DECLARATION

I, NICHOLAS MANGOMBE hereby declare that this dissertation represents my own work and that it has not previously been submitted for a degree at this or another University.

Mangombe

signature

<u>APPROVAL</u>

This dissertation of **NICHOLAS MANGOMBE** is approved as fulfilling part of the requirements for the award of the degree of Master of Science in Crop Science by the University of Zambia.

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ABSTRACT

The study was conducted to determine and characterize grain yield, grain yield stability, uniformity of three way cross (TWC), single cross (SC) hybrids and open pollinated (OP) varieties of sorghum and relate their grain yield to morphological and physiological attributes via leaf area index and duration.

Twenty five entries comprised of 12 TWC, 11 SC and two OP of sorghum, *Sorghum bicolor* (L) Moench were planted in a 5 x 5 triple lattice design at Lusitu, Masstock, Liempe Farm, Golden Valley and Field Station.

Plant aspect score, seedling vigour score, leaf area before flowering (LA1), leaf area after flowering (LA2), plant height, within plot standard deviation of plant height, grain yield, grain yield stability, 100 grain weight, disease score, days to 25%, 50%, and 75% heading were recorded. Leaf area index before flowering (LAI-1), leaf area index after flowering (LAI-2) and leaf area duration (LAD) were determined.

SC were superior to TWC and OP with regard to plant aspect score. On the other hand, TWC plant aspect score were similar for OP. The OP had higher 100 grain weight and better disease ratings than hybrids which were themselves similar.

Leaf area parameters were similar among TWC, SC and OP. Correlations between grain yield and leaf area parameters were positive and significant for TWC and SC.

SC gave better grain yields than both TWC and OP which were similar in grain yield, though in terms of grain yield stability, TWC and SC were marginally better than OP. Marginal advantages of TWC over OP in grain yield and grain yield stability should be considered in light of requirement of one more generation in seed production which is in itself a disadvantage. The uniformity of SC and OP was relatively better than that of TWC as depicted by plant height. Such differences were absent when days to maturity was used for uniformity.

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ABBREVIATIONS

ANOVA.	Analysis of variance
LA1.	Leaf area before flowering
LA2.	Leaf area after flowering
LAI-1	Leaf area index before flowering
LAI-2	leaf area index after flowering
OP.	Open pollinated variety
SADC.	Southern Africa Development Community
SC.	Single Cross hybrid
TWC.	Three way cross hybrid

1 INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) is the fifth most important cereal in the world and is a major staple in the diets of the people of the semi-arid tropics (Anonymous, 1990). In Southern Africa Development Community (SADC) region and most of Africa, sorghum ranks third among traditional cereals grown after maize (*Zea mays*. L.) and wheat (*Triticum aestivum*) (Schweppenhauser, 1980; Anonymous, 1989; Anonymous, 1990). Sorghum is a hardy and dependable crop that grows well under adverse conditions and thus play an important role as food in drier areas where it offers best food security (Mushonga, 1986; Anonymous, 1990; Yohe, 1990).

In the SADC region, single cross hybrids (SC), open pollinated varieties (OP) and traditional landraces sorghum varieties are cultivated. However, in general, with the exception of Zimbabwe, the use of hybrids remains negligible in the SADC region (Maunder, 1990). In Zimbabwe, sorghum hybrids are cultivated by commercial farmers for malt, while communal farmers cultivate OP and landraces as a staple food and for brewing beer (Mushonga, 1986).

In Botswana, Zambia and Mozambique, open pollinated sorghum varieties and landraces are grown and used as staple food and for brewing beer (Botswana, Ministry of Agriculture, 1991, Anonymous,1990).

Parents of single cross hybrids of sorghum used are low seed yielders and hence the seed is very expensive. Three way cross hybrids might be of importance in the SADC region since there is the possibility of seed production at reduced cost, because up to 20% gain in seed yield has been reported when compared with SC (Atkins, 1971; Hookstra and Ross, 1979; Kide et al., 1982).

Grain yields of sorghum and other crops for TWC, SC, OP and landraces have been reported to differ in several studies while other studies reported no significance differences between TWC and SC (Atkins, 1971; Walsh, 1971; Liang, 1971; Atkins, 1972; Lynch et al., 1973; Fazalullah Khan and Menon, 1973; Liang et al., 1974; Patanothai and Atkins, 1974; Kide et al., 1980; Kide et al., 1982; Torres-Cardona et al., 1983;). In general, grain yield of sorghum varieties have been observed to be of this order; SC>TWC>OP>landraces.

Landraces and open pollinated varieties are low and unreliable grain yielders. In addition, landraces are photosensitive and flower well after the rain season. The development of high grain yielding TWC will likely improve sorghum production within the small holder farmer.

Three way cross sorghum hybrids have been reported to be slightly stable in grain yield than SC, while hybrids are more stable than OP which in turn are stable than landraces (Atkins, 1971; Jowet, 1972; Atkins, 1974; Patanothai and

Atkins, 1974; Patanothai and Atkins, 1974a; Meenakshi *et al*., 1976; Tarumoto, 1977; Lazanyi and Papp, 1981).

Grain yields of sorghum often fluctuate from season to season and place to place in developing countries compared to developed countries where the environment which determine the growth of the crop can be modified. It seems, therefore, that the development of locally adapted varieties could be a solution. However, because of small scale sorghum production, it is difficult to produce several single cross hybrids and OP to suit specific environments. The goal should therefore be to produce high yielding, well buffered and adapted TWC sorghum varieties (Allard and Bradshaw, 1964).

Grain yield stability across different environments can be a result of heterogeneity within the population or it can be a characteristic of specific genotypes. In this vein, grain yield of TWC can be stable due to population buffering as well as individual genotype buffering (Patanothai and Atkins, 1974).

Grain yield differences in wheat and maize have been associated with leaf area index and duration differences (Winter and Ohlrogge, 1973; Prior and Russel, 1976).

Generally, high leaf area index and long leaf area duration have been associated with better light interception which drive photosynthesis and longer photosynthesis period if the leaves are properly orientated.

Three way cross have been reported to vary in plant height and days to mid bloom due to segregation of the SC parent (Atkins, 1971 and 1972; Walsh and Atkins, 1973; Miesner and York, 1973; Patanothai and Atkins, 1974a). The difficulties arising from variation within TWC at harvesting (heights and maturity) and the subsequent quality variations are not a desirable character to processors, growers, consumers and agriculture engineers.

The study was aimed at assessing the performance of TWC with respect to their grain yield, grain yield stability and uniformity. The main objectives of the study were:

1. To determine and characterize grain yield, grain yield stability, and uniformity of TWC, SC and OP of sorghum.

2. To relate grain yield of TWC, SC and OP to morphological and physiological attributes via leaf area index and duration.

2. LITERATURE REVIEW

2.1 HISTORY OF SORGHUM HYBRIDS

Around 1940's, the grain yield plateau of sorghum had been reached in the United States by traditional methods of plant breeding and there were no signs for further increase in grain yield (Dogget, 1987). Plant breeders resorted to deliberate hybridization in order to exploit the advantages of hybrid vigour (Dogget, 1987).

Hand and hot water emasculation techniques were employed as earlier techniques for making sorghum hybrids, but these methods were not practical for large scale hybrid seed production (Stephens, 1937; Stephens and Holland, 1954; Dogget, 1987). Most of the hybrids produced by the above techniques were high grain yielding, but late in maturity than open pollinated improved varieties (Stephens, 1937; Dogget, 1987).

Stephens (1937) devised a method for utilizing genetic male-sterility (ms). However, before the technique could be implemented, cytoplasmic male sterility was discovered (Stephens _et al_., 1952). The female lines were partial sterile, but after selection, pure male sterile lines were obtained which when crossed with certain varieties produced male sterile F1s and others restored fertility (Stephens _et al_., 1952).

Stephens _et al_. (1952) employed the cytoplasmic male sterility to produce experimental hybrid sorghum seed with a TWC. The discovery of cytoplasmic male sterility made it economically and practically feasible to produce sorghum hybrids on large scale (Schertz and Pring, 1982).

2.2 UNIFORMITY

Uniformity of a crop as may be represented through resemblance by any visually or quantitative measurable characteristic is a quality aspect. Suitability of a given crop for cultivation may be determined by uniformity. Plant height and maturity are some of the important characteristics for which uniformity is important.

Several studies have indicated that there is within-plot variability for the TWC than SC and OP for plant height and days to mid-bloom (Atkins, 1971; Atkins, 1972; Miesner and York, 1973; Walsh and Atkins, 1973; Patanothai and Atkins, 1974a). The OP and SC are uniform since they are either pure lines or derived from pure lines. Other characters, such as grain colour, disease resistance and 100 seed weight have been reported to be relatively uniform (Atkins, 1971). However, variability within-plot was found not large enough to cause problems at harvest (Walsh and Atkins, 1973; Atkins, 1972).

2.3 GRAIN YIELD AND GRAIN YIELD STABILITY

2.3.1. GRAIN YIELD

The development of sorghum hybrids resulted in higher grain yields, good grain yield stability and more acceptable adaptability to favourable conditions than OP (Kide et al., 1982; Artola, 1985). Hybrids are reported to have higher number of seeds per head, seed weight and threshing percentage (Artola, 1985).

Most studies have indicated that there is no significant difference in grain yield between SC and TWC (Atkins, 1971; Liang, 1971; Walsh, 1971; Atkins, 1972; Patanothai, 1972; Atkins, 1973; Patanothai and Atkins, 1974a; Perez and Miller, 1980; Kide et al., 1982). Lazanyi and Papp (1983) using pot trials showed that TWC yielded more than SC in grain yield. Similar results which indicated that TWC grain yield is greater than SC have been reported in field trials (Miesner and York, 1973; York et al., 1974). Walsh (1971) found out, that, although the highest grain yielding TWC hybrid always out yielded highest SC, mean grain yield of SC and TWC were statistically equivalent in each of the two years and when data for two years were combined. Bhale (1982) found that grain yield of TWC (heterosis 38.84% to 65.49%) was comparable to that of SC (heterosis 22.80% to 64.14%). Single crosses of sorghum were reported to be, on average, superior to TWC in grain yield (Fazalullah Khan and

Menon, 1973; Liang et al., 1974; Kide et al., 1980; Kide et al., 1982; Torres-Cardonna et al., 1983).

In maize, SC have been reported to out yield TWC and double crosses grain yield over years and environments (Lynch et al., 1973). The same authors found that average grain yield of SC was significantly greater than TWC, and, those of TWC were significantly greater than double crosses in both low and high yielding environments. A similar trend is expected on sorghum hybrids.

2.3.2. GRAIN YIELD STABILITY

The grain yield stability of a variety, that is, its reliability in terms of crop grain yields, is a more important characteristic in Africa were there is limited technology to modify the fluctuations in the environment (Jowet, 1972). The existence of genotype-environment interactions, means that locally adapted SC and OP varieties should be developed, however, this is too expensive and does little in overcoming season to season variation (Finlay and Wilkinson, 1963; Jowet, 1972; Francis and Kannenberg, 1978). The plant breeder should therefore aim to produce varieties or hybrids of as wide adaptation as possible (Eberhart and Russell, 1966; Jowet, 1972; Francis and Kannenberg, 1978).

Varieties which perform consistently over a wide range of environments are generally called well buffered varieties

(Allard and Bradshaw, 1964). There are two kinds of buffering. Individual buffering exists where a single genotype is able to perform consistently or to produce an acceptable phenotype over a wide range of environments; and population buffering which refers to the ability of a variety to perform consistently due to interaction among coexisting genotypes (Allard and Bradshaw, 1964).

Sorghum TWC have been reported to be slightly more stable compared to SC and OP (Walsh, 1971; Patanothai, 1972; Atkins, 1973; Patanothai and Atkins, 1974; Perez and Miller, 1980; Lazanyi and Papp, 1981). Three way cross are likely to be more stable as a group than SC because of slightly wider genetic base. Jowet (1972) working with sorghum, however, reported no significant difference in grain yield stability between TWC and SC. On the other hand, some studies have shown that some SC and OP might be more stable than TWC because of individual buffering (Patanothai, 1972; Atkins, 1973). As a group, hybrids in general have been reported to be more stable than OP (Reich and Atkins, 1970; Jowet, 1972).

In corn, Lynch et al. (1973) found that there is no difference in the average grain yield stability of the different type of hybrids over locations and years. Studies by Allard and Bradshaw (1964), Eberhart and Russell (1966) in corn, showed that double cross hybrids are more stable than TWC and SC due to population buffering. Similar results were demonstrated by Sprague and Federer (1951) in corn. It would appear that grain yield stability of TWC will vary depending on the crop, environments sampled and genetic material used.

Stability confirms existence of genotype-environment interaction which is manifested when genotype - environment components of total variation is significant from combined years and locations analysis of variance (ANOVA) (Jowet, 1972; Francis and Kannenberg, 1978).

Several methods have been described for partitioning the genotype and environment interactions (Finlay and Wilkinson, 1963; Eberhart and Russel, 1966; Perkins and Jinks, 1968; Shukla, 1972; Francis and Kannenberg, 1978; Lin et al., 1986; Eskridge, 1990).

Finlay and Wilkinson (1963) method measures varietal adaptation. A stable variety is defined as that, with a regression coefficient (b-value) close to unity (1.0). In addition, such a variety will have to be high grain yielding. Those varieties with b>1 are defined as unstable whereas those with b<1 are stable, but not responsive to favourable environments.

