.170	0.056	0.293	0.146	0.047	0.677
Length of third leaf internode	0.489	-0.456	0.005	0.309	0.024	-0.255	-0.032	0.230	0.027	0.663
Length of fourth leaf internode	0.078	-0.459	0.028	0.210	0.312	-0.121	0.232	-0.291	-0.386	0.661
Length of fifth leaf internode	0.641	-0.240	0.012	0.190	0.062	0.170	-0.061	-0.032	0.032	0.543
Leaf angle in degree	-0.202	-0.142	0.067	0.397	-0.295	0.035	-0.108	-0.279	0.540	0.690
Eigen value	2.753	2.253	2.121	1.661	1.443	1.275	1.171	1.052	1.002	=14.731
Total var.	12.51	10.24	9.64	7.55	6.56	5.79	5.32	4.78	4.58	=66.96%
Common var.	18.688	15.29	14.398	11.27	9.79	8.65	7.949	7.14	6.80	=99.975

*C^2 = Communality.

For the seventh factor (F7) grain weight per panicle, width of spikelet and length of fourth leaf sheath gave significant loadings, while the remaining characters were non-significant and twelve out of these had negative values. The eighth factor (F8), does not give any significant loading. We apply the rule by changing the signs of the all loadings within the factor. With the change in signs, there was only one character that loaded significantly, which is length of fourth leaf blade. This also becomes a unique factor.

In the last factor, factor nine (F9), length of panicle and leaf angle had significant loadings. The remaining characters had non-significant loadings, with nine (9) having negative values.

The total eigen values is 14.73, which accounts for a total variance of 66.96%. The cummunalities (C^2) ranged from 0.45 for length of spikelet to 0.79 for length of fourth leaf sheath, again the variances accounted for by the individual factors are given below their respective eigen values. Generally, all the factors are bipolar, except factor eight (F8) which is a unique factor. The factor are also group factors with none being general.

4.7 Principal Components Extracted From the Combine Correlation Matrix for the Three Years Data (1989, 1990, and 1991)

Table 19 shows the principal component matrix of the predictor variables of twenty (22) agronomic characters in sorghum for the three years combined (1989, 1990 and 1991). The communalities (C^2) that is the sums of squares of the loading, did not reach unity for

Table 19: Principal components (F) for the combined three (3) years data.

Test	F1	F2	F3	F4	F5	F6	F7	C^2
Protein percent (%)	0.017	0.087	0.195	0.020	-0.011	0.688	-0.029	0.521
Grain weight/plant	-0.112	0.191	0.096	0.315	0.644	-0.216	0.332	0.729
Length of panicle	0.142	0.121	0.219	0.046	0.423	0.451	-0.192	0.654
Spikelet No./panicle	-0.194	-0.152	0.356	0.175	0.488	-0.351	-0.241	0.578
Grain weight/spikelet	-0.161	0.434	-0.247	0.380	0.184	-0.083	0.520	0.730
Days of 50% flowering	-0.453	0.551	-0.022	-0.464	-0.031	0.051	0.125	0.742
Length of spikelet	0.333	0.442	-0.029	-0.046	0.309	-0.537	0.108	0.705
Width of spikelet	-0.005	0.157	0.162	0.183	0.200	-0.123	-0.200	0.179
Length of first leaf blade	-0.176	0.429	0.639	-0.322	-0.000	-0.133	-0.034	0.750
Length of second leaf blade	0.022	0.669	0.500	0.052	-0.188	-0.026	-0.020	0.738
Length of third leaf blade	0.185	0.449	0.463	0.338	-0.345	+0.043	-0.127	0.703
Length of fourth leaf blade	0.364	0.347	0.181	0.565	-0.293	-0.004	-0.154	0.714
Length of first leaf sheath	0.691	-0.472	0.041	0.361	-0.019	+0.002	-0.008	0.833
Length of second leaf sheath	0.748	-0.363	0.299	0.040	0.047	-0.022	0.168	0.813
Length of third leaf sheath	0.710	-0.300	0.360	-0.075	-0.112	-0.003	0.323	0.846
Length of fourth leaf sheath	0.589	-0.078	0.374	-0.277	-0.057	+0.064	0.445	0.775
Length of first leaf internode	0.594	0.181	-0.292	-0.040	0.082	-0.069	-0.289	0.791
Length of second leaf internode	0.685	0.303	-0.323	-0.082	0.088	-0.170	-0.204	0.736
Length of third leaf internode	0.700	0.307	-0.270	-0.158	0.103	-0.200	-0.071	0.681
Length of fourth leaf internode	0.705	0.216	-0.231	-0.179	0.043	-0.220	-0.039	0.639
Length of fifth leaf internode	0.704	0.240	-0.186	-0.176	-0.002	-0.125	0.067	0.639
Leaf angle in degrees	-0.101	0.295	-0.526	0.333	-0.312	-0.037	0.235	0.620
Eigen value	4.963	2.608	2.204	1.488	1.384	1.264	1.105	=15.0154
Total var.	22.560	11.850	10.020	6.760	6.290	5.740	1.107	68.25
Common var	33.05	17.37	14.67	9.90	9.22	8.22	7.36	=100.00

*C^2 = Communality.

any of the 22 tests (variables). This is because extracting the common variance makes it necessary that the communalities be less than 1. The factor loading for test 1 when squared and added gives the following $(0.017)^2 + (0.087)^2 + (0.195)^2 + (0.020)^2 + (-0.011)^2 + (0.688)^2 + (-0.029)^2 = 0.521$.

Therefore the unique variance which consists of the specific and error variances is 1.0 - 0.521 = 0.479. This figure of 0.479 indicates that the unreliability of the test is lower than 0.479. In actual sense the unreliability of the test is given by unique variance - specific variance = error variance. Thus error variance is less than 0.479 which is low indicating that the test is reliable. In this analysis all the tests are reliable except test 8 (C^2=0.179), because their communalities are above 0.5 and subsequently their unique variances will be less than 0.50 and so their error variances will be less than 0.40.

The latent root (eigen value) given at the bottom of each factor is the extracted variance. The value decreases in each of the subsequent factors, because as suggested earlier the factor procedure extracts the maximum possible variance for each factor in turn. Also, the sum of the latent roots is identical to the sum of the communalities. For the 22 tests each having a total variance of 1.00 makes the maximum possible variance of 22. The total variance extracted from factor 1 is 4.963. For example, the percentage variance for factor 1 is 22.56%. The percentage variance decreases with each subsequent factor, and the higher the percentage variance the more substaincial the claim that the characters with significant loadings have some property in common. The total extracted percentage variance for the first 7 factors is 68.25%. This is the variance attributable to interrelatedness of the variables.

In factor 1, the variables that had significant loadings are 13, 14, 15, 16, 17, 18, 19, 20,

and 21 with the following corresponding variances (0.691, 0.748, 0.710, 0.589, 0.594, 0.685, 0.700, 0.705 and 0.704), respectively. In factor 2 the characters with significant loadings included 5,6,7,9,10,11,12,18 and 19 and the corresponding variances are 0.434, 0.551, 0.442, 0.429, 0.669, 0.449, 0.347, 0.303 and 0.307, respectively. Factor 3 had chracters of 4,9,10,11,15 and 16 with significant loadings. In factor 4, six tests had significant loadings which include 2,5,11,12,13 and 22. In factor 5, four tests have significant loadings, these are 2,3,4 and 7. Factor 6 had significant loading on tests 1, and 3 while factor 7 had significant loadings on tests 2,5,15 and 16.

Total eigen values is 15.05, this accounts for 68.25% of the total variance. This gives the highest value so far. The communalities ranged from 0.179 for width of spikelet to 0.846 for length of third leaf sheath. This gives the highest ranged within the communalities. The variances for the individual factors are given below their individual eigen values.

In general all the factors in both the individual years as well as for the three years combined are bipolar and also tend to be group factors, except in a few cases where we had unique factors although the groupings were not clearly defined.

4.8 Rotated Factors Pattern Structure (Varimax = Variance Maximum).

Rotation refers to a further analysis of the initial results obtained from the principal components, and provides clearer results which show the importance of the individual variables in contributing to the variance of a factor. In most cases this will give both negative as well as positive loadings as it is found in bipolar factors. Only the factors extracted from the combined correlation matrix has been rotated. One important aspect of rotation is that it clearly

defines group factors. From Table 20, the first factor had significant loadings on characters that are closely related, and are grouped together, these characters include lengths of first, second, third, fourth and fifth internodes. All the other characters had low non-significant loadings, and are considered to contribute zero (0) loadings to the factor. In the second factor (F2), lengths of first, second, third and fourth leaf sheaths contribute significant loadings (taken as 1), which are also group together within the factor, while all the other characters had non-significant loadings. In factor three (F3), days to 50% flowering, lengths of first and second leaf blades had significant loadings, but here only the last two characters were grouped together. In the fourth factor (F4), lengths of second, third and fourth leaf blades contributed significant loadings, they were also grouped together. In the fifth

Table 20: Rotated factors (components) for the combined correlation matrix.