Eberhart and Russell (1966), stability model, defines stability parameters that describe the performance of a variety over a series of environments. The stability model is given as

$$Yij = \mu i + \beta iIj + dij$$

where Yij is the mean of the ith variety at the jth environment.

μi is the ith variety mean over all environments

βi is the regression coefficient that measures the response of the ith variety at the jth environment

Ij is the environment index obtained as the mean of all varieties at the jth environment minus the grand mean

dij is the deviation from regression of the ith variety at the jth environment.

A stable variety has a high grain mean yield, unity regression coefficient (bi=1.0) and small deviation from regression (Sd^2=0).

Francis and Kannenberg (1978) proposed the use of mean grain yield and coefficients of variation across environments as a measure of stability for each genotype. Varieties with low coefficient of variation are described as stable.

2.4. LEAF AREA INDEX AND DURATION:

Leaf area index (LAI) is the total leaf area of the plant per unit area of land (Watson, 1952; Radford, 1967). Leaf area measurements are taken as index of growth analysis of plants. Grain yield of plants is related to leaf area of the plant (Watson, 1952; Fischer and Wilson, 1971; Winter and Ohlrogge, 1973; Prior and Russel, 1976).

The amount of photosynthate that a maize (Zea mays .L) crop produces was reported to be partly dependent upon the crop's leaf area and leaf area duration (Watson, 1952; Krishnamurty et al., 1973; Prior and Russel, 1976; Winter and Ohlrogge, 1973; Maas et al., 1987). The relationship between grain yield, leaf area index vary appreciably among genotypes, such that the grain yield and leaf area index ratio showed wide divergence among genotypes used (Prior and Russel, 1976; Krishnamurty et al., 1973; Liang et al., 1973). Leaf area index is therefore particular to that genotype sampled and cannot be related to other genotypes. Hybrids of sorghum have been reported to have greater leaf area index than their parents until one week before flowering (Quinby, 1970; Gibson and Schertz, 1976). Liang et al. (1973) reported that in addition to greater leaf area, hybrids had greater leaf length, leaf width and grain yield compared to their parents. For several varieties grown at approximately constant spacing, variation in leaf area index depends mainly on change in leaf area per plant of that particular genotype (Watson, 1947).

Fischer and Wilson (1971) estimated the contribution of preflowering photosynthesis in sorghum to grain yield to be about 12%. The same authors also cited a study in which it was found that the contribution of preflowering photosynthesis was about 10% of total grain yield in wheat.

In wheat, a higher number of leaves can result from the increase in rate of leaf production from meristems, the increase in number of meristems and tillering (Watson, 1952). Fischer and Wilson (1971) reported the existence of positive correlation between grain yield and leaf area index of sorghum before ear emergence. Similar results were obtained with wheat (Khalifa, 1973).

Total leaf area has been reported to be important during flowering and grain filling in corn (Watson, 1952). Subsequent importance of leaf area depend on the photosynthetic capacity of the leaves in comparisons to other parts of the plant capable of photosynthesizing. Fischer and Wilson (1971) concluded from their findings that although conditions of growth prior to anthesis do not greatly influence the grain yield through assimilate supply, they may affect the grain yield potential of sorghum.

It has been reported that with increase in leaf area, there is greater competition between the plants for light, and with higher leaf area index plants tend to shade the lower ones (Krishnamurty et al., 1973). There is a need for optimum leaf blade area and plant canopy that permits high light penetration for maximum grain yield in sorghum (Liang et al., 1973; Maas et al., 1987). This means that leaf area per se is not sufficient in increasing grain yield, rather upright leaves which improve light interception of the plant communities are required also in sorghum (Radford, 1967; Krishnamurty, 1973; Winter and Ohlrogge, 1973).

Allen et al. (1973) cited a study on grain sorghum in which it was found that the earliest maturing varieties had the lowest number of leaves, in addition late maturing varieties had larger leaves than early varieties.

2.5 LEAF AREA DURATION

Leaf area duration (LAD) is the period when the leaves of the plant are photosynthetically active (Krishnamurty et al., 1973). The formula for LAD of the plant canopy according to Radford (1967) can be expressed as

$$\sum_{n1}^{n} Ai$$

or

$$\int_{t1}^{t2} A\,dt$$

where A= leaf area of the ith sample

n= total number of leaf areas taken

t= time

"Stay green" is a desirable trait in sorghum since varieties with this property have LAD which allows for proper grain filling (Rosenow et al., 1988).

In wheat, it has been found that, grain yield is mainly a reflection of the LAD after ear emergence (Khalifa, 1973). Thorne and Watson (1955) found that early and late nitrogen application increased LAD and therefore grain yield. Early nitrogen application increased initial leaf area (Khalifa, 1973). Krishnamurty et al. (1974) reported that there was no statistical significant differences in LAD between sorghum genotypes studied, though one hybrid had greater LAD than varieties after head emergence.

2.6 SEEDLING VIGOUR SCORE.

Farmers prefer varieties with high seedling vigour which can compete with weeds. These varieties can be identified three weeks after planting. Studies by Artola (1985) indicate that OP are superior in seedling vigour score than both TWC and SC, however, no significance different was observed between the hybrids.

2.7 PLANT ASPECT SCORE

Plant aspect score refers to the agronomic aspects of the crop. Traits such as disease resistance, lodging, plant height, exertion of the panicle and the quality of the grain are considered in determining plant aspect score. Three way cross hybrids have been reported to vary in plant height, disease resistance and days to flower within each plot and this makes them less attractive to farmers than SC and OP (Atkins, 1971 and 1972; Bhale, 1982; Artola, 1985). Walsh and Atkins (1973) reported no significant difference between TWC and SC in plant height and days to mid bloom.

2.8 DISEASE SCORE

Leaf blight (*Helminthosporium turcicum* Pass), downy mildew (*Sclerospora sorghi* Weston and Uppal) and anthracnose (*Colletotrichum graminicola* Wilson) are the major diseases of sorghum (House, 1985). Anthracnose and downy mildew are not as important as leaf blight in the Southern Africa. There are varieties of sorghum which can resist infestation by the above diseases (House, 1985). Three way cross hybrids can enable disease resistance to be included in the varieties, at the same time allowing successful techniques for producing high grain yielding varieties.

2.9 PLANT HEIGHT

Sorghum hybrids have been reported to be taller than OP (Dogget, 1987). The TWC have been reported to be taller than SC (Liang _et al_., 1974; Torres-Cardona _et al_., 1983). However, other studies indicate that there are no differences in plant height (Atkins, 1971 and 1973; Miesner and York, 1973; Walsh and Atkins, 1973; Bhale, 1982). The differences in plant height can make mechanical harvesting difficult.

3 MATERIAL AND METHODS

3.1 MATERIALS

Eight pairs of male-sterile (A) and maintainers (B) lines (isogenic lines) and three fertility restoring (R) lines were obtained from the Zambian National Sorghum Improvement Programme based at Mt Makulu Research Station, Chilanga, Zambia. These are listed below:

A lines	B - lines
SPL 177A	SPL 177B
ICSA 16	ICSB 16
ICSA 23	ICSB 23
ICSA 24	ICSB 24
ICSA 40	ICSB 40
MA-9	MB-9
SDS 4287A	SDS 4287B
SDS 4340A	SDS 4340B

R-Lines (Fertility restoring)

MR 102

MR 101 (SDS 3845)

1580

The A-lines were crossed to the B-lines in 1990/91 season in a manner avoiding a cross between isogenic lines. This resulted in 28 SC. The crossing was done under strict supervision at the University Field Station. Twelve of these crosses were chosen based on flowering synchrony which had a bearing on seed set for crossing with R-lines. These were crossed to each of the R-lines to produce seeds of TWC during 1991 dry season under irrigation at National Irrigation Research Station (Mazabuka). Twelve TWC which had sufficient seed were included in the experiment. In addition eleven fertile SC and two OP which were at advanced stages of testing were obtained from the Zambian National Sorghum Improvement programme at Mt Makulu Research Station, Chilanga, Zambia were included in the trials (Table.1).

Table.1. List of entries in the trials.

Entry	Name	Pedigree
1	TWC-1	(MA-9 x SDS 4287b) x SDS 3845*
2	TWC-2	(MA-9) x SDS 4287B) x MR 102
3	TWC-3	(MA-9 x SDS 4340B) x SDS 3845
4	TWC-4	(MA-9 x SPL 177B) x SDS 3845
5	TWC-5	(MA-9 x SPL 177B) x MR 102
6	TWC-6	(SDS 4287A x SDS 4340B) x SDS 3845
7	TWC-7	(SPL 177A x MB-9) x 1580
8	TWC-7A	(SPL 177A x MB-9) x MR 102
9	TWC-8	(ICSA-24 x ICSB 23) x SDS 3845
10	TWC-9	(ICSA-24 x SDS 4287B) x SDS 3845
11	TWC-10	(ICSA-40 x ICSB-24) x SDS 3845
12	TWC-11	(ICSA-40 x SDS 4340B) x SDS 3845
13	MMSH 625 (SC)	
14	MMSH 375 (SC)	
15	MMSH 714 (SC)	
16	WSH 287 (SC)	
17	MMSH 740 (SC)	
18	MMSH 413 (SC)	
19	MMSH 1040 (SC)	
20	MMSH 1028 (SC)	
21	MMSH 928 (SC)	
22	MMSH 1141 (SC)	
23	MMSH 1012 (SC)	
24	Sima (O.P)	
25	Kuyuma (O.P)	

*. SDS 3845 is the same as MR 101
N.B. TWC, SC and OP stands for three way cross, single cross and open pollinated varieties, respectively.

3.2 METHODS

3.2.1 GENERAL

The 25 entries were planted at five locations namely the University Field Station (Lusaka province), Liempe farm (Lusaka province), Golden Valley (Lusaka Province), Lusitu (Southern province) and Masstock-Chiawa (Southern Province) during the 1991/92 rain season. Southern province represents the major sorghum growing area of Zambia. The sites are described in Table 2.

Differences in planting dates, interrow spacing, inherent soil fertility and climatic conditions provided a wide range in environmental variation among the different sites.

3.2.2 FIELD MANAGEMENT

Entries were arranged in a 5 x 5 triple lattice design with three replications at each location. The entries were planted in four row plots spaced at 75 cm apart with the exception of Masstock were the space between the rows was 110cm apart to create a different environment from that of Lusitu which is in the same locality. Each row was four metres long. The seed was drilled in the rows and were thinned to a within-row plant spacing of 15 cm three weeks after planting. The centre two rows for each plot were used

Table. 2. Site description and planting dates.

Site	Soil type	pH	Planting date
Field Station	clay loam	5-7	6/12/91
Liempe	clay loam	4	13/12/91
Golden Valley	heavy clay	5-7	12/12/91
Masstock	Sand loam	5-6	12/2/92
Lusitu	Sand loam	5-6	16/1/92

Source: Davies (1971)

for grain yield, leaf area determination, plant height measurements, disease score, plant aspect score and plant stand count.

Compound "D" fertilizer was applied as basal dressing at a rate of 200 kg/ha (40.8 kg - nitrogen, 40.8 kg - Potassium, 81.7 kg - phosphorus and 36.7 kg - sulphur) before planting. 45 days after, urea $[CO(NH_2)_2]$ fertilizer was applied at a rate of 100 kg/ha (46 kg- nitrogen). In Lusitu and Masstock, furadan was applied at a rate of about 20 kg/ha to control shootfly and termites attack on young seedlings plants. In Lusitu, atrazine was applied to control weeds.

3.3 OBSERVATIONS

Observations were taken from the two central rows with the exception of seedling vigour which was recorded from all four rows of the plot. The observations taken were:

a. Seedling vigour score. This was based on visual score, the score ranged from 1 to 5, 1-excellent, 2-good, 3-average, 4-poor, and 5-very poor. Seedling vigour scoring was observed at three weeks after planting in all five locations.

b. Days to 25% heading. This was recorded as the days from planting to when 25% of the plants in the two middle rows had headed. The observations were recorded at the Field Station and Liempe which were very close to the Universty since they required frequent visits to estimate the days to flowering.

c. Days to 50% heading. This was recorded as days from planting to when 50% of the plants in the two middle rows had headed. Locations: Field Station, Liempe, Golden Valley, Masstock and Lusitu. Very few entries reached 50% heading at Lusitu, therefore, the location was not included in the analysis.

d. Days to 75% heading. This was recorded as the days from planting to when 75% of the plants in the two middle rows had headed. The observations were recorded at Field Station and Liempe since they required regular visits to take the observations.

e. Plant height. Twenty randomly selected plants from the two middle rows of the plot were measured from ground level to the top of the head at physiological maturity for each plot at the following locations: Field Station, Liempe, Golden Valley, Masstock and Lusitu.

f. Plant aspect score. An agronomic score was made based on visual scores ranging from 1 to 5, 1- excellent, 2-good, 3-average, 4-poor, 5-very poor. The score was made just before harvesting and the main characters which determined the score were size and shape of the head, plant height, quality and size of the grain and the ability to withstand lodging. Locations: Field Station, Liempe, Golden Valley, Masstock and Lusitu.

g. Disease score. Disease scoring was done for combined effects of leaf blight (*Helminthosporium turcicum* Pass), downy mildew (*Sclerospora sorghi* Weston and Uppal) and anthracnose (*Colletotrichum graminicola* Wilson). A visual score was made based with scores ranging from 1 to 5, where 1-excellent (disease free), 2-good, 3-average, 4-poor, 5-very poor (susceptible to disease). Locations: Field Station, Liempe, Golden Valley and Masstock. At Lusitu disease score was not taken because plants dried of severe drought.

h. Leaf area before flowering. Leaf area of five plants per plot was determined using only the main tiller per chosen plants at random. The length and width of each green leaf per plant were measured. The area per leaf was then estimated using the following equation: Leaf area = length x width x 0.75 (Prior and Russel, 1976; Krishnamurty, *et al.*, 1974). The sum of individual leaf areas per plant then determines the leaf area per plant. The average of five plants was then multiplied by the number of plants on the plot to determine the leaf area per plot. Leaf area index was then determined by dividing the leaf area per plot by the corresponding land area ($4.5m^2$). The measurement of leaf area was time consuming cosidering the number of entries in the trial and hence Field Station was the only site used.

i. Leaf area after flowering. This leaf area was measured two weeks after all the plants had flowered. The method used to determine the leaf area and leaf area index is the same as that for leaf area measurement before flowering. Location: Field Station.

j. Leaf area duration. The sum of the leaf area before and after flowering measured at Field Sttion was considered as the leaf area duration.

k. Grain weight. The grain weight was obtained from the two middle rows. Half a meter was not harvested from the alleys to avoid border effect. The total area harvested was 4.5 m^2 The moisture content was determined and the grain weight was converted to 13% moisture content. Locations: Field Station, Liempe, Golden Valley, Masstock and Lusitu.

l. 100 grain weight. 100 grains of sorghum were counted and then weighed. Three samples were obtained per plot and their average was used in this analysis. Locations: Field Station, Liempe, Golden Valley and Masstock. Lusitu was not included since some plots yielded nothing because of severe drought.

m. Uniformity. Uniformity was derived from individual plant height measurements within the plot whose standard deviations within the plot were determined, and difference between 25 and 75% days to heading. Varieties with small within plot standard deviation for plant height were considered to be uniform.