Test	F1	F2	F3	F4	F5	F6	F7	C^2
Protein Percent(%)	-0.082	-0.133	-0.086	-0.013	-0.298	-0.054	-0.631	-0.521
Grain weight/plant	-0.045	0.032	0.047	-0.077	0.507	0.677	0.045	0.729
Length of panicle	0.200	0.189	-0.099	0.103	0.336	-0.090	0.661	0.654
Spikelet No./panicle	-0.187	-0.055	-0.046	-0.040	0.725	0.001	-0.104	0.578
Grain weight/spikelet	-0.004	-0.144	0.083	0.092	-0.095	0.827	0.035	0.730
Days to 50% flowering	-0.040	-0.249	0.802	-0.058	-0.143	0.113	-0.012	0.744
Length of spikelet	0.273	0.109	0.147	0.089	-0.022	0.200	0.741	0.705
Width of spikelet	0.054	-0.111	0.007	0.192	0.352	0.049	0.007	0.178
Length of first leaf blade	-0.119	0.175	0.707	0.314	0.291	-0.128	0.046	0.746
Length of second leaf blade	0.031	0.079	0.494	0.685	0.096	0.066	0.069	0.737
Length of third leaf blade	0.010	0.097	0.087	0.825	+0.029	-0.026	0.055	0.702
Length of fourth leaf blade	0.196	0.010	-0.256	0.774	-0.007	+0.095	0.041	0.714
Length of first leaf sheath	0.237	0.454	-0.742	0.094	0.063	-0.090	0.004	0.833
Length of second leaf sheath	0.244	0.755	-0.391	0.090	+0.051	-0.142	0.001	0.813
Length of third leaf sheath	0.190	0.859	-0.230	0.083	-0.047	-0.100	-0.006	0.846
Length of fourth leaf sheath	0.179	0.845	0.091	0.030	-0.100	-0.014	0.098	0.775
Length of first leaf inrternode	0.711	-0.030	-0.174	0.058	+0.016	-0.103	0.131	0.567
Length of second leaf internode	0.853	0.023	-0.090	0.080	-0.007	-0.003	0.081	0.750
Length of third leaf internode	0.840	0.146	-0.009	0.037	-0.023	0.052	0.059	0.736
Length of fourth leaf internode	0.793	0.217	-0.036	0.021	-0.051	0.008	-0.006	0.681
Length of fifth leaf internode	0.725	0.293	-0.005	0.055	-0.131	0.050	0.064	0.639
Leaf angle in degrees	0.100	-0.352	-0.115	0.164	-0.505	0.446	-0.108	0.639
Eigen value	3.505	2.717	2.327	1.987	1.576	1.490	1.462	=15.015
Total var.	15.93	12.35	10.58	9.04	6.94	6.77	6.65	=68.25
Common var	23.34	18.09	15.498	13.23	10.49	9.92	9.74	100.300

factor (F5), grain weight per panicle, length of panicle and spikelet number per panicle had been grouped together although length of panicle did not load significantly. In the sixth factor (F6), grain weight per panicle, length of panicle, spikelet number per panicle and grain weight per spikelet are grouped together, except for length of panicle and spikelet number per panicle, all the other characters had non-significant loadings. In factor seven (F7), percentage protein , length of panicle and length of spikelet were grouped together, they also had significant loadings. In the same group are found grain weight per panicle, spikelet number per panicle, grain weight per spikelet and days to 50% flowering which are all related, but the latter characters had non-significant loadings.

The total eigen value still remained the same with the rotation as 15.05 which also gives a total variance of 68.25%. The communalities also remain unchanged ranging from 0.178 for width of spikelet to 0.846 for length of third leaf sheath.

To reflect the relative importance of the first two components (factors) in explaining the correlation pattern of the characters, the vectors (test loadings) have been multiplied by the square roots of their eigen values and were plotted on a common scale (Smith and King, 1962). The graphical representation of factor in principal component analysis shades more light in the interpretation of the relationship between characters.

In Figure 1, (1989) percentage protein (1), grain weight per panicle (2), spikelet number per panicle (4), grain weight per

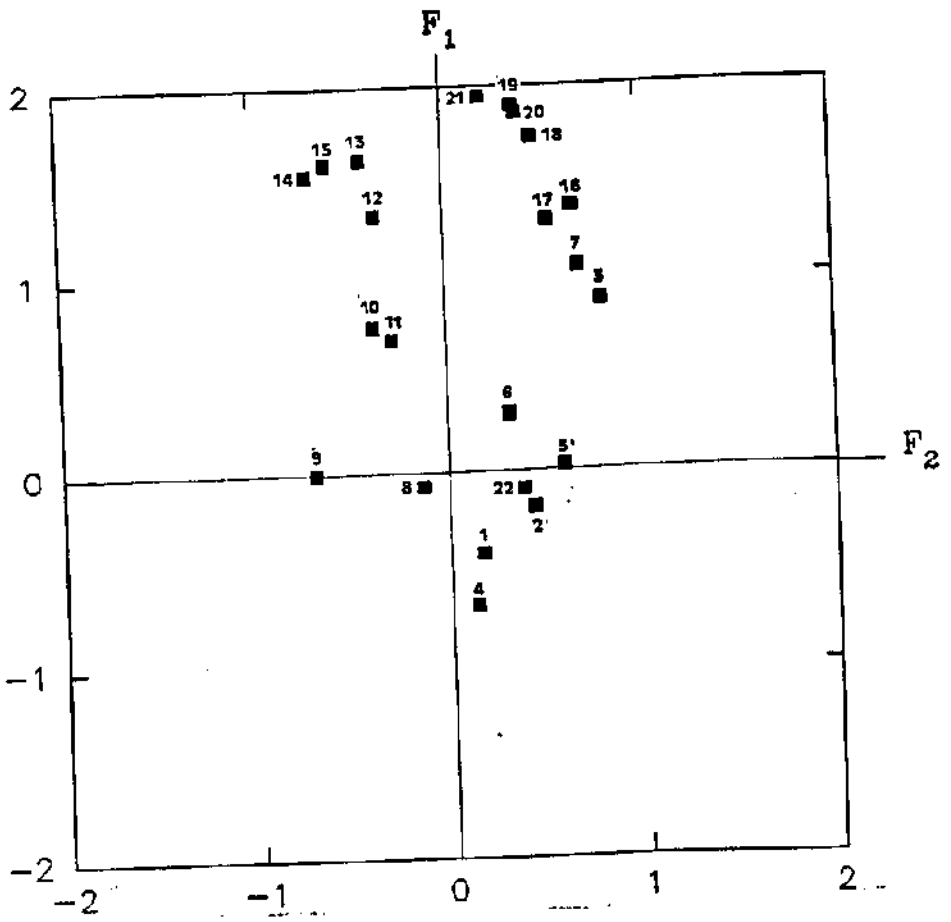


Figure 1: Internodes lengths and lengths of leaf sheaths (F1) versus lengths of panicle, spikelet and fourth leaf sheath and first internode (F2) using principal component analysis in 1989 in four quadrants (i, ii, iii and iv)

I
1. Protein percent
2 Grain weight per plant
3 Length of panicle
4 Spikelet number per panicle
5 Grain weight per spikelet
6 Days to 50% flowering
7 Length of spikelet
8 Width of spikelet

II
9 Length of first leaf blade
10 Length of second leaf blade
11 Length of third leaf blade
12 Length of fourth leaf blade
13 Length of first leaf sheath
14 Length of second leaf sheath
15 Length of third leaf sheath
16 Length of fourth leaf sheath

III
17 Length of first internode
18 Length of second internode
19 Length of third internode
20 Length of fourth internode
21 Length of fifth internode
22 Leaf angle in degrees.

spikelet (5), days to 50% flowering (6), width of spikelet (8), length of first leaf blade (9), and leaf angle (22) are clustered around the origin, this shows that they have low loadings on both the reference axes but negative on F1 (factors F1 and F2). Length of panicle (3), length of spikelet (7), length of fourth leaf sheath (16) and length of first internode (17), have high loadings on both the reference axes thus they are clustered together in quadrant I. Lengths of first, second, third and fourth leaf sheaths (12, 13, 14 and 15), are also clustered together in quadrant II, which is also indicative of their relatedness in origin. They all have high loadings on reference axes one (F1) and low negetive loadings on the reference axes two (F2). Lengths of second, third, fourth and fifth internodes (18, 19, 20 and 21) have high loadings on F1 and low in F2 axes, and so they are clustered together in quadrant I.

In Figure 2 (1990), grain weight per panicle (2), grain weight per spikelet (5), width of spikelet (8) and leaf angle (22) have low loadings on both the reference axes, while lengths of first, second, third and forth leaf blades (9, 10,11,12) have high loadings on both reference axes in quadrant I, thus they are clustered together. Length of first , second, third, and fourth leaf sheaths and length of first, second, third, forth and fifth internodes (13,14,15,16,17, 18, 19, 20, 21) load high on the first reference axes but low and negative loadings on the second axes in quadrant II. Spikelet number per panicle (4) seems to be alone in the cluster, having high loading on the F2, and high negative

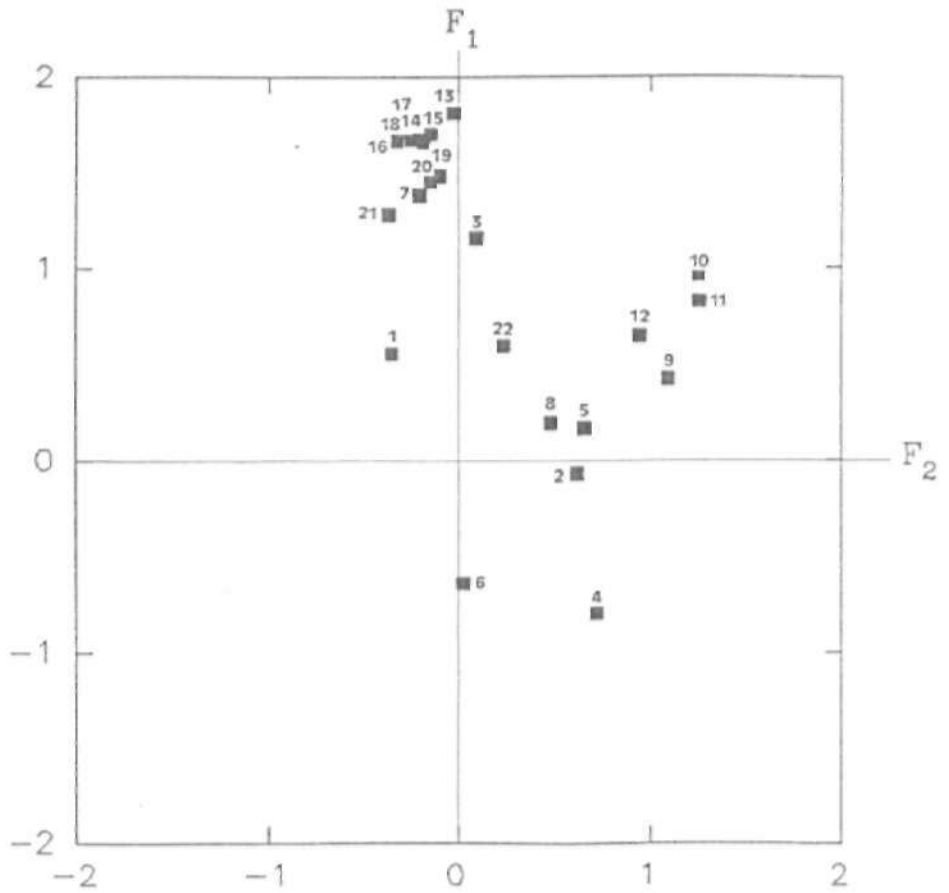


Figure 2: Internodes lengths (F1) versus leaf blade lengths (F2) using principal component analysis in 1990 in four quadrants (i, ii, iii and iv)

I

1. Protein percent
2. Grain weight per plant
3. Length of panicle
4. Spikelet number per panicle
5. Grain weight per spikelet
6. Days to 50% flowering
7. Length of spikelet
8. Width of spikelet

II

9. Length of first leaf blade
10. Length of second leaf blade
11. Length of third leaf blade
12. Length of fourth leaf blade
13. Length of first leaf sheath
14. Length of second leaf sheath
15. Length of third leaf sheath
16. Length of fourth leaf sheath

III

17. Length of firstt internode
18. Length of second internode
19. Length of third internode
20. Length of fourth internode
21. Length of fifth internode
22. Leaf angle in degrees

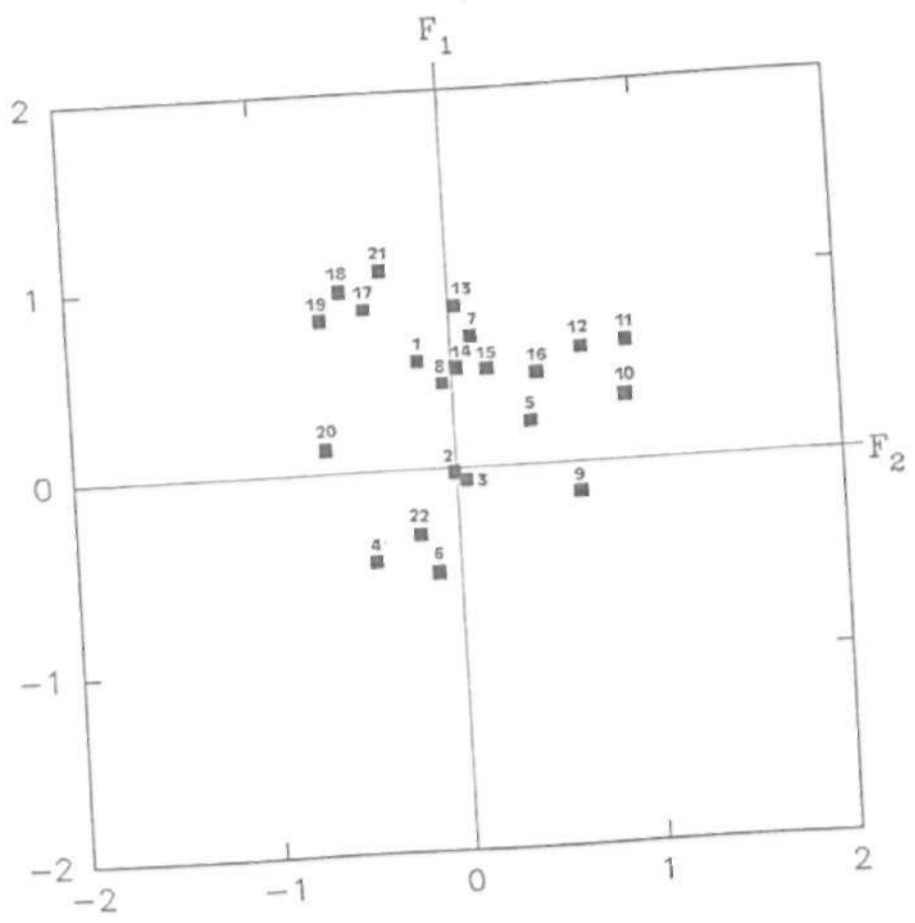


Figure 3: Internodes lengths (F1) versus leaf blade lengths (F2) using principal component analysis in 1991 in four quadrants (i, ii, iii and iv)

I
1. Protein percent
2. Grain weight per plant
3. Length of panicle
4. Spikelet number per panicle
5. Grain weight per spikelet
6. Days to 50% flowering
7. Length of spikelet
8. Width of spikelet

II
9. Length of first leaf blade
10. Length of second leaf blade
11. Length of third leaf blade
12. Length of fourth leaf blade
13. Length of first leaf sheath
14. Length of second leaf sheath
15. Length of third leaf sheath
16. Length of fourth leaf sheath

III
17. Length of firstt internode
18. Length of second internode
19. Length of third internode
20. Length of fourth internode
21. Length of fifth internode
22. Leaf angle in degrees.

loading on the F1 (quadrant III) length of panicle (3) has high loading on F1 and low negative loading on the F2 in quadrant I. Days to 50% flowering (6) loads negatively high on F1 and low in F2 in quadrant III.

Figure 3 (1991), shows that grain weight per panicle (2), spikelet number per panicle (4), grain weight per spikelet(5) and leaf angle (22) and days to 50% flowering (6) have low negative loadings on both the reference axes in quadrant IV, they are therefore clustered together around the origin of the axes. Lengths of second, third and fourth leaf blades (10, 11, 12) have high loadings on both reference axes and so they are found further away from the origin within the first quadrant. Length of spikelet (7), lengths of first, second and third leaf sheaths (13, 14, 15) load high on the first reference axes (F1), and low loadings on the second (F2) axes in quadrant I. Percentage protein (1) and lengths of first, second, third , forth and fifth internodes (17, 18, 19, 20, and 21) load high on reference axes one (F1) but negative loading in F2, thus they are found in the same cluster in the second quadrant.