3.4 STATISTICAL ANALYSIS

Data collected was tested for homogeneity of variances for each location and across locations using Bartlett's test.

Analysis of variance (ANOVA) for each location and across locations was carried out on the following observations: seedling vigour, days to 50% heading, plant height, plant aspect score, disease score, leaf area before and after heading, leaf area index before and after heading, grain weight and 100 grain weight. The above observations with exception of grain yield had no lattice corrections and were analyzed as randomised complete block design (RCBD) in combined analysis and therefore RCBD error was used as basis for comparison. Effective error for lattice design was used where there were lattice corrections. In addition, where there were lattice corrections, adjusted means were separated.

The following non-orthogonal comparisons were carried out:

-TWC versus SC.

-TWC versus OP.

-SC versus OP.

Stability analysis was carried out using Eberhart and Russel (1966) method. Least significant differences (LSD) method was used to determine the significance of the b-values following Steel and Torrie (1960) method.

$$LSD \doteq t\alpha_{(d.f)} \sqrt{(MS \text{ pooled error}/\Sigma I^2 j)}.$$

where: $t\alpha$, = is the t-value at α=0.05 for the number of degrees of freedom associated with error mean square.

s= number of sites

r= number of replications

$S.E_b$= standard error of the b-value

I^2= sums of squares for the environmental index

The entry mean, b-value, and standard deviation from regression were used to characterize the stability of the entries.

Correlations among leaf area, leaf area index before and after heading, leaf area duration and grain yield, and, other components of yield were determined.

4 RESULTS AND DISCUSSION

There was within location heterogeneity of variances for grain yield and harvested head weight at Liempe, Lusitu and Golden Valley. However, combined location analysis was homogenous for all characters. Since individual locations were not as important as overall locations, the heterogeneity of individual locations was ignored on the assumption that it did not affect combined location analysis.

4.1 SEEDLING VIGOUR SCORE

Table 3 presents ANOVA for seedling vigour per location and across location. Table 4 presents means for seedling vigour.

Entries effects were not significantly different ($p<0.05$) within each location except at Lusitu. Locations and entries were significantly different ($p<0.01$), while locations by entries interactions were not significant in combined analysis of variance. The location with the best seedling vigour was Masstock (2.0) and the poorest was Golden Valley (3.0). Across locations means indicate that MMSH 740, Sima, TWC-6, MMSH 1141 and TWC-8 had the best seedling vigour and did not differ significantly ($p<0.05$) from each other. There were no differences among the groups of genotypes across locations. Artola (1985) found out that OP were superior to hybrids which does not conform with the present study which indicate no differences among the groups.

Table. 3. Mean squares for analysis of variance for seedling vigour scores for twelve three way cross (TWC), 11 single cross hybrids (SC) and two open pollinated varieties (OP) of sorghum at five locations in 1991/92 season.

Source of variation	Degress of freedom	Location				Combined	
		Field Station	Liempe	Masstock	Lusitu	D.F	Mean square
location	—	—	—	—	—	4	17.74**
Replication(loc)	2	0.65	2.44	0.17	0.16	10	0.68
Entries (unadj)	24	0.27	0.46	0.05	1.73*	24	0.77**
location X Entries unadj.	—	—	—	—	—	96	0.44
RCBD error	48	0.18	0.75	0.05	0.87	240	0.37
Blocks (within adj.)	12	0.35	0.76	0.10	0.84		
Intrablock error	36	0.12	0.74	0.03	0.88		
Entries (adj.)	24	0.24	—	0.04	—		
- TWC vs SC	—	—	—	—	—	1	0.50
- TWC vs O.P	—	—	—	—	—	1	0.21
- SC vs O.P	—	—	—	—	—	1	0.03
Effective error	36	0.14	—	0.04	—		

*,** Indicates significance at p<0.05 and P<0.01, respectively.

N.B. RCBD error was used to compare entries across locations.

Table. 4. Mean of seedling vigour scores for 12 three way cross (TWC), 11 single cross (SC) hybrids and two open pollinated (OP) varieties of sorghum at five locations in 1991/92 season.

Entry	Field Station	Liempe	Golden Valley	Masstock	Lusitu	Overall mean
TWC-1	2.5	2.3	3.0	2.1	3.3	2.5
TWC-2	3.0	2.7	3.0	2.0	4.0	2.9
TWC-3	2.7	2.3	3.0	2.0	2.0	2.4
TWC-4	2.8	2.0	3.0	2.0	2.7	2.5
TWC-5	2.4	2.7	3.0	1.9	3.7	2.7
TWC-6	2.7	2.0	3.0	1.7	2.3	2.3
TWC-7	2.6	1.7	3.0	2.0	3.7	2.6
TWC-7A	3.1	2.3	3.0	2.0	3.3	2.7
TWC-8	2.9	2.0	3.0	2.0	2.3	2.6
TWC-9	3.0	2.7	3.0	2.0	2.0	2.5
TWC-10	2.4	2.7	3.0	1.8	3.0	2.6
TWC-11	2.9	2.3	3.0	2.3	3.0	2.7
MMSH 625 (SC)	2.8	2.3	3.0	2.0	2.7	2.6
MMSH 375 (SC)	3.2	2.3	3.0	2.0	3.3	2.8
MMSH 714 (SC)	3.0	1.7	3.0	2.1	3.3	2.6
WSH 287 (SC)	2.6	2.3	3.0	2.0	4.3	2.8
MMSH 740 (SC)	2.1	1.7	3.0	1.9	2.0	2.1
MMSH 413 (SC)	2.8	2.3	3.0	2.0	3.0	2.6
MMSH 1040 (SC)	3.0	2.3	3.0	2.0	4.3	2.9
MMSH 1028 (SC)	3.0	2.3	3.0	1.8	3.7	2.8
MMSH 928 (SC)	3.4	2.0	3.0	2.0	4.3	2.9
MMSH 1141 (SC)	3.0	2.0	3.0	2.0	2.3	2.5
MMSH 1012 (SC)	2.6	2.0	3.0	2.0	2.3	2.4
Sima(OP)	2.5	1.7	3.0	2.0	2.3	2.3
Kuyuma (OP)	3.0	2.3	3.0	2.0	3.7	2.8
Grand Mean	2.8	2.2	3.0	2.0	3.1	2.6
LSD 0.05	0.6	1.4	0.0	0.3	1.5	0.5
C.V %	13.6	38.5	-	9.9	30.4	23.2
TWC	2.8	2.3	3.0	2.0	2.9	2.6
SC	2.9	2.1	3.0	2.0	3.2	2.6
OP	2.8	2.0	3.0	2.0	3.0	2.6

N.B. Seedling vigour scores were as follows, 1-excellent, 2-good, 3-average, 4-poor and 5-very poor.

The results suggest that locations used had different climatic and soil factors. These differences, however, did not result in the sorghum entries responding differently from location to location in terms of their seedling vigour.

The severe drought stress experienced at Lusitu could explain the significant differences among entries for seedling vigour (Appendix. IV). Only those entries which tolerated dry conditions had better seedling vigour. Another factor which might have contributed to the differences in seedling vigour score at Lusitu could be the effect of the chemicals used. These chemicals, atrazine and furadan could have affected the growth and development of the entries differently.

4.2 PLANT ASPECT SCORE

Table 5 presents the ANOVA table for plant aspect score per location and across location. Table 6 presents means for plant aspect score.

Entries were significantly different ($p<0.05$) at most locations for plant aspect score except at Field Station (Table 5). Locations, entries and locations by entries interaction sources of variation were significantly ($p<0.05$) in combined analysis for plant aspect score. Mean plant

Table. 5. Mean squares for analysis of variance for plant aspect scores of twelve three way cross (TWC), 11 single cross hybrids (SC) and two open pollinated varieties (OP) of sorghum at five locations in 1991/92 season.

		Location					Combined	
Source of Variation	Degrees of Freedom	Field Station	Liempe	Golden Valley	Masstock	Lusitu	D.F	Mean square
Location	--	--	--	--	--	--	4	21.70**
Replication(loc)	2	2.08	0.41	0.09	2.17	1.05	10	1.16
Entries (unadj)	24	0.81	0.90*	0.53**	1.56**	2.06**	24	2.26**
Location X Entries unadj.	--	--	--	--	--	--	96	0.90**
RCBD error	48	0.55	0.40	0.16	0.40	0.69	240	0.44
Blocks (within adj.)	12	0.75	0.52	0.20	0.52	1.46	60	0.69
Intrablock error	36	0.49	0.36	0.15	0.36	0.44	180	0.36
Entries (adj.)	24	0.78	0.86*	0.52**	1.64**	2.11**	24	2.25**
- TWC vs S.C	1	3.23**	3.66**	0.66**	1.06	5.14**	1	12.41**
- TWC vs O.P	1	0.97	0.03	0.06	3.57**	6.13**	1	0.46
_ SC vs O.P	1	0.00	0.75	0.47	5.94**	1.51	1	1.54**
Location x Entries adj.	--	--	--	--	--	--	96	0.92**
Effective error	36	0.34	0.39	0.16	0.38	0.51	180	0.39

*,** Indicates significance at p<0.05 and P<0.01, respectively.

N.B Effective error was used to compare entries across locations.

Table. 6. Means of plant aspect scores for 12 three way cross (TWC), 11 single cross (SC) hybrids and two open pollinated varieties (OP) of sorghum across locations and combined over locations.

Entry	Field Station	Liempe	Golden Valley	Masstock	Lusitu	Overall mean
TWC-1	2.3	3.9	3.3	3.6	4.1	3.4
TWC-2	2.9	2.6	2.3	1.6	4.4	2.8
TWC-3	3.4	2.5	2.4	3.4	3.9	3.1
TWC-4	3.0	2.9	2.6	3.3	4.2	3.2
TWC-5	2.8	2.2	2.3	2.3	3.9	2.7
TWC-6	2.4	3.0	3.0	3.4	3.4	3.0
TWC-7	2.8	2.1	2.3	2.7	4.5	2.9
TWC-7A	2.4	2.3	2.4	2.7	4.5	2.9
TWC-8	3.0	3.0	3.0	2.4	4.2	3.1
TWC-9	2.5	3.0	3.3	2.4	4.3	3.1
TWC-10	3.4	3.0	3.0	3.6	4.5	3.5
TWC-11	3.0	3.4	3.0	3.0	4.5	3.4
MMSH 625 (SC)	1.7	1.7	2.0	1.5	4.5	2.3
MMSH 375 (SC)	1.5	1.7	2.0	1.6	3.3	2.0
MMSH 714 (SC)	2.6	2.4	3.0	4.0	2.3	2.9
WSH 287 (SC)	1.8	2.4	1.9	2.1	3.1	2.2
MMSH 740 (SC)	3.3	2.7	3.0	3.8	2.5	3.1
MMSH 413 (SC)	1.8	2.4	2.7	3.0	4.4	2.9
MMSH 1040 (SC)	2.7	2.4	2.7	2.9	4.1	3.0
MMSH 1028 (SC)	3.0	2.7	2.7	2.6	4.8	3.2
MMSH 928 (SC)	2.6	3.0	3.0	2.0	3.3	2.8
MMSH 1141 (SC)	3.0	3.0	3.0	3.0	4.3	3.3
MMSH 1012 (SC)	2.4	1.6	2.1	2.3	3.5	2.4
Sima(OP)	2.4	2.6	3.0	4.0	4.7	3.3
Kuyuma (OP)	2.4	2.9	2.7	3.4	1.5	2.6
Grand Mean	2.6	2.6	2.7	2.8	3.9	2.9
LSD 0.05	1.2	1.0	0.7	1.0	1.2	1.0
C.V. %	13.6	38.5	-	9.9	30.4	23.2
TWC	2.8	2.8	2.7	2.9	4.2	3.1
SC	2.4	2.4	2.6	2.6	3.6	2.7
OP	2.4	2.8	2.9	3.7	3.1	3.0

N.B. Plant aspect scores were as follows; 1-excellent, 2-good, 3-average, 4-poor and 5-very poor.

aspect score of TWC and SC were significant different ($p<0.05$) from each other at Field Station, Liempe, Golden Valley and Lusitu. The mean plant aspect score of TWC were not significantly different ($p<0.05$) from that of OP at Field Station, Liempe and Golden Valley. However, TWC were significantly different ($p<0.05$) at Masstock and Lusitu. SC were not significantly different ($p<0.05$) from that of OP at all locations except at Masstock.

Across locations, TWC plant aspect score were significantly different ($p<=0.01$) from that of SC (Table 5). TWC and OP were not significantly different ($P<0.05$) from OP, however, SC were significantly different ($p<0.01$) from OP.

The following entries were rated best at each of the locations; MMSH 625, WSH 287, MMSH 375 and MMSH 413 (Field Station), MMSH 625, MMSH 375 and MMSH 1012 (Liempe), WSH 287, MMSH 625, MMSH 375 and MMSH 1012 (Golden Valley), TWC-2, MMSH 375, MMSH 625 and MMSH 1012 (Masstock), and, Kuyuma (Lusitu) (Table 6). At Field Station, Liempe farm, Golden Valley and Lusitu, SC had better score than TWC. At Masstock, TWC had better score than OP, but at Lusitu, OP had better score than TWC. At Masstock, SC had a better score (2.6) than OP (3.7).

Field Station had the best score (2.6) and Lusitu, the poorest (3.9) (Table 6). SC (2.7) were superior to TWC (3.1) and OP (3.0) when overall means were considered.

The results indicate that the effects of locations on plant aspect score were different. These differences resulted in sorghum entries responding differently to the change from one location to another as confirmed by significant location by entries interaction.

The TWC had better plant aspect score at Masstock than OP as they have responded better to irrigation. The OP out performed TWC at Lusitu probably because they tolerated drier conditions better than TWC, since, Kuyuma one of the OP used had been selected for drier environments (Dr. Verma - Pers. com.[1]).

Overall, SC had superior plant aspect score than TWC and OP since they had been selected by local breeding programme for their agronomic performance whilst TWC were not. In the same token, it was expected that OP would have better score than TWC, but this was not the case. The reason might be due to the fact that very few OP were used compared to TWC to give a representative response of the OP.

4.3 DISEASE SCORE

The ANOVA for scores for presence of combinations of the following diseases: Leaf blight (Helminthosporium turcicum),

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[1]Dr. B N Verma is the Principal Sorghum Breeder for the Zambia Sorghum and Millet Improvement Team.

Downy mildew (Sclerospora sorghi, Weston and Uppal) and anthracnose (Colletotrichum graminicola, Wilson) is presented in Table 7. Means for disease scores are presented in Table 8.

Entries had significant effect ($p<0.01$) at all locations for disease score (Table 7). Mean disease scores for TWC and SC score were not significantly different at all locations. Mean disease scores of hybrids were significantly different ($p<0.05$) from that of OP at Field Station, Liempe and Masstock except at Golden Valley.

Locations, entries and locations by entries interaction effects were significant ($p<0.05$) across locations. The TWC and SC mean disease scores were not significantly different ($p<0.05$) from each other while hybrids were significantly different ($p=0.05$) from that of OP across locations.

The best tolerant entries to disease pressure were; Sima and MMSH 1040 (Field Station); Sima, WSH 287, MMSH 1040 and MMSH 1012 (Liempe); Sima, MMSH 1040 and MMSH 1012 (Golden Valley); and, Sima, MMSH 1040 and WSH 287 (Masstock) (Table 8). MMSH 1028 was the worst affected by disease at most locations except Masstock. The OP were superior, overall, in their scores than hybrids.

The highest disease pressure was at University Field Station (3.0) followed by Liempe (2.5), Golden Valley (2.5) while the

Table. 8. Means of disease score for 12 three way crosses (TWC), 11 single cross hybrids (SC) and two open pollinated (OP) varieties of sorghum at four locations in 1991/92 season.

Entry	Field Station	Liempe	Golden Valley	Masstock	Overall mean
TWC-1	3.9	3.0	3.1	2.7	3.2
TWC-2	2.1	2.0	1.9	1.6	1.9
TWC-3	2.9	2.3	2.3	2.8	2.6
TWC-4	3.9	3.0	2.7	3.4	3.3
TWC-5	2.7	2.3	2.1	2.8	2.5
TWC-6	2.6	2.3	2.0	2.1	2.3
TWC-7	2.9	3.0	2.7	1.0	2.4
TWC-7A	2.8	2.0	1.8	1.3	2.0
TWC-8	4.0	3.0	2.6	2.7	3.1
TWC-9	2.9	2.7	2.6	1.7	2.5
TWC-10	2.9	2.0	2.2	3.0	2.6
TWC-11	3.0	2.3	2.1	3.0	2.6
MMSH 625 (SC)	2.3	2.3	1.9	1.9	2.1
MMSH 375 (SC)	2.7	2.7	2.3	2.7	3.6
MMSH 714 (SC)	3.3	2.3	4.2	3.1	3.6
WSH 287 (SC)	2.2	1.7	2.6	1.0	1.9
MMSH 740 (SC)	2.1	2.7	2.8	2.5	2.5
MMSH 413 (SC)	2.8	2.3	2.1	2.7	2.7
MMSH 1040 (SC)	2.0	1.7	1.2	1.0	1.4
MMSH 1028 (SC)	4.4	4.3	3.6	3.1	3.9
MMSH 928 (SC)	3.6	2.7	2.0	1.9	2.6
MMSH 1141 (SC)	3.4	3.0	2.6	2.9	3.0
MMSH 1012 (SC)	2.7	1.7	1.8	3.5	2.4
Sima(OP)	1.7	1.0	1.4	1.0	1.3
Kuyuma (OP)	2.8	2.7	2.1	1.5	2.5
Grand Mean	3.0	2.5	2.4	2.3	2.5
LSD 0.05	1.0	1.2	0.8	0.9	1.0
C.V.%	21.3	30.3	19.8	23.1	24.4
TWC	3.1	2.5	2.3	2.3	2.6
SC	2.9	2.5	2.5	2.4	2.7
OP	2.3	1.9	1.8	1.3	1.9

N.B Disease scores were as follows: 1-disease free, 2-good, 3-average, 4-susceptible and 5-very susceptible.

least pressure was at Masstock (2.3). The OP had better mean disease score than hybrids (Table 8).

The results suggest that the disease pressure among the locations was different. The differences in disease pressure among locations resulted in the sorghum entries performing differently relative to each other.

The significant effects of entries within each location and across locations indicate that entries differ in their ability to tolerate disease pressure. From the results, it can be suggested that Sima, MMSH 1040, WSH 287 and TWC-2 can tolerate disease pressure.

Overall, the two kinds of hybrids, TWC and SC responded equally to disease pressure as indicated by lack of significance difference between TWC and SC. The results show that OP are superior to hybrids in their ability to tolerate disease. The OP were superior to hybrids in disease tolerance because, there was an inclusion of disease tolerance in their selection (Verma - Pers. com[2])

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[2]Dr B. N. Verma - Principal Sorghum Breeder for the Zambia Sorghum and Millet improvement team at Mt Makulu, Chilanga.

4.4 DAYS TO 50% HEADING.

Table 9 presents the ANOVA for days to 50% heading. Table 10 presents the means for days to 50% heading.

Entries effects were significantly different ($p<0.01$) within each location for days to 50% heading (Table 9). Locations, entries and locations by entries interaction were significantly different ($p<0.05$) across locations. The TWC and SC were significantly different ($p<0.05$) from each other at Field Station, Liempe and Golden Valley except at Masstock. Mean days to 50% heading of TWC were significantly different ($p<0.05$) from that of OP at all locations. Mean days to 50% heading of SC and OP were significantly different ($p<0.05$) from each other at Field Station and Masstock but not at Liempe and Golden Valley. Mean days to 50% heading of TWC and SC were significantly different ($p<0.05$) across locations, while no significant difference was observed between the hybrids and OP across locations.

The earliest entries to head within each location were; MMSH 1028 (Field Station), MMSH 1012 (Liempe), MMSH 714 (Golden Valley) and MMSH 740 (Masstock) (Table 10). Entries identified as late in maturity at the same locations were; MMSH 1028, TWC-7A, MMSH 1040 and WSH 287, respectively (Table 10). TWC had higher mean than OP. Days to 50% heading of TWC

Table. 9. Mean squares for analysis of variance for days to 50% heading of twelve three way cross (TWC), 11 single cross hybrids (SC) and two open pollinated varieties (OP) of sorghum at four locations in 1991/92 season.

		Location				Combined	
Source of Variation	Degrees of Freedom	Field Station	Liempe	Golden Valley	Masstock	D.F	Mean square
Location	—	—	—	—	—	3	1259.95**
Replication(loc)	2	7.00	400.57	0.52	58.89	8	116.75
Entries (unadj)	24	33.91**	158.29**	55.15**	16.77**	24	147.89**
Location X Entries unadj.	-	—	—	—	—	72	38.74**
RCBD error	48	8.12	57.46	6.01	3.56	192	18.79
Blocks (within adj.)	12	21.96	77.39	9.51	4.37	48	28.31
Intrablock error	36	3.51	50.82	4.84	3.29	144	15.62
Entries (adj.)	24	31.03**	150.71**	55.29**	16.88**	24	142.00**
- TWC vs S.C	1	22.77*	822.38**	69.92**	1.68	1	195.80*
- TWC vs O.P	1	22.60*	249.60*	37.03*	26.23**	1	36.00
_ SC vs O.P	1	53.01**	0.01	2.27	19.22*	1	2.68
Location x Entries adj.	—	—	—	—	—	72	37.30**
Effective error	36	4.25	55.18	5.43	3.49	144	17.09

*,** Indicates significance at $p<0.05$ and $p<0.01$, respectively.

N.B. Effective error was used to compare entries across locations.

Table. 10. Means of days to 50% heading of 12 three way cross (TWC), 11 single cross (SC) hybrids and two open pollinated varieties (OP) of sorghum at four locations in 1991/92 season.

Entry	Field Station	Liempe	Golden Valley	Masstock	Overall Mean
TWC-1	78	97	75	65	79
TWC-2	81	109	79	66	84
TWC-3	76	98	74	65	78
TWC-4	77	99	75	64	79
TWC-5	78	106	80	68	83
TWC-6	78	100	76	65	80
TWC-7	76	102	75	67	80
TWC-7A	78	108	77	68	83
TWC-8	71	88	75	66	75
TWC-9	78	97	75	66	79
TWC-10	71	99	74	65	77
TWC-11	75	99	75	64	78
MMSH 625 (SC)	79	102	76	66	81
MMSH 375 (SC)	77	100	81	66	81
MMSH 714 (SC)	72	90	64	63	72
WSH 287 (SC)	77	104	78	73	83
MMSH 740 (SC)	72	89	67	61	70
MMSH 413 (SC)	76	90	74	65	76
MMSH 1040 (SC)	83	96	85	68	83
MMSH 1028 (SC)	70	89	72	66	74
MMSH 928 (SC)	75	92	70	69	76
MMSH 1141 (SC)	74	98	76	64	76
MMSH 1012 (SC)	74	86	74	65	75
Sima(OP)	80	88	77	69	78
Kuyuma (OP)	78	99	70	67	78
Grand Mean	76	97	75	67	78.4
LSD 0.05	3	12	4	3	74.9
C.V %	2.7	7.7	3.1	2.8	5.3
TWC	76	100	76	66	80
SC	75	94	74	66	77
OP	79	94	74	68	78

within each location was slightly longer than those of SC (Table 10). OP had a slightly higher mean at the two locations.

Maturity was latest at Liempe followed by Field Station, Golden Valley and then Masstock (Table 10). The TWC had mean of 80 days and SC had 77 days.

The differences in locations resulted in entries having different days to maturity at different locations. The differences in location might be due to temperature differences. At Masstock and Lusitu which had the highest temperatures, entries matured early than Liempe and Field Station with lower temperatures. High temperature hasten growth and development.

The results indicate that TWC were later in maturity than SC across locations. These results agree with studies by Liang at al. (1974) who reported that TWC were later in maturity than SC. However, the results contradict the studies by Walsh (1971) who reported that TWC and SC did not differ in their maturity. The results also show that, there are no differences in maturity between the hybrids and OP which contradict the findings by Dogget (1987) who reported that hybrids in general were later in maturity than OP.

Difference in the results of the study from those reported by other researchers could be related to the genetic material included.

4.5 DAYS BETWEEN 25% AND 75% DAYS TO HEADING.

Table 11 presents ANOVA for days between 25 and 75% days to heading. Table 12 presents the means of days between 25 and 75% days to heading.

Entries effects was not significant ($p<0.05$) in days between 25 and 75% heading at Field Station and Liempe. Entries and locations by entries interaction effects were not significant ($p<0.05$) across locations, however, locations effects was significant ($p<0.01$) (Table 11).

High coefficients of variation where recorded for days between 25 and 75% days to heading at Field Station, Liempe and across these two locations. This was due to uneven germination of the entries planted within the replications. Mean days between 25 and 75% days to heading for TWC was the same as those for SC and OP.

Table. 11. Mean squares for analysis of variance for days between 25% and 75% days to heading for twelve three way cross (TWC), 11 single cross hybrids (SC) and two open pollinated varieties (OP) of sorghum at two locations in 1991/92 season.