The first two factors from the three years combined are represented in figure 4. Percentage protein (1), grain weight per panicle (2), grain weight per spikelet (5), width of spikelet (8), length of first leaf blade (9) and leaf angle (22) have low loadings on both the reference axes but negative in F1 so that they are clustered around the origin within the third quadrant. Length of spikelet (7), lengths of third and fourth leaf blades

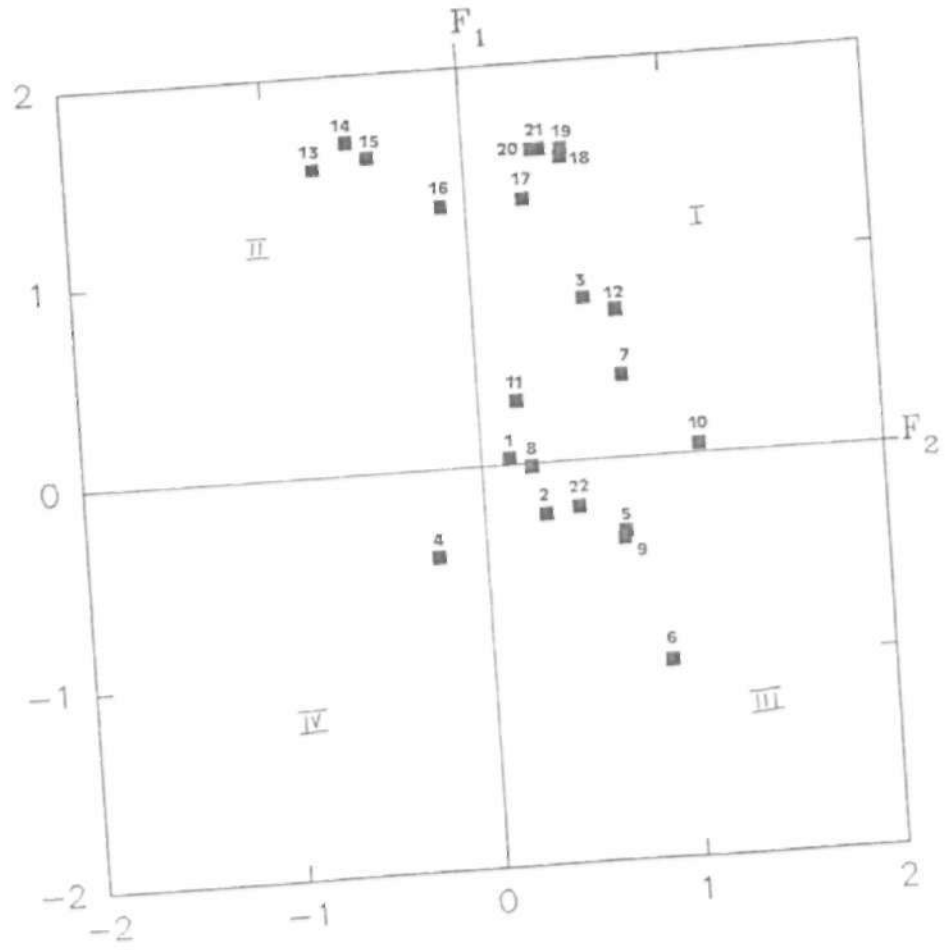


Figure 4: Internodes lengths (F1) versus leaf sheath lengths (F2) using principal component analysis in 1989 - 1991 in four quadrants (i, ii, iii and iv)

I
1. Protein percent
2. Grain weight per plant
3. Length of panicle
4. Spikelet number per panicle
5. Grain weight per spikelet
6. Days to 50% flowering
7. Length of spikelet
8. Width of spikelet

II
9. Length of first leaf blade
10. Length of second leaf blade
11. Length of third leaf blade
12. Length of fourth leaf blade
13. Length of first leaf sheath
14. Length of second leaf sheath
15. Length of third leaf sheath
16. Length of fourth leaf sheath

III
17. Length of firstt internode
18. Length of second internode
19. Length of third internode
20. Length of fourth internode
21. Length of fifth internode
22. Leaf angle in degrees

(11, 12) have high loadings on both reference axes, and so they are clustered together within the first quadrant. Lengths of first, second, third and fourth leaf sheaths (13, 14, 15, 16) have high loadings on F1, but moderately high negative loadings on F2, they are clustered together within the second quadrant. Lengths of first, second, third, fourth and fifth internodes (17, 18, 19, 20, 21) load high on factor one (F1), but low in F2 within quadrant I. This clustering of the characters gives some information on their relatedness, which also goes to explain the correlation between them.

CHAPTER FIVE

DISCUSSION

A genetic plant type may be defined as a genetically conditioned association of morphologic traits (Morishima *et al.*, 1967)[I], represented by a certain combination of leaf, stem (culm) and panicle characters. Growth type or shape is easily recognized, but difficult to measure. The present study attempts to investigate the genetic variation resulting from irradiation of a local variety of sorghum (S.K. 5912), using multivariate analysis, and to estimate correlations between their characters and their yielding potentials, and the extent to which such characters involved can be inherited.

From Table 4 of the mean performance of the characters, it was observed that there was less variation for panicle characters and more for the leaf and stem characters. A similar trend was also observed for the range in the coefficient of variability in the combined analysis, in which there was a range from 2.38% for days to flowering to 35.61% for grain weight per panicle. These low variability in the panicle characters is not encouraging since it forms the bases for any crop improvement programme which usually focuses on yield. The low variability will make it difficult for improvement in such characters.

The coefficients of variation in leaf blade characters were moderate, while the variations were more with the leaf sheaths and internode lengths. For the combined years data, the coefficient of variations for the leaf characters ranged from 9.85% for length of third leaf blade to 22.74% for length of fourth leaf sheath. Parra-Negrette *et al.*, (1984), observed a similar trend in character variation when they showed that phenotypic

variation due to irradiation was larger in variables related to plant maturity (Days to flowering) and plant height (panicle length, exertion, culm height) in sorghum. There is generally high coefficient of variations in stem (culm) characters, which could be useful in improving characters that are significantly and are positively correlated to them through indirect selection for the leaf and stem characters, since variability is the key to successful crop improvement.

Scossiroli *et al.,* (1960) Scossiroli and Polligrini-Scossiroli (1962) Gaul and Nittlestenscheid (1961), Gaul (1964), and Swaminathan (1961) and Borojevic (1963 and 1965), studied changes in quantitative characters in wheat, after mutagenic treatment found that, the treatment decreased the mean value of the characters but increased the variability of the quantitative characters in M_2 and M_3 generations this might be indicating that quantitative characters are induced much more than qualitative triats. In general, Days to 50% flowering had the lowest coefficient of variations while grain weight per spikelet had the highest, this could be selected for in order to improve yield. Panicle and leaf characters showed low ranges of phenotypic variation (Parra-Negrette *et al.*, 1984) while there were high phenotypic variations in stem characters.

Rawlings *et al.*, (1958), observed a significant increase in variability in soyabean yield in the M_2 generation of the varieties, Adams and Hawkeye, treated with x-rays and thermal neutrons, but the increased variance was largely in the negative direction. Although, the same plant specie was used in this study, as Parra-Negrette *et al.* (1984), the dossage of the irradiation differed, and so the effects will also differ which could result in an uncomparable variation. Wright (1994) a member of the Medical Research

Council Team in Britain working on experiments using different doses and sources of radiations, found that the effects resulting from alpha irradiation are different from those from gamma-ray irradiation. Also effects at different dosses of the same radiation material have different effects on similar cells exposed to them. This means that it is not possible to extrapolate the effects of one type or level of radiation from the effects of another, in whichever living tissue the irradiation is applied.

5.1 Analysis of Variance

The result of the analysis of variance for the individual years as well as for the three years combined are presented in Tables 5 and 6. From Table 5, the result shows highly significant (P=0.01) year effects for all the characters except for grain weight per spikelet and width of spikelet. This indicates that year to year differences influence the behaviour of the characters in addition to the genetypic differences within the same year. The effect of yearly difference is important in relation to the selection method that might be adopted, in chosing the best performers. The percentage scoring of the plant for any particular character will depend partly on the year to which it is selected, therefore the mean value of the year must also be taken into consideration.

The result of the analysis of variance for the three years combined (Table 6), shows that there is highly significant (P=0.01) mean squares for years for all the characters except for grain weight per spikelet and width of spikelet. The variances due to genotype x year interactions were significantly large, this is similar to the findings of Morishima *et al.* (1967)(II), indicating that the plants response to the growing seasons is genetically controlled. They concluded that selection for seasonal adptability and for high yielding

capacity may be made simultaneously within a season.