Source of variation	Degrees of freedom	Location		Combined	
		Field Station	Liempe	D.F	Mean square
Location	--	--	--	1	1944.00**
Replication(loc)	2	7.37	26.17	4	16.77
Entries (unadj)	24	4.25	58.38	24	29.63
Location X Entries unadj.	--	--	--	24	33.00
RCBD error	48	3.69	47.33	96	25.50
Blocks (within adj.)	12	5.80	61.58	24	11.23
Intrablock error	36	2.99	42.57	72	22.78
Entries (adj.)	24	4.61	51.43	24	26.62
Location x Entries adj.	--	--	--	24	29.42
Effective error	36	3.35	45.86	72	24.61

** Indicates significance at $p<0.01$.

N.B. Effective error was used for comparing entries since there were lattice corrections.

Table. 12. Means of days between 25 and 75% days to heading of twelve three way cross (TWC), 11 single cross (SC) hybrids and two open pollinated (OP) varieties of sorghum at two locations in 1991/92 season.

Entry	Field Station	Liempe	Overall mean
TWC-1	6	14	10
TWC-2	9	7	8
TWC-3	5	16	11
TWC-4	4	21	12
TWC-5	7	10	8
TWC-6	4	15	9
TWC-7	6	10	8
TWC-7A	6	8	7
TWC-8	7	21	16
TWC-9	7	18	11
TWC-10	5	11	8
TWC-11	6	15	10
MMSH 625 (SC)	6	15	11
MMSH 375 (SC)	6	16	10
MMSH 714 (SC)	6	8	7
WSH 287 (SC)	6	10	8
MMSH 740 (SC)	4	6	5
MMSH 413 (SC)	6	17	11
MMSH 1040 (SC)	7	9	8
MMSH 1028 (SC)	5	13	9
MMSH 928 (SC)	6	9	7
MMSH 1141 (SC)	6	15	11
MMSH 1012 (SC)	5	10	7
Sima(OP)	6	14	10
Kuyuma (OP)	4	15	9
Grand Mean	6	13	9
LSD 0.05	3	11	8
C.V %	32.2	52.5	53.9
TWC	6	14	10
SC	6	12	8
OP	5	15	10

These results contradict the findings by Atkins (1971, 1972 and 1973), Miesner and York (1973), Walsh and Atkins (1973), and, Patanothai and Atkins (1974) who reported that TWC varied in days to heading. The variability in days to heading was reported to be significantly related to grain yield in TWC (Atkins, 1972).

4.6 PLANT HEIGHT

The ANOVA for plant height is presented in Table 13.

The effects of entries was significant different ($p<0.01$) at all locations for plant height. Locations, entries and locations by entries interaction effects were significantly ($p<0.01$) in combined location analysis.

Mean plant height of TWC and SC were not significantly different ($p<0.05$) at all locations. Mean plant height of TWC and OP plant height were significantly different ($p<0.05$) at Golden Valley and Lusitu. SC and OP were not significantly different ($p<0.05$) at all locations except at Field Station and Lusitu. Across locations, mean plant height of TWC and SC did not differ significantly ($p<0.05$), however, mean plant heights of hybrids and OP differed signicantly ($p<0.05$).

Table. 13. Mean squares for analysis of variance for plant height of twelve three way cross (TWC), 11 single cross hybrids (SC) and two open pollinated varieties (OP) of sorghum at five locations in centimetres for 1991/92 season.

Source of variation		Location					Combined	
Source of Variation	Degrees of Freedom	Field Station	Liempe	Golden Valley	Masstock	Lusitu	D.F	Mean square
Location	—	—	—	—	-	—	4	60122.71**
Replication(loc)	2	8.69	38.44	120.37	7745.01	309.10	10	1644.30
Entries (unadj)	24	760.33**	256.70**	509.05**	690.43**	615.27**	24	1738.61**
Location X Entries unadj.	—	—	—	—	—	—	96	273.29**
RCBD error	48	103.05	82.79	117.23	223.72	256.56	240	156.56
Blocks (within adj.)	12	222.49	121.06	151.32	340.90	343.72	60	236.69
Intrablock error	36	61.91	70.03	105.87	184.66	227.52	180	129.99
Entries (adj.)	24	676.36**	261.74**	486.09**	697.49**	598.52**	24	1708.26**
- TWC vs S.C	1	9.16	0.44	118.85	17.03	6.08	1	15.67
- TWC vs O.P	1	261.08	184.12	622.29*	0.44	2331.44**	1	1129.70**
_ SC vs O.P	1	313.22*	172.12	355.91	8.40	2431.91**	1	976.06**
Location x Entries adj.	—	—	—	—	—	—	96	252.99**
Effective error	36	73.16	77.41	113.82	205.82	246.75	180	143.39

*,** Indicates significance at p<0.05 and P<0.01, respectively.

N.B Effective error was used to compare entries across locations.

Table. 14. Means for plant height of 12 three way cross (TWC), 11 single (SC) and two open pollinated (OP) varieties of sorghum at five locations in 1991/92 season in centimetres.

Entry	Field Station	Liempe	Golden Valley	Masstock	Lusitu	Overall mean
TWC-1	144.8	81.0	115.0	146.0	101.2	117.6
TWC-2	132.7	98.0	129.2	149.6	83.6	118.6
TWC-3	147.3	83.5	119.8	162.0	107.8	124.1
TWC-4	144.2	83.3	119.9	128.9	103.1	115.9
TWC-5	149.2	85.9	121.0	157.6	96.3	122.8
TWC-6	158.1	91.6	125.0	167.4	99.8	128.4
TWC-7	147.6	86.3	128.7	163.0	97.5	124.6
TWC-7A	139.2	93.9	125.5	153.4	89.9	120.4
TWC-8	139.8	89.7	121.6	160.1	117.1	125.7
TWC-9	152.6	79.6	117.6	152.5	100.8	120.6
TWC-10	148.1	89.8	119.6	151.9	87.7	119.4
TWC-11	145.6	85.0	123.5	130.9	97.8	116.6
MMSH 625 (SC)	158.4	111.9	150.1	162.6	109.2	138.4
MMSH 375 (SC)	146.8	78.8	123.1	166.6	106.6	124.4
MMSH 714 (SC)	106.4	76.9	97.7	114.2	81.1	95.3
WSH 287 (SC)	146.7	99.8	133.7	154.2	113.3	129.5
MMSH 740 (SC)	146.9	93.9	131.2	147.1	100.0	121.8
MMSH 413 (SC)	155.8	103.8	126.0	157.8	87.4	126.2
MMSH 1040 (SC)	152.8	93.2	134.1	172.6	104.6	131.5
MMSH 1028 (SC)	166.4	72.1	129.2	158.2	106.2	126.4
MMSH 928 (SC)	124.6	74.7	106.2	141.4	82.0	105.8
MMSH 1141 (SC)	161.1	84.9	124.8	171.2	85.7	125.5
MMSH 1012 (SC)	129.5	82.2	117.1	136.4	101.5	113.3
Sima(OP)	181.2	84.9	160.2	174.0	148.8	149.8
Kuyuma (OP)	124.6	78.4	106.1	129.3	90.9	105.9
Grand Mean	146.0	87.1	124.2	152.4	100.0	121.9
LSD 0.05	14.0	14.4	17.4	23.4	25.6	19.2
C.V %	5.9	10.1	8.6	9.4	15.7	9.8
TWC	134.0	87.3	122.2	151.9	98.6	121.2
SC	145.0	88.4	124.8	152.9	98.0	121.7
OP	152.9	81.7	133.2	151.7	119.9	127.9

The tallest and shortest entries were; Sima and MMSH 714 at Field Station, Golden Valley, Lusitu and Masstock; and MMSH 625 and MMSH 1028 at Liempe. The OP were taller than all hybrids across these locations (Table 14). The tallest entry across locations was Sima (150 cm) and the shortest MMSH 714 (95 cm) (Table 14).

The differences in locations resulted in the sorghum entries responding differently relative to each other to the change in environment.

It is evident basing on genotypes used that the entries were different, with hybrids generally being shorter than OP. The results contradict those of other studies which reported that hybrids in general are taller than OP (Stephens, 1937; Dogget, 1987). The results that TWC and SC were similar for plant height conform with those by Walsh (1971) who reported that TWC and SC were similar in plant height. However, Liang et al., (1974) reported that TWC were taller than SC.

The results in plant height differ from one study to another since they depend on the genotypes of the entries used.

4.7 WITHIN PLOT STANDARD DEVIATION FOR PLANT HEIGHT

Table 15 presents ANOVA for within plot standard deviation for plant height. Within plot standard deviation of plant height refers to the deviation of individual plants height from the mean. The greater the deviation, the less uniform are the groups in their plant height.

The entries were significantly different ($p<0.05$) within each location studied for this derived parameter except at Liempe (Table 15). Locations, entries and locations by entries interaction were significantly different ($p<0.01$) across locations. The TWC and SC were significantly different ($p<0.05$) at all locations. The TWC and OP were significantly different ($p<0.05$) at Field Station and Golden valley but not at other locations. No significance difference between SC and OP were observed at all locations. The TWC were significantly different ($p<0.01$) from SC and OP in the overall analysis, however no significant differences were observed between SC and OP.

Means for within plot standard deviation for plant height are presented in Table. 16. The entries with the highest within plot standard deviations were; TWC-10 (Field Station and Golden Valley), TWC-8 (Liempe) and TWC-11 (Masstock). The TWC had higher means for within plot standard deviations than SC within each location. However, the deviations of TWC were greater than of OP at all locations. The highest within plot standard deviation for plant height, 19.2 cm was at Field Station, followed by 15.8 cm at Liempe, 14.5 cm at Masstock and 13.8 cm at Golden Valley with the mean for TWC being greater than those of both SC and OP.

Table. 15. Mean squares for analysis of variance for within plot standard deviations of plant height of twelve three way cross (TWC), 11 single cross hybrids (SC) and two open pollinated varieties (OP) of sorghum at four locations in centimetres for 1991/92 season.

Source of Variation	Degrees of Freedom	Location				Combined	
		Field Station	Liempe	Golden Valley	Masstock	D.f	Mean square
Location	—	—	—	—	—	3	438.01***
Replication(loc)	2	4.33	14.81	2.41	3.19	8	6.18
Entries (unadj)	24	119.30**	20.12	77.51**	70.63**	24	168.48***
- TWC vs SC	1	1680.18**	52.75*	1254.60**	497.27**	1	2807.22***
- TWC vs O.P	1	392.48**	39.77	333.34***	34.08	1	630.42***
- SC vs O.P	1	6.63	5.39	1.20	39.80	1	14.63
Location X Entries unadj.	—	—	—	—	—	72	39.69***
RCBD error	48	25.68	13.74	11.40	29.43	192	20.06
Blocks (within adj.)	12	40.38	14.58	8.61	29.85		
Intrablock error	36	20.78	13.46	12.33	29.30		
Entries (adj.)	24	110.88***					
Effective error	36	23.30					

*,**, *** Indicates significance at $p<0.05$, $p<0.01$ and $p<0.01$, respectively.

N.B RCBD error was used to compare entries across locations.

Table. 16. Means of within plot standard deviations for plant height for 12 three way cross (TWC), 11 single cross (SC) hybrids and two open pollinated varieties (OP) of sorghum at four locations in centimetres for 1991/92 season.

ENTRY Means	Field Station	Liempe	Golden Valley	Masstock	Overall mean
TWC-1	24.4	16.9	17.6	17.2	19.0
TWC-2	20.6	15.6	21.8	22.2	20.0
TWC-3	20.9	16.6	23.0	14.4	21.2
TWC-4	29.3	13.7	15.8	13.3	18.0
TWC-5	23.5	18.0	14.2	17.7	18.4
TWC-6	21.4	17.3	15.6	16.5	17.7
TWC-7	20.6	15.2	18.5	14.7	17.3
TWC-7A	18.6	16.2	20.0	15.4	17.5
TWC-8	21.5	21.6	13.4	10.2	16.7
TWC-9	23.3	16.2	14.5	14.1	17.0
TWC-10	31.1	15.5	22.7	18.6	21.9
TWC-11	26.1	19.2	21.6	30.1	24.3
MMSH 625 (SC)	19.0	11.6	13.0	10.4	13.5
MMSH 375 (SC)	13.9	15.2	9.9	12.1	12.8
MMSH 714 (SC)	9.4	20.5	7.3	10.1	11.8
WSH 287 (SC)	17.1	14.5	12.3	11.2	13.8
MMSH 740 (SC)	17.1	18.0	9.2	9.9	13.6
MMSH 413 (SC)	17.0	14.0	10.4	11.1	13.1
MMSH 1040 (SC)	13.7	18.6	8.9	11.6	13.2
MMSH 1028 (SC)	9.4	14.5	11.3	18.1	13.3
MMSH 928 (SC)	14.5	12.6	8.2	7.9	10.8
MMSH 1141 (SC)	15.1	13.2	9.0	8.3	11.4
MMSH 1012 (SC)	12.1	13.1	7.3	17.4	12.5
Sima(OP)	16.6	16.4	10.4	16.3	15.0
Kuyuma (OP)	14.5	11.6	9.9	12.6	12.2
Grand Mean	19.2	15.8	13.8	14.5	15.8
LSD 0.05	7.9	6.0	5.7	8.8	28.3
C.V.	25.09	23.41	25.39	37.54	28.28
TWC	23.4	16.8	18.2	17.0	19.1
SC	14.4	15.1	9.7	11.6	12.7
OP	15.6	14.0	10.2	14.5	13.6

The results showed that locations used had different climatic and edaphic factors as reflected through within plot standard deviations for plant height as derived measure of uniformity. The variation in locations affected plant development for plant height deviations. Similarly entries were different overall.