5.2 Variance Components

Table 7,8,9 and 10 give the variance components of the individual years as well as for the three years combined. Variance components in the individual years showed that genotypic variance (σg^2), phenotypic variance ($\sigma^2 ph$), and error variance ($\sigma^2 e$) were high for all traits except for grain weight per panicle and spikelet number per panicle. This shows that the characters are influenced by changes in years and could respond to improvement methods whereas all the other characters might be stabilizing from M_4 generation because of genetic diversity, either in heterozygotes or in mixtures of different genotypes often leads to stability under varying environmental conditions (Allard and Bradshow, 1964) or that the mean square for the interaction (M_{gy}) was almost equal to the error mean square (M_e) which seems to be true in this study. The genotypic variance ($\sigma^2 g$) from the combined data analysis shows that it is high for all the characters except for percentage protein and width of spikelet. All other characters have lower genotypic variances ($\sigma^2 g$) than all their respective phenotypic variances ($\sigma^2 ph$) and error variance ($\sigma^2 e$), except for percentage protein. This result might be indicating that the gene controlling these characters are almost stable at M_4 generation, which tends to agree with the findings of Scossiroli *et al.*, (1960), Scossiroli and Polligrini-Scossiroli (1962), Gaul and Nittlelstensheid (1961), Gaul (1964), Swaminathan (1961) Borojevic (1963 and 1965) who reported that variability of quantitative characters in wheat treated with some mutagen increased up to four times in the M_2 and M_3, gradually decreased in later generations and stabilized around M_5. All the characters have lower genotype x year

interaction components (σ^2gy) than their respective genotypic (σ^2g), phenotypic (σ^2ph) and error variance (σ^2e). This might be indicating that the years are not influencing the performances of the traits which will make it difficult to select for these traits in these particular years (Opeke and Fakorede, 1986). The low genotype x year variance (σ^2gy) component could indicate low genotypic variance components (σ^2g) in one year or two years (1990 and 1991) than in the other year (1989) which is actually true in this study (Tables 7, 8 and 9), this could also indicate that the characters are monogenic and therefore reguire simple selection procedures for meaningful improvement. Low genotype x year suggests immediately that even the appropriate breeding program may prove difficult for the development of a number of varieties, that are particularly adapted to any special environment or year (Allard and Bradshow, 1964). The G x E interactions are important since the fluctuations in environment or year for most of the part can not be predicted in advance and hence can be avoided by developing varieties in which developmental sequences are canalized along pathways that lead to high performance (Allard and Bradshow, 1964). The presence of low G x E interaction could also indicate that the performance of any one of the genotypes relative to the others grown in the same environment will be consistent (Hill, 1975).

5.3 Heritability

Heritability estimates computed from the variance components show that percentage protein which had almost the lowest variance components (σ^2g, σ^2ph, σ^2e and σ^2gy) has the highest heritability of 77.36 percent, in the combined years, other characters with

high heritabilities include length of second internode, lengths of 3rd and fifth internodes in that order. This is only indicating that their genotypic variances (σ^2g) were higher or larger than their phenotypic variances (σ^2ph) which could also be interpreted that their genetic variation is large due to major genes controlling the characters which can easily be inherited, and that selection would be effective in the desired direction for each of these traits in the population (Opeke and Fakorode, 1986). Days to 50% flowering, lengths of first and second leaf sheaths and length of fourth internode have moderate heritabilities. This results are in agreement with the findings of Morishima *et al.*, (1967)(II), and Ado (1983) in segregating populations of rice, and peppers respectively. After irradiation the sorghum seeds may undergo chromosomal abberations with possible gene mutation, resulting in individual seeds representing single plant types which constitute a population. This population then undergoes segregation from the M_2 to higher generations, until advance generations are reached when most of the plant types will stabilize for most of the characters.

5.4 Yearly Response index (R)

Examining the distribution of the R values, it is clear that the characters vary greatly. Percentage protein, grain weight per panicle, grain weight per spikelet and leaf angle have positive response, index (R) values in all the years, which indicates that they have increased mean values from year I (1989) to year III (1991). The mode of segregations in some characters was transgressive resulting in negative R values from low mean values (Rawlings *et al.*, 1958). For instance, length of panicle, spikelet number per panicle, length of fourth leaf blade and lengths of first, second, third and fourth

sheaths, and lengths of first, second, third, fourth and fifth internodes had negative R values in 1990. Grain weight per panicle, length of panicle, spikelet number per panicle days to 50% flowering, length of spikelet, width of spikelet, lengths of first, second and third leaf blades and length of fourth leaf sheath had negative R values in 1991. Similarly length of panicle, spikelet number per panicle, length of first, second and third leaf blades, lengths of first, second, third and fourth leaf sheaths and length of first, fourth and fifth internodes also had negative R values in 1992 (1989/1991). This shows that these characters had lower mean values for the preceeding years which means there is a reduction in the mean performance of the characters. This findings compare well with the results reported by Sullins and Roodney (1977b) who reported a reduction in lysine content in sorghum mutants as compared to the normal, this is explained by the harmful effect of the irradiation which are usually expressed in early generations of selections. Scossiroli *et al.*, (1960), Gaul and Nittlestenscheid (1961) Gaul (1964), Swaminathan (1961), Borojevic (1963 and 1965) reported a decrease in the mean performance of some quantitative characters of wheat after mutagenic treatment, but there was increase in the variability of the traits in M_2 and M_3 generations, which could be due to mean recessive mutant gene action for these characters.

Parra-Negrette *et al.*, (1984) also reported a similar reduction in plant height (PH), internode number (IN), and length of leaf (LL), leaf area at anthesis (LA), and the duration of grain filling period (GFP), total dry matter production at anthesis (DMP) and at physiological maturity (DMPM), days to anthesis (DA) and to physiologic maturity (DPM). In contrast they reported an increase in mean value of harvest index (HI),

panicle length (PL) and excertion which were significantly higher in the mutant lines than the normal sorghums. Naphade and Ghwaghawe (1971) also reported a reduction in the mean value of percentage protein in irradiated sorghum in R_1 generation but increased in the R_2 generation.

5.5 Correlation Matrix

A correlation matrix represents the inter-relationship of concerned variates distributed in a multidimensional space (Morishima and Oka, 1968). The correlation matrixes of the individual years and that of the years combined are given in Tables 12, 13, 14 and 15. The results of the correlation matrix for 1989 (Table 12) showed that there was highly significant correlations between the stem characters, while there was significant correlations between the leaf characters. This goes to explain the close relationship between the two groups of characters. It also relates to their structures and function as photosynthetic organs. Most of the panicle characters have positive correlations with both the leaf and stem characters, this is indicating the source-sink relationship. Similarly Eckebil *et al.*, (1977) reported positive genotypic correlations between 1000 seed weight and grain yield per unit area and grain yield per plant, height and threshing percentage; between plant height and internode number, internode number and panicle length were positively correlated. However, Eckebil *et al.*, (1977) reported negetive genotypic correlations between days to flowering and yield.

In 1990, significant correlations were found between length of panicle and length of spikelets. There were highly significant correlations between length of third and length of forth leaf sheath and first internode. Similar observations were reported by Morishima

et al., (1967)(I), in irradiated rice lines, in which they found that significant genetic and environmental correlations exist between lengths of panicle and first, second, third, fourth and fifth internodes that constitute plant height, which they explain, that organs located near each other tend to be strongly correlated both genetically and environmentally.

Quendeba *et al.*, (1995) reported that grain yield and spike yield of millet landraces were significantly correlated with spike length, spike girth, stem diameter, spike number/plant, plant height and 1000 grain weight. They also reported a negative correlation between spike length with peduncle exsertion, but positive correlation to spike yield and grain yield.

In 1991, days to 50% flowering was largely negatively correlated to both leaf and stem characters, while significant correlations were found between leaf characters (Table 14). Significant correlations are found between some leaf characters and some stem characters. This goes to emphasize the close relationship between traits that are located near each other; they are also structurally and functionally similar being photosynthetic and supportive organs (Morishima and Oka, 1968). Yield improvement is likely to be achieved in our 'plant types' if selection is targeted at lengths of leaf baldes, lengths of leaf sheaths and length of internodes that are quite variable and load significantly along with the yield componets.

5.6 Principal Components

In order to visualize patterns of character association involved in the correlation matrix, and because the variables were not commensurate, the technique of principal

component analysis was adopted (Kendal, 1965), so as to extract factors (components) responsible for the variation in our 'plant types'. The factors extracted from the matrix of genetic correlations and their contribution (% variance) to the total variation for the individual years as well as for the combined years are given in Tables 16, 17, 18 and 19. Principal components extracted from a correlation matrix are independent of one another (Morishima *et al.*, 1967)(II).

Kaiser's (1960), criterion which states that the number of common factors to be retained should be equal to the number of principal components having eigen values greater than one. Harman (1967), states that this criterion is quite plausible since the sum of all N roots (eigen values) is precisely N, so that a value of one is merely par and if another dimension (factor) is to be added, it will be desireable to have it account for at least an average contribution. Kaiser (1961) provided an emperical evidence in support of this criterion namely, that in a large number of different factor analytic studies, the factors retained by applying the criterion are usually interpreted whereas those not retained are normally difficult to interprete.

Another important aspect of component analysis is that we use one's (1.00) in the diagonal of the correlation matrix, in that case we are in effect saying that the test (variable) is completely reliable and without error. If we then square the loadings and add to give us the variance, we should end up with commonalities equal to unity (1.00) because we started off by assuming all the variance to be common (Dennis, 1978). Within the loadings obtained, there may be unique variance, but this should be ignored based on the earlier assumption. The principal components analysis identifies inherent

variabilities that exist within the characters these might be useful if they are significantly correlated to the target traits (yield) since they can be selected for indirectly in order to improve the target traits.