The results also showed that TWC were not as uniform as either SC or OP as confirmed by the significance difference between TWC and the two groups. The variation of within plot standard deviation for plant height as a derived measure of uniformity could be due to segregation of the female single cross parent used in the production of TWC. The OP were more uniform than TWC hybrids because they are progeny of an individual plant selection, which is expected for the most part to breed true.

These findings conform with other studies which revealed that TWC were not as uniform as SC and OP due to segregation of the female single cross parent used in the production of TWC (Atkins, 1971; Walsh, 1971; Atkins, 1972; Miesner and York, 1973; Walsh and Atkins, 1973; Patanothai and Atkins, 1974; and, Perez and Miller, 1980).

However, plant height variation might not be of importance in sorghum production in the SADC region since all operations in the field are carried out by hand.

Matching the seed parents of TWC might result in the production of TWC which are uniform in plant height.

4.8 100 GRAIN WEIGHT

The ANOVA for 100 grain weight are presented in Table 17 and means in Table 18.

The effects of 100 grain weights of entries was significant ($p<0.01$) at all locations (Table 17). The mean 100 grain weight of TWC and SC were not significantly different ($p<0.05$) at all locations, however, hybrids and OP were significantly different ($p<0.01$) at all locations.

The effects of locations, entries and locations by entries interaction were significant ($p<0.05$) for 100 grain weight across locations (Table 17). Mean 100 grain weight of TWC and SC did not differ significantly ($p<0.05$), however, hybrids were significantly different ($\alpha=0.05$) from OP across locations.

The means for the locations were: 3.0 grams (Masstock), 2.4 grams (Field Station and Golden Valley), and 2.1 grams (Liempe) (Table 18). Sima had the highest 100 grain weight (3.4g) across locations. Hybrids had lower mean 100 grain weights than OP as group at all locations (Table 18). The OP had greater mean 100 grain weights than hybrids (Table 18).

Table. 17. Mean squares for analysis of variance for 100 grains weight of twelve three way cross (TWC), 11 si-gle cross hybrids (SC) and two open pollinated varieties (O.P) of sorghum at four locations in grams for 1991/92 season.

Source of Variation	Degrees of Freedom	Location				Combined	
		Field station	Liempe	Golden Valley	Masstock	D.F	Mean square
Location	--	--	--	--	--	2	9.91**
Replication(loc)	2	0.07	0.09	0.01	0.16	8	0.08
Entries (unadj)	24	0.35**	0.50**	0.21**	0.44**	24	1.08**
- TWC vs SC	1	0.01	0.16	0.04	0.08	1	0.02
- TWC vs O.P	1	2.90**	4.98**	0.86**	1.56**	1	9.31*
- SC vs O.P	1	3.00**	3.99**	0.66**	1.94**	1	8.79*
Location X Entries unadj.	--	--	--	--	--	72	0.14**
RCBD error	48	0.03	0.08	0.04	0.12	192	0.07
Blocks (within adj.)	12	0.02	0.14	0.03	0.08		
Intrablock error	36	0.04	0.06	0.04	0.13		
Entries (adj.)	24	--	0.46**				
Effective error	36	--	0.07				

, Indicates significance at $p<0.05$ and $p<0.01$, respectively.

N.B. RCBD design error was used for comparing entries across locations..

Table. 18. Means for 100 grain weight of 12 three way cross (TWC), 11 single cross hybrids (SC) and two open pollinated varieties (OP) of sorghum at four locations and across locations in grams.

Entry	Field Station	Liempe	Golden Valley	Masstock	Overall mean
TWC-1	2.4	2.1	2.4	2.6	2.4
TWC-2	2.5	1.9	2.5	3.3	2.6
TWC-3	2.2	2.1	2.4	3.5	2.6
TWC-4	2.4	2.1	2.2	2.7	2.4
TWC-5	2.5	1.6	2.6	3.2	2.5
TWC-6	2.4	2.0	2.2	2.7	2.3
TWC-7	2.5	1.7	2.2	3.1	2.4
TWC-7A	2.5	1.6	2.4	3.3	2.5
TWC-8	2.4	2.0	2.3	2.8	2.4
TWC-9	2.3	1.9	2.2	2.7	2.3
TWC-10	2.3	2.2	2.3	2.7	2.4
TWC-11	2.4	2.4	2.4	2.8	2.5
Sima(OP)	3.7	3.4	3.2	4.1	3.4
MMSH 625 (SC)	3.0	2.8	3.1	3.1	3.0
MMSH 375 (SC)	2.1	1.9	2.2	2.4	2.2
MMSH 714 (SC)	1.9	2.0	2.1	2.9	2.2
WSH 287 (SC)	2.7	1.9	2.5	3.6	2.7
MMSH 740 (SC)	2.2	2.1	2.3	2.6	2.3
MMSH 413 (SC)	2.6	2.4	2.6	3.0	2.7
MMSH 1040 (SC)	2.5	2.0	2.6	3.1	2.6
MMSH 1028 (SC)	2.5	1.6	2.3	2.9	2.2
MMSH 928 (SC)	2.3	1.7	2.3	3.0	2.3
Kuyuma (OP)	2.6	2.5	2.3	2.9	2.6
MMSH 1141 (SC)	2.1	2.2	2.2	2.6	2.3
MMSH 1012 (SC)	2.2	2.1	2.2	2.5	2.3
Grand Mean	2.4	2.1	3.4	3.0	2.5
LSD 0.05	0.3	0.4	0.3	0.6	0.4
C.V %	7.9	12.5	8.7	12.2	10.6
TWC	2.4	2.0	2.3	3.0	2.4
SC	2.4	2.1	2.4	2.9	2.4
OP	3.2	3.0	2.8	3.5	3.0

The results indicate that the environments used differ with respect to 100 grain weight. The variation in 100 grain weight across the locations was partly related to the amount of water available to the crop as reported by Reich and Atkins (1970). Manjarrez-Sandoval et al. (1989) reported that water stress can reduce grain weight by as much as 50%. The highest 100 grain weight was at Masstock where there was full irrigation. In terms of rainfall, Golden Valley received the highest rainfall, followed by Field Station and Liempe, respectively (Appendix I-IV). From the results it can be seen that the trend almost correspond to the 100 grains weight across the locations.

Sima, with bold grains had the heaviest grain weight than the rest of the entries.

The OP based on genotypes used had higher 100 grains weight than hybrids which conform with the studies by Perez and Miller (1980), and, Artola (1985), who reported that 100 grain weight of OP was greater than hybrids. Kuyuma and Sima which represent OP have large bold grains (DR B.N. Verma - Pers. com[3]). Atkins (1971, 1976), Walsh and Atkins (1973) reported that there was no difference in 100 grain weight between TWC and SC which agree with the present study. TWC

[3]Dr B N Verma - Principle Sorghum Breeder for the Zambia Sorghum and Millet Improvement team, at Mt Makulu, Chilanga.

and SC hybrids used share the same parents and hence there were no differences in their 100 grain weight.

4.9 GRAIN YIELD

The ANOVA for grain yield is presented in Table 19 and the means in Table 20.

The grain yield of the entries was significant ($p<0.05$) at Liempe, Golden Valley and Lusitu, but, not at Field Station and Masstock (Table 19). The effects of locations, entries and locations by entries interaction were significant ($p<0.05$) for grain yield in combined location analysis (Table 19). Mean grain yields of TWC, SC and OP were not significant ($p<0.05$) at Field Station and Liempe (Table 20).

The entries with highest means in their descending order were: TWC-8, MMSH 1028 and Kuyuma at Field Station; TWC-3, MMSH 413 and Sima at Liempe; TWC-7A, MMSH 625, and Sima, at Golden Valley; TWC-8, WSH 287, and Sima at Masstock; TWC-1, MMSH 714 and Kuyuma at Lusitu; and TWC-8, MMSH 625 and Sima at combined locations analysis (Table. 20). It is evident that each location had different best entry from different genotype groups. The location which gave the highest performance of sorghum was Masstock (WSH 287) while the lowest performance was at Lusitu (TWC-7A), with 6615 kg/ha and 31 kg/ha, respectively. In general SC were best within each location.

Table. 19. Mean squares for analysis of variance for grain yield in tons/ha of 12 three way cross (TWC), 11 single cross hybrids (SC) and two open pollinated varieties (OP) of sorghum at five locations in 1991/92.

Source of Variation	Degrees of Freedom	Location: Field Station	Liempe	Golden Valley	Masstock	Lusitu	Combined: D.F	Mean square
Location	—	—	—	—	—	—	4	399.64**
Replication(loc)	2	1.94	1.09	1.81	39.47	0.13	10	8.89
Entries (unadj)	24	0.65	0.33**	1.52**	1.23	0.32*	24	1.25**
Location X Entries unadj.		—	—	—	—	—	96	0.70*
RCBD error	48	0.52	0.13	0.49	1.16	0.17	240	0.49
Blocks (within adj.)	12	1.00	0.16	0.62	2.08	0.25	60	0.82
Intrablock error	36	0.36	0.12	0.44	0.85	0.15	180	0.38
Entries (adj.)	24	0.65	0.35**	1.42**	1.06	0.31*	24	1.17**
- TWC vs S.C	1	0.01	0.13	5.48**	1.94	0.23	1	4.02**
- TWC vs O.P	1	0.70	0.00	2.06*	7.43**	0.66*	1	0.33
_ SC vs O.P	1	0.60	0.03	0.02	12.01**	0.30	1	2.74**
Location x Entries adj.	—	—	—	—	—	—	96	0.66**
Effective error	36	0.41	0.13	0.48	0.97	0.16	180	0.43

*,** Indicates significance at $p<0.05$ and $p<0.01$, respectively.

N.B. Effective error was used for comparing entries since there were lattice corrections.

Table. 20. Means of grain yield of 12 three way cross (TWC), 11 single cross (SC) and two open pollinated varieties (OP) of sorghum at five locations in kg/ha in 1991/92 season.

Entry	Station	Liempe	Golden Valley	Masstock	Lusitu	Overall mean
TWC-1	3324	941	3702	5627	576	2834
TWC-2	3985	416	3091	5182	53	2545
TWC-3	3849	1297	3674	5565	558	2989
TWC-4	4144	1088	3812	5280	320	2928
TWC-5	3370	442	3826	4894	158	2538
TWC-6	4296	784	4026	5646	312	3012
TWC-7	4278	557	3907	5727	139	2922
TWC-7A	4265	519	4261	5964	31	3008
TWC-8	4675	1239	3458	6221	286	3176
TWC-9	4517	820	3289	6265	210	3020
TWC-10	4606	898	3182	6195	141	3005
TWC-11	4135	966	3907	5950	357	3063
MMSH 625 (SC)	4442	695	5684	6404	61	3457
MMSH 375 (SC)	4348	1352	3790	6527	511	3306
MMSH 714 (SC)	3269	424	3225	5676	1174	2754
WSH 287 (SC)	4583	720	5070	6615	670	3532
MMSH 740 (SC)	4443	685	4985	6158	691	3392
MMSH 413 (SC)	4411	1694	4558	5873	244	3356
MMSH 1040 (SC)	3507	1153	4466	5662	184	2994
MMSH 1028 (SC)	4834	495	3674	6576	167	3149
MMSH 928 (SC)	3299	591	3066	5276	151	2477
MMSH 1141 (SC)	3858	860	3837	5475	128	2832
MMSH 1012 (SC)	4035	1425	4307	6190	177	3227
Sima(OP)	3668	905	5112	4342	32	2812
Kuyuma (OP)	3834	761	3510	4661	1207	2799
Grand Mean	4079	870	3977	5755	342	3004
Environmental index	1075	-2134	973	2751	-2662	
LSD 0.05	1051	586	1127	1609	659	790
C.V %	15.8	41.8	17.4	17.1	118.2	23.4
TWC	4120	831	3678	5710	262	2920
SC	4094	918	4242	6039	378	3134
OP	3751	843	4311	4502	620	2805

The grain yields of sorghum at Liempe and Lusitu were not reliable as evidenced by high coefficients of variation (Table.20). Trial sites were not sufficiently homogeneous within replications resulting in high coefficients of variation. The results to some extent, particulary at Lusitu, because of high coefficients of variation are unreliable, but the inclusion of the site is necessary to depict the effect of drought at some locations. Some plants at Lusitu died of severe drought. This affected the grain yields particulary for cultivars TWC-2, TWC-7A, MMSH 625 and Sima which failed to reach 50% heading and produced very little grain yield, thus lowering their grain yield means across locations.

The mean grain yield for each location ranged from 342 kg/ha at Lusitu to 5755 kg/ha at Masstock (Table 20). The grain yield for other locations were; 4079 kg/ha at Field Station, 3977 kg/ha at Golden Valley and 870 kg/ha at Liempe. WSH 287 (3530 kg/ha) was the highest grain yielding entry followed by MMSH 625 (3450 kg/ha), MMSH 740 (3380 kg/ha), MMSH 413 (3360 kg/ha) and MMSH 375 (3330 kg/ha). However, the grain yields of most entries did not differ significantly from that of WSH 287 across locations (Table. 20).

Mean grain yields of SC and OP of 3678 kg/ha and 4311 kg/ha, respectively, were superior to TWC which had a yield of 3678 kg/ha, however, the performance of SC and OP were similar (Table 20). The hybrids, TWC (5710 kg/ha) and SC (6039 kg/ha) performed equally, but there were all superior to OP (4502 kg/ha) at Masstock. However, at Lusitu, OP out performed hybrids which were similar in performance. Overall, SC with 3134 kg/ha were superior in performance than TWC (2920 kg/ha) and OP (2805 kg/ha). The performance of OP and TWC were similar, although TWC had a numerical higher grain yield than OP.

Grain yield across the locations was mainly related to the amount of water available to the crop during the growing period. Masstock which was under fully irrigation had the highest mean grain yield. Golden Valley received the highest rainfall and was followed by Field Station, Liempe and Lusitu in that order (Appendix I-IV). The order of grain yield almost follow this pattern except at Golden Valley which had lower grain yield than the Field Station (Table 20). The factor that would have affected performance at Golden Valley probable is soil type (Table.2). Golden Valley had heavy clay soils which hinders root penetration and reduces the ability of the roots to exploit water resources.

The inherent differences in locations resulted in entries performing differently at different locations. Lusitu which received the least amount of rainfall favoured the OP, Kuyuma, in the drier condition. WSH 287 on the other hand performed very well at Masstock where soil water conditions were never limiting.

It is important to note that TWC appeared at least once at each location on the best five entries except at Golden Valley, showing, that the grain yield of the best TWC was comparable to those of SC. This also show, that, among TWC, there are some which are high grain yielding and comparable to SC in their grain yield.

The results also show that the grain yields of TWC was similar with that of OP although TWC had a numerical higher mean though not significantly different from that of OP.

The results conform with studies carried out by Fazalullah Khan and Menon (1973), Liang et al. (1973), Kide et al. (1980) and Torres-Cardonna et al. (1983) which indicates that on average, SC are superior in grain yield than TWC and OP. However, other studies reveal that TWC and SC do not differ significantly in grain yield, but hybrids as a group are higher grain yielding than OP (Atkins, 1971; Walsh, 1971; Liang, 1971; Patanothai and Atkins, 1974; Perez and Miller, 1980; Kide et al., 1982; and, Lazanyi and Papp, 1983).

In this study, TWC were inferior to SC, and similar in grain yield performance with OP. This disagree with the findings in maize by Sprague and Federer (1951) and Lynch et al. (1973) which indicated that SC were superior in performance to TWC, and that TWC were superior to OP. The present study, failed to confirm this, but had a strong tendency to follow a similar order. This could be explained by the fact that in this study, TWC which were used were not selected on basis of their grain yield, whereas, SC and OP were in the current breeding program and are currently cultivated because of their good performance. In addition, the small representation of OP in the total number of entries tested could have given a bias towards the hybrids.

4.10 GRAIN YIELD STABILITY

The results from ANOVA for grain yield stability are presented in Table 21 and the stability parameters in Table 22.

The effects of entries was significant ($p<0.05$) across locations in their grain yield (Table 21). The entries by environment (linear) interaction effect was also significant ($p<0.05$). Sima, MMSH 625 and MMSH 714 sum of squares were significant on the analysis of variance (Table 21).

Entries with large regression coefficients (b-values) in order of their ranking were: MMSH 625 (1.23), MMSH 1028 (1.19), WSH 287 (1.16) and TWC-7A (1.12) (Table 22). Entries with low b-values in their ascending order were: Kuyuma (0.726), MMSH 714 (0.855), TWC-3 (0.880), Sima (0.884) and TWC-1 (0.897). The b-values of Kuyuma (0.726) and MMSH 625 (1.23) were significantly different ($p<0.05$) from unity (Table 22).

The standard deviations from regression were generally high due to severe drought during the growing season which affected locations differently and also enhanced unreliability of the data observed.

Table. 21. Analysis of variance for mean data partitioned into various components of 12 three way cross hybrids (TWC), 11 single cross hybrids (SC), and two open pollinated varieties (OP) of sorghum for grain yield in kg/ha for 1991/92 season.

Source of variation	Degrees of Freedom	Sum of squares	Mean Square
Entries	24	9361840	0.36**
Envi+(Entries x Env)	100	554151000	
Env (linear)	1	532763000	
Entries x Env (Linear)	24	7450244	0.30*
Pooled deviation	75	13938062	0.18
TWC-1	3	331292	
TWC-2	3	329613	
TWC-3	3	100859	
TWC-4	3	122573	
TWC-5	3	225664	
TWC-6	3	67541	
TWC-7	3	62816	
TWC-7A	3	52350	
TWC-8	3	786089	
TWC-9	3	804805	
TWC-10	3	1041183	
TWC-11	3	31983	
MMSH 625	3	1375774*	
MMSH 375	3	480381	
MMSH 714	3	1358009*	
WSH 287	3	377612	
MMSH 740	3	532988	
MMSH 413	3	523874	
MMSH 1040	3	652277	
MMSH 1028	3	615577	
MMSH 928	3	207163	
MMSH 1141	3	21978	
MMSH 1012	3	353908	
Sima	3	3069295***	
Kuyuma	3	412458	
TWC	3	46178	
SC	3	30862	
OP	3	850594	
Pooled error	180		143333.3

*,**, *** indicates significance at p<0.05, p<0.01 and p<0.01, respectively.

Table. 22 . Stability parameters of 12 three way cross hybrids (TWC), 11 single cross (SC) hybrids and two open pollinated (OP) varieties of sorghum in 1991/92 season.

Entry	Grain Yield Kg/ha	b-value	Sd^2
MMSH 625 (SC)	3457	1.233	314147
MMSH 1028 (SC)	3149	1.190	60748
WSH 287 (SC)	3532	1.160	-18574
TWC-7A	3008	1.123	-126994
MMSH 740 (SC)	3392	1.091	33218
TWC-9	3020	1.078	123824
TWC-10	3005	1.069	202617
TWC-7	2922	1.060	-123506
TWC-8	3176	1.037	117585
MMSH 375 (SC)	3306	1.035	15682
MMSH 1012 (SC)	3227	1.034	-26475
TWC-11	3063	1.013	-133783
TWC-6	3012	1.011	-121931
MMSH 413 (SC)	3356	0.988	30180
MMSH 1141 (SC)	2832	0.974	-137118
MMSH 1040 (SC)	2994	0.973	72981
TWC-2	2545	0.923	-34573
TWC-4	2928	0.915	-103587
TWC-5	2553	0.912	-69223
MMSH 928 (SC)	2477	0.909	-75390
TWC-1	2834	0.897	-34014
Sima(OP)	2812	0.884	878654
TWC-3	2989	0.880	-110825
MMSH 714 (SC)	2754	0.855	308225
Kuyuma (OP)	2799	0.726	-6958
LSD 0.05	--	0.184	--
TWC	2920	0.997	12760
SC	3134	1.040	13650
OP	2805	0.803	13870

N.B. b-value - regression coefficient.
Sd^2 - squares of standard deviation from regression.

Entries with high standard deviations from regression (Sd^2) were: Sima (878654), TWC-10 (202617), MMSH 625 (314147) and MMSH 714 (308225). Entries with low Sd^2 were: Kuyuma (6958), TWC-1 (-34014), TWC-5 (-69223), MMSH 375 (15682), WSH 287 (18574), MMSH 740 (33218), MMSH 413 (30180) and MMSH 1012 (26475). As a group, TWC had a b-value of 0.997 which was not significantly different ($p<0.05$) from unity and Sd^2 of 127600. THe b-value of SC, 1.04, was not significantly different ($p<0.05$) from unity and Sd^2 of 136500. The OP had a b-value of 0.805 which was significantly different ($p=0.05$) from unity and Sd^2 of 138700. Figure.1 presents the responses of TWC, SC and OP to different environments.

High b-values means poor adaptability to change in environments and vice versa. MMSH 625 and MMSH 1028 with b-values of 1.23 and 1.90, respectively are seen as the least stable entries, although they have the highest mean across locations (Table 22). MMSH 625 is adaptable to specific high grain yielding environments. Kuyuma with b-value of 0.726 is adapted to a wide range of environments. Kuyuma exhibit very little change in grain yield despite large changes in environment. Kuyuma produces above average grain yield in low yielding environments, but the low b-value is associated with lack of responce to high grain yielding environments.

When considering b-value equal to unity for any entry to be stable, most of the entries under this study are stable since their b-values did not differ significantly from unity with the exception of MMSH 1028, Kuyuma and MMSH 625.

The Sd^2 measures the reliability of the response, that is the resistance to change in environments which determines stability. High Sd^2 values means that the varieties are not reliable whereas low values means that the varieties are reliable. The results show that Sima, with high Sd^2 (878654) was the most inconsistent entry in it's yielding ability. Kuyuma with Sd^2 value of 6000 was the most consistent. Kuyuma is a variety selected and being grown in low yielding environments, specifically, Western and Southern Provinces of Zambia, that is why it has low Sd^2 and highest grain yield at Lusitu. Most SC are more stable than TWC, however, hybrids were more stable than OP.

When considering high mean grain yield and b-value, TWC and SC are equally desirable. Their b-values were 0.996 and 1.049, respectively, however, the b-values of TWC was closer to unity compared to SC (Figure 1). The OP had a b-value of 0.805, significantly different from unity indicating that they were less responsive to change in environments, and they can perform well under a wide range of environments. OP being insensitive to environmental change they yield less in high grain yielding environments. However, comparison of OP being represented by only two entries with SC and TWC is likely to be misleading because of the biased data sets.

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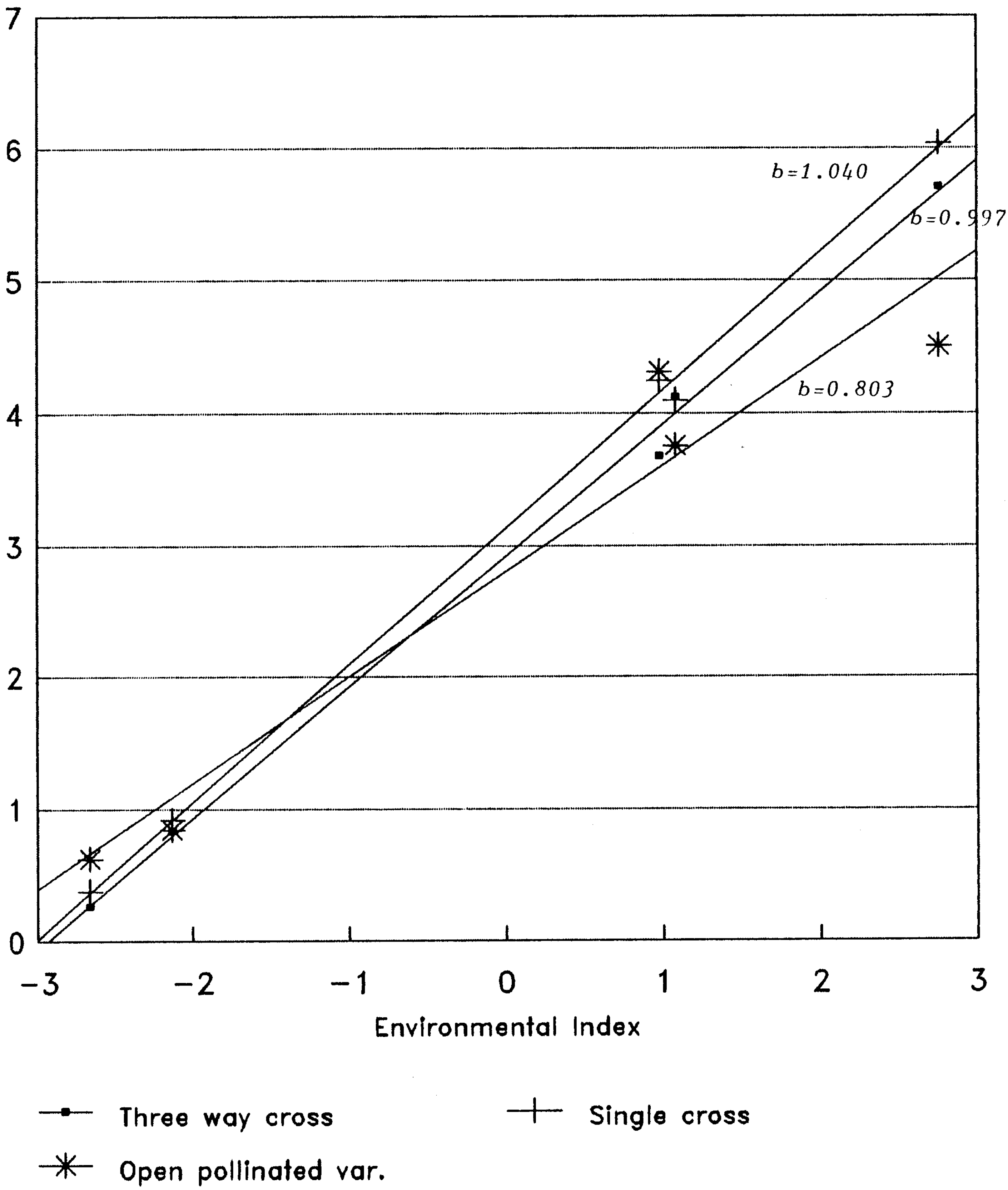

Figure 1: Regression lines of mean grain yields of three way cross, single cross hybrids and open pollinated varieties of sorghum on environmental index.

The Sd^2 of the groups, TWC, SC and OP with the values 12760, 13650 and 13870 in that order indicate that TWC were the most reliable group than SC and OP.

When considering the mean grain yields, b-values and Standard deviation from regression, it is very difficult to distinguish among the groups of the hybrids which ones are more stable than the others. The TWC with low b-value and Sd^2 had a lower mean yield than SC (Table 20). It is obvious that hybrids as a group were more stable than OP.