5.6.1 Principal Components Extracted from the Correlation Matrix in Year I (1989)

In component analysis the factors are usually ordered, from the largest to the smallest in terms of the sizes of their eigen values, or equivalently, in terms of the percentage of the total variance accounted for. It can also easily be verified that the sum of the products of the elements of any pair of columns, is equal to zero (within rounding error) a consequence of the fact that all the factors are orthorgonal and independent (Richard *et al.*, 1980). Table 16 shows that lengths of third and fourth leaf blades, lengths of first, second, third, fourth and fifth internodes have significant loadings on the first factor. Table 12 of correlations shows that there was significant correlations between the internode lengths. From component analysis the first factor usually accounts for the highiest variation within the characters studied. It therefore means that length of internodes, which in actual sense is the plant height, and lengths of leaf sheaths are the two most important characters accounting, for the variation within the 'plant types'. Of course it is the green stem, leaves and sheaths that manufacture the food for the development of the other organs (sink). The food so synthesized is distributed to areas of growth, development and storage by the phleom cells of the stem and leaves.

The second factor shows that length of panicle, length of spikelet and length of fourth leaf sheath have significant loadings. The same characters show significant correlations

between them. This factor has a variance of 10.19%, which is next to that of the first factor, 26.12%. This shows that these characters are the next most important in accounting for the variability in our 'plant types', although they are not grouped together as is in the first factor.

Third factor shows that grain weight per panicle, grain weight per spikelet, width of spikelet, length of spikelet and length of first leaf blade have significant loadings. This factor accounts for the third largest variance of 8.53%. These characters are yield components, except length of first leaf blade, and are also largely correlated. They are also quite related in terms of their location in the plant and function.

The fourth factor has significant loadings on grain weight per spikelet and length of fourth leaf sheath. This factor accounted for the fourth largest variance of 7.99%.

Factor five has significant loadings on days to 50% flowering and length of 3rd leaf blade, which accounted for the fifth largest variance of 5.99%.

The sixth factor loaded significantly on percentage protein only. This factor with only one character having high loading is referred to as a unique factor (Dennis, 1978). It is unique in the sense that only that character accounts for all of the variance of that factor. This differs with all the other factors which are group factors having two or more characters loading high and account for the variability of the factor. The variance accounted for by this factor is 5.31%, which is almost the same with that accounted for by the sixth factor, 5.99%. This is indicative that the characters could be useful in yield improvement because of their variability and loading significantly with yield components, could therefore be selected for. The total eigen value is 14.14 which accounts for

64.15% as total variance. It is pertinent to say that the six factors are thus responsible for more than sixty (60%) percent of the variability within the characters of the 'plant types' during the first year of evaluation (1989). The communalities (C^2) ranged from 0.192% for spikelet number per panicle to 0.843 for length of 3rd leaf sheath. Twelve characters that have significant loadings therefore accounted for more than 60% of the common variance, thus leaving less than 40% of it for the factors not retained by our criterion. It is therefore true to say that the analysis has succeeded in extracting most of the variance in the 'plant types'. In general all the factors were group factors except the sixth one which was unique.

5.6.2 Principal Components Extracted from the Correlation Matrix of the Second Year (1990)

Six factors were retained by the criterion, similar to that of the first year. The F_1 has significant loadings on length of panicle, length of second leaf blade, length of spikelet, lengths of first, second, third and fourth leaf sheaths and also lengths of the first, second, 3rd, fourth and fifth internodes. The correlations in Table 13 show that there is a significant relationship between the internode lengths, which agrees with the loadings in the factors. This shows a close relationship between the panicle and leaf blade, leaf sheaths and length of internodes. The leaves and internodes are photosynthetic organ (sources), while the panicle utilizes the photosynthate (sinks). The factor has a total common variance of 25.80% being the highest, since the extraction is usually in the order of their magnitude. This implies that most of the variations are due to the lengths of the leaf sheaths and internodes. This observation confirmed the results obtained

during the first year (1989). It also seems to indicate the superiority of the two characters involved in explaining the variation in the 'plant types'. This also makes them important to be selected for, to indirectly improve the yield (panicle characters) of sorghum.

The F_2 accounts for 12.37% variance, with spikelet number per panicle and lengths of first, second, 3rd and fourth leaf blades having significant loadings. This does not however agree with the result of the second factor of the first year, in which panicle characters dominated. This is suggesting that the variation is explained by three major components; lengths of leaf sheaths, lengths of leaf blades and the lengths of internodes which are again photosynthetic structures. The F3 accounts for a variance of 8.04% being the third largest. Grain weight per panicle, grain weight/spikelet, lengths of fourth and fifth internodes load high, which means that only these characters account for the common variance of the factor. This also indicates the importance of the photosynthetic organs to the yield components. Length of forth and fifth internodes could be selected for in order to improve yield being in the same factor with significant loading. In F4, length of spikelet, percentage protein and length of panicle load significantly, with a total common variance of 7.91% the fourth largest. The variance of this factor does not differ much from that of the F1, thus might be indicating the close relationship between the characters in the two factors which are panicle characters. In F5, there is significant loadings on spikelet number/panicle and width of spikelet. The F5 accounts for 6.66% of the common variance, which is also close to those of the F3 and F4, 8.04% and 7.91% respectively.

The characters in the three factors (F3, F4 and F5) are positively and significantly correlated and are located near each other on the plant, so there is a close relationship between them (Morishima and Oka, 1968), thus confirming the earlier relationship. In F6 only days to 50% flowering accounts for the variance of the factor, the variance is therefore attributed to it. The variance is 5.21% being attributable to the only character with the significant loading, this seems to be that Days to 50% flowering accounted for a large portion of the variation in the 'plant types', an important trait in crop improvement that can be selected for.

Eigen value for all the factors amounted to 14.357 accounting for a variance of 65.26%, which is not much different from that of the previous year (1989, 64.15%). This shows that the same number of factors were extracted for both years and the same characters seem to be accounting for most of the variation in the 'plant types', which might be indicating that selection for one could lead to the selection of the other or others. The communalities ranged from 0.39 to 0.89, this is a lower range than in 1989. In general, the F1 is a general factor, while all the other factors are group factors, except the sixth, which is unique in 1990. It is known that the higher the total variance for each factor the more substantial can be claimed that the items with significant loadings have some property in common (Dennis, 1978). Also, the total extracted variance gives an idea of the variance attributable to interrelatedness of the variates. this is true for leaf blades, length of leaf sheaths and lengths of internodes which are structurally and functionally similar.

5.6.3 Principal Components from the Third Year (1991)

Principal components from the third year (1991) are given in Table 18. Nine components were extracted and retained by the criterion, the highest number in the three years. The F1 loaded significantly on length of spikelet, lengths of first leaf sheath and lengths of first, second, third, fourth and fifth internodes. This result confirms the superiority of the length of internodes (plant height) in explaining the variations in the 'plant types'. It also indicates that plant height could be selected for in order to improve yield. The F1 accounts for 12.5% of the common variance. There is significant correlations between the internode lengths which goes to emphasize their interrelatedness and also that they have some property in common, that is structure and function. The F2 loads significantly on lengths of first, second, third and fourth leaf blades, this observation agrees with that of the F2 in 1990, but different from that of 1989. The results of the last two years (1990 and 1991) were more consistent, which indicates that internode lengths (plant height) are responsible for most of the variation followed by lengths of leaf blades. The variance accounted for by the F2 is 10.24% which is similar to those of the F2's in the previous years (1989 and 1990). The F3 has significant loadings on grain weight/panicle, spikelet number/panicle and grain weight/spikelet. This shows a similar trend to F3,s of the first two years. These is ascertaining that they are closely related and so have some property in common. The variance accounted for by this F3 is not quite different from that of the previous factor (F2), 9.64% and 10.24% respectively. The F4 loads significantly on only days to 50% flowering, which is similar to what was observed in the previous year (1990). Days to 50% flowering seems to be

quite unique in determining the variations in the 'plant types'. Days to 50% flowering is quite an important character in crop improvement, it is not surprising therefore, that it (which is a function of maturity period) is a character that accounted for much of the variations in the 'plant types'. The variance for this F4 is 7.55%. We are beginning to recognize 'plant types' that may be developed genetically from four main characters, lengths of internode (plant height), lengths of leaf blades, lengths of leaf sheaths and days to 50% flowering. The variations in the 'plant types' studied are due to these four characters since they load significantly along with the yield components, they could be selected for as an indirect way of improving yield. The F5 loads significantly on length of panicle and length of second leaf sheath. It is difficult to interpret the factors as one moves from lower to higher ones as indicated by Kaiser's criterion. There is a close relationship between the two characters, in that, the flag leaf is the nearest (source) to the panicle (sink), followed by the first leaf blade and first leaf sheath, then comes the second leaf blade and second leaf sheaths serving as sources to the panicle (sink). The variance of this factor is 6.56%. There seems to be small difference between the variances of the factors in this analysis as compared to those of the first two years. The F6 load significantly on width of spikelet and length of first internode, after reversing the signs of all the loadings, to ensure that at least one character loads significantly. The change of sign does not affect the eigene value and subsequently the variance of the factor (Dennis, 1978). The F7 loads significantly on grain weight/panicle, width of spikelet and length of fourth leaf sheaths. The panicle characters are usually grouped together whenever they occur in the same factor in all the years. This could be as a

result of their relatedness as yield components and thus having some property in common, which are their structure and function. The total variance for the F7 is 5.32%. The F8 has significant loading only on length of fourth leaf blade. This is after changing the signs of all the loadings in the factor, and it becomes another unique factor in this analysis. F9 loads significantly on length of panicle and leaf angle, and leaf angle is negatively correlated to internodes lengths. This is similar to the observation by Morishima and Oka, 1968 in rice 'plant types'. This might be indicating that selection for shorter plants with errect leaves could lead to yield improvement. Shorter, erect leaves are better position in harvesting the light energy for increased photosynthesis.

The total eigen values contributed by all the nine factors is 14.73, which accounts for a total variance of 66.96%, which was higher than that of the previous years (1989 and 1990). It is true, to say that the variations in the 'plant types' were expressed better in the first two years (1989 and 1990) with fewer number of factors (six) than in the third year which has a larger number of factors (nine) with almost the same total variance. The significant correlation between these characters also indicates that they could be selected for in order to indirectly improve those related to them.

Since in principal component analysis, one's (1.00) are put in the diagonals of the correlation matrix, it means that all the variables are assumed to be completely reliable, and unique variances become merged with the common variance to become a kind of hybrid common variance. Therefore, the number of factors is usually equal to the number of variables, and so the total communality for a test is expected to be unity (1.00). But because only the factors with eigenvalues equal to or greater than one are

retained by the criterion the cummunalities (C^2) are usually less than one. The remaining part of the common variance is therefore shared by the other lower factor not retained in the analysis.

Although principal components analyses results for the individual years were similar, because the same materials were used, a combined correlation matrix was computed for the three years and the principal components extracted from it, with a view to achieving more reliable results.

5.6.4 Principal Components Extracted from the Combined Correlation Matrix (1989, 1990 and 1991)

Table 19 shows that seven factors have been retained, this is lower than that of the third year (1991) but higher than that of the first two years (1989 and 1990) which were 9, 6 and 6 respectively, incidentally being the average for the three years. The F1 loads significantly on length of panicle, lengths of first, second, third and fourth leaf sheaths and lengths of first, second, third, fourth and fifth internodes. This results conforms with what was obtained in all the three years, the characters are also grouped together in the F1. This also confirms the 'source-sink' relationship existing between these characters. This is a common factor, not a general factor as is usually the case with most F1's in most analysis. This results confirm the previous findings, that the variability in our sorghum 'plant types' is mostly explained by the lengths of the leaf sheaths and lengths of internodes which are photosynthetic organs. These organs load significantly along with grain weight/panicle and grain weight/spikelet and therefore could be selected for in order to improve yield. The F2 has significant loadings on grain

weight/panicle length of spikelet lengths of first, second and third leaf blades and Days to 50% flowering. This is similar to what was obtained for the F2 in 1990 and 1991, but does not conform with that of 1989. Lengths of leaf blades seem to be the third most important character responsible for the variations in 'plants types' after lengths of internodes and lengths of leaf sheaths in that order. The variance of the F1 is much higher than that of the F2, which are 22.56% and 11.85%, respectively. It shows that the characters with high loadings in the F1 accounted for more variation than those in the F2. Also, the same variates in F1 that are responsible for the large variance, are more related and have some properties in common which goes to suggest that similar genes could be influencing the development of these characters (pleiotropism) than those in the F2. This is further confirmed by the significant correlations between those variables in the F1 than those in the F2. The third factor, F3 loads significantly on length of first, second and third leaf blades, similar to the F2. This result indicates that selecting for photosynthetic structures will lead to improving yield in the sorghum 'plant types'. It shows that the complexities of these variables are greater than one (1.00), meaning that they contribute variability in more than one factor (Norman *et al.*, 1975). It also indicates that the correlations between these variables are significant. The F4 loads significantly on only one variable, length of second leaf blade. This shows a case of a unique variance, also indicating that the complexity of that variable, to be equal to one, thus responsible for the total variance in that factor (Norman *et al.*, 1975). Within the F5, length of panicle, spikelet number per panicle and grain weight per panicle have significant loadings. The F5 here is different from the F5's of all the individaul years.

The variance accounted for by F2 and F3 are similar (11.85% and 10.02%), while those of the F4 and F5 are different, 10.02% and 6.76%, respectively. The variables that load high in F5 also load high in the F5's of nearly all the years, which shows that they are quite related and also have some properties in common, that is, their development might be influenced by similar genes (pleiotropism). The variables in F5 have significant correlations with those that load significantly in F1 and F2 which tends to indicate a causal effect relationship. The F6 loads high on length of panicle and percentage protein. Length of panicle loads significantly on more than one factor which shows that its complexity is more than one, (Norman *et al.*, 1975). The variance of the F6 is close to that of the F5, 5.74 and 6.76%, respectively, which shows that their contributions to the variations are almost the same and also suggesting that they might be influenced by similar genes. The F7 loads significantly on length of fourth leaf sheath and grain weight per panicle, having a variance of 5.02, close to those of the F5 and F6 , this also indicates a 'source-sink' relationship. The total eigen valuc is 15.015, which accounts for a total variance of 68.25%, which is higher than those obtained for the individual years. The analysis has succeeded in extracting the highest variance (almost 70%) with low number of factors, two less than for 1991 and one more than that for the first two years. It therefore contains more information on the variables than it is obtained in the individual years analysis, and so it may be more reliable. The communalities ranged from 0.521 to 0.845 which is lower than that obtained for the individual years which shows that, the factor loadings are more consolidated and contain more information than it is given for the individual years. Most of the variability here is attributable to the four

major factors; leaf lengths, leaf sheaths and internode lengths, and days to 50% flowering, which are all photosynthetic structures.

Quendeba *et al.*, (1995) reported 92% of total variation to four principal components in millet landraces populations using Kaisers minimum eigen valaue criterion (PC1 - PC4). The PC1 accounted for 49% of the total variance which was associated with spike length, stem diameter, days to 50% flowering and plant height (internode length). The PC2 accounted for 24% of the total variance which was associated with grain yield and spike yield (yield components). The PC3 explained 11% of the total variance which is associated with non productive tillers but are photosynthetic structures. This is similar to the findings in these study that most of the variations in our 'plant types' are explained by photosynthetic structures, yield components and days to 50% flowering.

Generally, all the factors are bipolar and grouped, except for F1 in 1989 that is a general factor, and four others, that are unique, F6's in 1989 and 1990 and F4 and F8 in 1991.

The results obtained from the principal component analysis, usually group two or more characters in a factor which does not clearly define the importance of each variable in contributing to the variability, therefore interpretation is difficult. The results are therefore term initial solutions. A second step is required which will give clear define groups for better interpretation of the results, this step is discussed as the final solution, which is rotation.

5.8 Rotated Factor Pattern (varimax).

The unrotated factors extracted through the principal component analysis did not give enough information about the contribution of the individual tests to the variation, and therefore rotation is done for the component analysis for the combined years. The initial solutions usually produce tests which decomposed into positive and negetive loadings, and their complexities are usually geater than one. It is also in the light of these problem that rotation is employed.

Rotation gives a clearer picture of the group factors than the direct components analysis. Rotation in itself does not affect the common variance of the tests (communalities, C^2), provided the rotation is done about the origin, and the tests vector remains stationary (Dennis, 1978).

In this study, the orthorgonal rotation is used, applying the varimax criterion which defines a simple factor as one with only one's (1.00) and zero's (0.00) in the column. This means that after rotation the variables will either load significant (1.00) in a factor or it will not be significant (0.00). Since rotation is orthorgonal, it then represents both regression weights and correlation coefficients (Norman *et al.*, 1975). This loadings in a given row represent regression coefficient of factors describing a given variable.

Thurstone (1947), simple structure requires that as many as possible of the variables should give negligible loadings. Principal components extracted from a correlation matrix are independent of one another (orthorgonal). After rotation to simple structure the vectors (factor) are still independent.

Table 20 shows that F1 has lengths of internodes loading significantly (1.00) and are

grouped together, while the rest of the variables are not. The F2, shows that lengths of leaf sheaths load significantly while all others are not. This trend in which similar variables give significant loadings in a factor, also shows the contribution of those variables to the variations in the 'plant types' in an ordered sequence. The F3 loads significantly on lengths of all of leaf blades with all other tests being non-significant. The results satisfied Thurstone's rules of thumb. The F4 loads significantly on lengths of second to fourth leaf blades, this is quite significant, this might be indicating pleiotropism. In F5, grain weight per panicle, length of panicle, spikelet number per panicle are grouped together and they also have significant loadings except spikelet number per panicle, and are also yield compnents. In F6, grain weight per panicle, length of panicle, spikelet number per panicle and grain weight per spikelet again are grouped together, but only grain weight per panicle and grain weight per spikelet have significant loadings. This also indicates that they have more than one factorial complexity and should be significantly correlated. In F7, percentage protein and length of panicle have significant loandings, although they are not grouped together as observed in other cases. A general observation is that as one moves from lower to higher factors more variables tend to increase in complexity. An important aspect of the rotation is that though factor variance may be affected, the total common variance remains unchanged, and so at the end of the rotation the total variance is the same (68.25%). The communalities also remain unchanged. Most of the tests especially in the lower factors have significant loadings on only one factor indicating that their factorial complexities are one (1.00) (Norman *et al.*, 1975).

From the F1, it is observed that lengths of internodes (plant height), are significantly and negetively correlated to Days to 50% flowering. This confirms the earlier relationship which suggests that, selecting for shorter plants will favour early maturity and thus may increase yield. Leaf sheaths are negetively correlated to plant maturity, it goes to favour selection for shorter plants with shorter and erect leaves and sheaths which will favour early maturing plants and improvement in yield.

For this study, it has been possible to investigate variation in the yearly response of characters in sorghum 'plant types'. The yearly response of 'plant types' were evaluated using the response to selection index (R). These computations showed that in stem and leaf characters variability changes with the magnitude of the yearly changes among the lines which for a greater part is genetically controlled. Morishima *et al.*, (1967)(II) reported that yearly changes which lead to changes in plant types of rice were genetically controlled. One could consider the changes due to the environmental effects on the plant types as being due to linear combination of the characters. That is to say, that plant types may change in some given variables or the variables only may change.

The matrixes of correlations from all the years dont seem to differ much, contrary to the results reported by Morishima *et al.*, (1967)(I), which indicate that they maintain their variability year after year, which might be indicating genetic stability and thus making selection possible at this stage.

After rotation of the extracted component vectors, the loadings on the rotated axes did not differ much, this is expected, since the combined correlation matrix was used for extracting the factors, and the same factors were rotated. This may be suggesting

that if we rotate factors extracted from the different years we are likely going to obtain the same results, and since the same 'plant types' were used for the evaluation for the three years, indicating that they maintian their variations, thus confirming their stability in M_4. If the factors extracted from these correlations are essentially of the nature of the rotated vectors, it could be inferred that yearly changes in the 'plant types' are made along the rotated factor axes. If that is not true, then yearly changes in the character association should have been different. The first assumption is likely to be true, since the loadings giving by the first three or four component vectors from the correlation in the rotated factor vectors obtained from the combined correlations remain unchanged. This shows that the gentype x year interractional variance in the characters association was largely explained by the yearly changes in the 'plant types'. Also, analysis of variance for the rotated factors showed that yearly responses in these lines, in the characters could largely be genetically determined since the characters maintained their variability in most of the years. This observation is similar to the results reported by Morishima *et al.*, (1967)(I), in f_3 'plant types' of rice. Morishima *et al.*, (1967)(I), showed that genetic correlations of characters are due to pleiotropy and linkage of relevant genes. Pleiotropic relation might be reajusted by modifying genes and linkage relations change due to recombinations. In this situation Morishima *et al.*, (1967)(I) explained that the characters are to some extent developmentally correlated as shown by pleiotropic relations, and that plants have systems of canalization of developmental sequences through which genetic effects on development give rise to certain similar patterns as shown by the 'plant types'. Thus it could be concluded that 'plant type'

variation, or its basic pattern of character association, though may change, according to the genotype, can be maitained constantly in different segregating generations.

5.9 Graphical Representation of the First Two Factors

Graphical representation of the first two factors from principal component analysis sheds more light in interpreting the interrelationships between the characters. Fig 1, 2, 3 and 4 show more clearly the the grouping of characters into different clusters.

The first two components (F1 and F2) are used in plotting the graphs, this is to indicate the relative importance of the components in explaining the variations and the correlation patterns. The vectors were multiplied by the square roots of their eigenvalues and plotted on a common scale. Traits close together are similar in nature while those at right angles to each other are independent and those diametrically opposed are equivalent in that they measure the same quantity but differ in sign. Smith and King, (1962) emphasized that the first two factors merely approximate the actual correlations, so that the spatial arrangement of the figures account for only some part of the relationship among the traits. In Figure 1, length of leaf blades (10, 11 & 12), lengths of leaf sheaths (13, 14 and 15), are in one quadrant (II), while lengths of internodes (18, 19, 20 and 21), are clustered together in quadrant (I), these is similar to the observation made by Smith and King (1962), since they are similar in structure and function. Length of panicle (3), and length of spikelet (7) are also close together, being yield components. Lengths of leaf sheath (16) and length of first internode (17), are close together, they could be considered to be similar in function. Grain weight per panicle

(2), grain weight per spikelet (5), days to 50% flowering (6) and width of spikelet (8) are almost at opposite to lengths of leaf blades and lengths of leaf sheath (10, 11, 12, 13, 14 and 15), suggesting that they are dependent in nature (Smith and King, 1962). This agrees with this study since the leaves are concerned with food synthesis, which is utilized by the yield components. It may not be true to say that the leaf blades and sheaths are equivalent and measure the same quantity with percentage protein (1.00) and spikelet number per panicle (4) since they are diametically opposed. This is inconsistent with the findings of Smith and King, (1962).

In Figure 2, lengths of leaf sheaths (13, 14 and 15) and lengths of internodes (17, 18, 19, 20 and 21) may be said to be equivalent or contributing to the same quantity with days to 50% flowering (6), because they are clustered together in the same quadrant. The same characters, lengths of leaf sheaths and lengths of internodes, are close together, may not be independent of lengths of leaf blades (9, 10 and 11), since they are almost at right angle to one another. Percentage protein (1), could not be said to be measuring a similar quantity with spikelet number per panicle (4) which are diametrically opposed. Also, length of panicle (3) might not be measuring the same quantity with Days to 50% flowering (6). Percentage protein (1) might be independent of leaf blades (9, 10 and 11), but certainly not independent of grain weight per panicle (5) and width of spikelet (8).

Figure 3 shows that length of internodes (17 - 21) are independent of leaf blades (9 - 12) while leaf angle (22) might be equivalent to lengths of internodes (17, 18, 19 and 20), measuring a similar quantity. Days to 50% flowering (6), continoeus to indicate

that it is measuring the same quantity with length of leaf blades (13, 14 and 15).

Figure 4 shows that lengths of leaf sheaths (13, 14, 15 and 16) are in one cluster, in quadrant II, lengths of internodes (17, 18, 19 20 and 21) are in one cluster, in quadrant I, being of similar structure and function. Lengths of leaf blades (10, 11 and 12), can not be independent of lengths of leaf sheaths (13, 14, 15 and 16) because they are almost at right angle to each other. Days to 50% flowering (6) may not be equivalent or measuring the same quantity with leaf blades lengths (13, 14, 15 and 16), since they are diametrically opposed (Smith and King, 1962). These graphical representation of the factors demonstrated the relationship of these characters, and being grouped together in the same clusters and having significant correlations between them emphasizes their having some properties in common. These help in deciding which characters can be selected together in order to improve yield in the sorghum 'plant types'.

5.10 Summary and Conclusion

The evaluation of 34 "plant types" of sorghum (family selections) developed from the irradiation of a common variety of sorghum S.K 5912 (Samsorg 17) using Co^{60}, was carried out for three years (1989, 1990 and 1991) in the Institute for Agricultural Research fields, using the Randomized complete block Design (RCBD). Family means were used for the analysis of variance and covariances, and the variances and covariances were used to compute correlations for the individual years and for the three years combined. The correlation coefficients which represent the pattern of character

association, using pricipal components analysis procedure of Kendel, (1961). Correlations of characters have been shown to be due to pleiotropic and linkage of relevant genes. From the factors extracted from the combined correlations it has been, found that irradiation has created variability in the 'plant types' in the variables, lengths of internodes (plant height), lengths of leaf sheaths, lengths of leaf blades and days to 50% flowering (maturity period). These photosynthetic characters (leaf and stem characters) tend to be significantly and negetively correlated to days to 50% flowering, and load significantly in the same factor with grain weight/panicle, grain weight per spikelet, spikelet number per panicle (yield components and percentage protein). It could be infered that selecting for shorter plants with shorter leaf sheaths and leaf blades, could lead to early maturing plants with greater yielding potentials. Graphical representation of the first two factors in each year and for the three years combined and also for the rotated factors, showed that characters that are of the same origin, similar structure, and function are naturally grouped together in the same cluster. This study also indicated that characters that are not related (independent) lie at right angle to each other and can not be selected together, while others that are equivalent, or measuring the same quantity, could lie diametrically opposed due to differences in the signs of their loadings can be selected together. For any crop improvement in the sorghum "plant types" used in this study, selection should be based on stem and leaf characters with high variability having moderate heritabilities found within the same cluster along with those diametrically opposed to them might lead to a success in yield improvement in these sorghum 'plant types'.

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