Several studies have indicated that, as a group, sorghum TWC are numerically more stable compared to SC and OP (Patanothai, 1972; Patanothai and Atkins, 1974; Perez and Miller, 1980; Lazanyi and Papp, 1981; Walsh, 1971).

From this study, it can be deduced that TWC as a group are not significantly more stable than SC. Hybrids in general were significantly more stable compared to OP because of genetic buffering. The hybrids TWC and SC used share the same parents and therefore, the effect of genotypic buffering in TWC which was expected from broad genetic base due to three parents is not evident.

4.11 LEAF AREA, LEAF AREA INDEX BEFORE AND AFTER FLOWERING

The ANOVA for leaf area, leaf area index before and after flowering are presented in Table 23 and means of leaf area, leaf area index before and after flowering are presented in Table 24.

4.11.1 LEAF AREA (LA1) AND LEAF AREA INDEX (LAI-1) BEFORE FLOWERING.

The effects of entries was significant ($p<0.05$) for LA1 (Table 23). There was no significant difference among the groups for LA1 (0.300, 0.300 and 0.295 m^2 for TWC, SC and OP respectively). Entries were not significantly different for LAI-1. There was no significance difference among the groups (TWC, SC and OP).

MMSH 1141 and WSH 287 had leaf area of 0.38 m^2 being the highest (Table 24). MMSH 928 had the lowest LA1 of 0.24 m^2.

Although there was no statistical differences among hybrids, studies by Quinby (1970), and, Gibson and Schertz (1976) have reported that the leaf area of sorghum hybrids was greater than that of OP up to one week before flowering.

Table. 23. Mean squares for analysis of variance for leaf area before and after heading, leaf area index before and after heading (m^2), and, leaf area duration of twelve three way cross (TWC), 11 single cross hybrids (SC) and two open pollinated varieties (OP) of sorghum at University Field Station in 1991/92 season.

Source of Variation	Degrees of Freedom	leaf area before heading	leaf area after heading	leaf area index before heading	leaf area index after heading	leaf area duration
Replication	2	47.00	31.03	0.29	0.84	1.83
Entries (unadj)	24	45.55**	21.97	0.33	0.30	1.03
RCBD error	48	18.86	27.50	0.28	0.29	0.93
Blocks (within adj.)	12	39.09	0.38	0.40	1.24	1.24
Intrablock error	36	15.51	23.64	0.24	0.26	0.82
Entries adj.	24	42.97**	20.12	0.30	0.24	0.85
- TWC vs SC	1	0.00	0.00	0.29	0.13	0.36
- TWC vs O.P	1	0.00	0.00	0.03	0.16	0.64
- SC vs O.P	1	1.50	0.01	0.16	0.36	0.89
Effective error	36	17.31	25.97	0.26	0.28	0.89

** Indicates significance at $p<0.01$.

N.B Effective error was used for comparing entries since there were lattice corrections

Table. 24. Means of leaf area per plant (LA1) and leaf area index (LAI-1) before flowering, leaf area per plant (LA2) and leaf area index (LAI-2) after flowering, and their leaf area duration for three way cross hybrids (TWC), 11 single cross (SC) hybrids and two open pollinated varieties (OP) of sorghum at University Field Station in square metres for 1991/92 season.

ENTRY	LA1	LA2	LAI-1	LAI-2	LAD
TWC-1	0.31	0.27	1.88	1.64	3.52
TWC-2	0.30	0.30	1.97	1.99	3.96
TWC-3	0.30	0.25	2.16	1.82	3.98
TWC-4	0.30	0.28	2.00	1.98	3.99
TWC-5	0.31	0.29	2.54	2.39	4.94
TWC-6	0.27	0.27	1.56	1.55	3.12
TWC-7	0.27	0.26	1.93	1.79	3.72
TWC-7A	0.34	0.30	2.39	2.20	4.59
TWC-8	0.31	0.27	2.37	2.15	4.52
TWC-9	0.32	0.29	2.64	2.44	5.08
TWC-10	0.31	0.29	2.36	2.22	4.58
TWC-11	0.31	0.26	2.52	2.15	4.67
MMSH 625 (SC)	0.26	0.29	1.81	1.98	3.79
MMSH 375 (SC)	0.29	0.32	2.20	2.41	4.61
MMSH 714 (SC)	0.25	0.21	1.73	1.41	3.14
WSH 287 (SC)	0.38	0.30	2.43	1.94	4.36
MMSH 740 (SC)	0.28	0.28	1.98	2.01	3.99
MMSH 413 (SC)	0.36	0.29	2.24	1.79	4.03
MMSH 1040 (SC)	0.27	0.28	1.85	1.89	3.73
MMSH 1028 (SC)	0.29	0.28	2.21	2.12	4.32
MMSH 928 (SC)	0.24	0.24	1.68	1.67	3.34
MMSH 1141 (SC)	0.38	0.23	2.71	1.69	4.40
MMSH 1012 (SC)	0.28	0.31	2.20	2.40	4.60
Sima(OP)	0.34	0.30	2.47	2.18	4.66
Kuyuma (OP)	0.25	0.27	1.98	2.23	4.20
Grand Mean	0.30	0.28	2.15	2.00	4.15
LSD 0.05	0.07	0.08	0.84	0.86	1.54
C.V %	13.85	18.37	23.84	26.41	22.76
TWC	0.30	0.28	2.19	1.94	4.22
SC	0.30	0.28	2.09	1.94	4.03
OP	0.29	0.29	2.08	2.19	4.43

WSH 287 had the highest LA1 at the Field Station, but was not the highest grain yielding entry at this location, though it was the highest grain yielding entry across locations (Table 20 and 24). It would appear, that, LA1 is not important in determining the grain yield. Other factors such as the orientation of the leaves and their angle have been reported also to determine the capacity at which leaves can intercept sunlight which drive the photosynthesis process (Radford, 1967; Krishnamurty, 1973; and, Winter and Ohlrogge, 1973).

Differences among the entries reported earlier do not seem to be related to LAI-1 rather to LA1.

4.11.2 LEAF AREA (LA2) AND LEAF AREA INDEX (LAI-2) AFTER FLOWERING.

Entries were not significantly different for LA2 and LAI-2 (Table 23 and 24). The three groups of entries (TWC, SC and OP) were not also significantly different for LA2 and LAI-2.

4.11.3 LEAF AREA DURATION (LAD)

No significant differences were observed among entries, and among groups of varieties for their LAD (Table 23).

These results agree with those reported by Krishnamurty et al. (1973) which showed no statistical difference in LAD among sorghum entries.

There appears to be no relationship between leaf area, leaf area index and leaf area duration, in general, since there were no differences among entries and among groups of entries for any of these parameters. The differences observed among entries for LA1 could suggest that entries developed their leaf area at different rates during vegetative growth stage, but such differences were insignificant by the reproductive period.

4.12 CORRELATIONS BETWEEN LA1, LA2, LAI-1, LAI-2 AND LAD WITH COMPONENTS OF GRAIN YIELD.

The results of correlations are presented in Table 25. No significant ($p<0.05$) correlations among days to 50% heading, days between 25 and 75% heading, 100 grains weight, and, disease score with leaf parameters were observed for all entries combined, TWC, SC and OP (Table 25).

Significant correlations between plant height and LA1, LA2, LAI-2 and LAD were observed for all entries and SC as

Table 25. Correlation coefficients (r) for leaf area (LA1, LA2), leaf area index (LAI-1, LAI-2) before and after heading and leaf area duration (LAD) of sorghum (Overall, TWC, SC and OP) in 1991/92 season.

Character	LA1	LA2	LAI-1	LAI-2	LAD
50% days to heading[4]	-0.097	0.041	-0.137	-0.041	-0.098
TWC	-0.116	-0.122	-0.172	-0.182	-0.188
SC	-0.023	0.159	-0.119	0.017	-0.047
OP	-0.670	-0.085	-0.711	-0.027	-0.628
Difference between 25 and 50% days to heading	0.164	-0.086	0.120	-0.060	0.032
TWC	0.079	-0.055	0.187	0.102	0.153
SC	0.183	-0.163	0.026	-0.213	-0.066
OP	0.740	-0.457	0.713	-0.527	0.306
Plant height	0.315*	0.330*	0.266	0.253*	0.287*
TWC	0.146	0.230	0.126	0.159	0.151
SC	0.300**	0.392**	0.290	0.340*	0.359*
OP	0.670	0.318	0.632	0.101	0.606
100 grains weight	0.179	0.178	0.117	0.106	0.123
TWC	-0.079	0.126	0.012	0.115	0.068
SC	0.232	0.104	0.014	0.063	0.004
OP	0.748	0.500	0.709	0.273	0.769
Disease score	0.075	-0.137	0.072	-0.070	0.000
TWC	0.092	-0.034	-0.042	-0.089	-0.070
SC	0.060	-0.182	0.222	0.012	0.171
OP	0.046	-0.170	0.023	-0.026	0.003
Plant aspect score	-0.009	-0.425**	-0.012	-0.305**	-0.177
TWC	0.011	-0.242	0.043	-0.106	-0.033
SC	-0.093	-0.535**	-0.143	-0.463**	-0.313
OP	-0.426	-0.750	-0.520	-0.765	-0.004
Head weight	0.146	0.568**	0.303**	0.570**	0.485**
TWC	0.244	0.471**	0.494**	0.614***	0.588***
SC	0.087	0.644***	0.190	0.578***	0.401*
OP	0.162	0.754	0.148	0.764	0.578
Grain yield	0.458**	0.473**	0.418**	0.392**	0.448**
TWC	0.319	0.487**	0.433**	0.522**	0.507**
SC	0.371*	0.541**	0.428*	0.501**	0.563***
OP	0.479	0.573	0.470	0.506	0.705

*,** indicates significance at 0.05, 0.01 respectively.

[4]Figures appearing in the first row within each character represent overall correlations coefficients.

a group, however, no significant correlations between leaf parameters and plant height were observed for TWC and OP as groups (Table 25). Negative correlations between plant aspect score with LA2 and LAI-2 were observed for all entries as a group and SC, however, no significant correlations between plant aspect score and, LA1 and LAI-1 were observed (Table 25).

Head weight was significantly and positively correlated with all leaf parameters except LA1 for all entries as a group studied and TWC as a group (Table 25). Significant correlations between head weight, and, LA2, LAI-2 and LAD were also observed.

Grain yield was significantly and positively correlated with all leaf parameters for all entries, SC and TWC as groups with exception of TWC for LA1. No correlations were observed for grain yield with leaf parameters for OP.

Plant aspect score was negatively correlated with LA2 (r= -0.425) and LAI-2 (r=-0.305) (Table 25). This is because, with plant aspect score, a score of one represented excellent and five very poor. Therefore, the results, in reality implies positive relationship.

The positive and significant correlations between plant height and leaf area parameters, in general is an expected phenomena as both are vegetative attributes which would develop in a similar manner.

Agronomically, plants which maintained their leaves after flowering are desirable.

It is very evident that leaf parameters determined grain yield and head weight for TWC, SC and all entries combined, TWC and SC. These results agree with studies carried out by Watson (1952), Fischer and Wilson (1971), Winter and Ohlrogge (1973), Prior and Russel (1976), who found that grain yield of maize was related to leaf area. In maize, the amount of photosynthate produced was reported to be partly dependent upon the leaf area and it's duration (Watson, 1952; Winter and Ohlrogge, 1973; Krishnamurty <u>et al</u>., 1973, Prior and Russel, 1976; Maas <u>et al</u>., 1987)

5. CONCLUSION

The results based on one season indicate that TWC were inferior in grain yield to SC, while TWC were similar to OP. However, there where individual TWC whose grain yield was good as that of SC. There was no difference in grain yield stability between hybrids. Hybrids were more stable in grain yield than OP.

Uniformity as determined by period to heading was similar for all entries and groups of varieties. However, SC and OP were more uniform than TWC when uniformity was based on within plot plant height standard deviation.

Leaf area parameters were more strongly associated with grain yield than any other measured plant attribute for TWC, SC and all entries as group. Leaf area parameters of OP were not associated with grain yield.

The present study fails to reveal any advantages of TWC over SC and OP with grain yield stability and uniformity. Marginal advantages of TWC over SC have to be considered in light of the requirement of one more generation in seed production which in itself is a disadvantage.

The results are based on one season data which was hit by severe drought and therefore are not likely to be representative of an average season. Additional two or more seasons data is needed to make conclusive findings. For future research, equal representation of entries from TWC, SC and OP should be included in the study to avoid bias since a small sample is not likely to represent the group. In addition, inclusion of released varieties with known grain yield performance for other groups should be avoided. Released varieties are likely to be high grain yielders and stable in grain yield than other entries, therefore, selection of entries will not only be by chance.

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Appendix . I. Rainfall data at the University Field Station in millimetres.

Days	December	January	February	March	April	May
1	–	–	–	–	–	–
2	–	–	–	13.4	–	–
3	–	15.6	–	1.0	–	–
4	–	–	–	0.7	–	–
5	–	–	1.4	–	–	–
6	23.8	–	–	–	–	–
7	–	28.2	–	–	–	–
8	–	–	–	–	–	–
9	–	–	–	–	–	–
10	–	3.0	–	–	–	–
11	–	–	–	–	–	–
12	–	3.6	–	–	–	–
13	–	–	–	–	–	–
14	–	–	–	10.4	–	–
15	–	1.0	–	–	–	–
16	28.0	–	–	6.0	–	–
17	–	–	–	–	–	–
18	–	18.6	–	–	–	–
19	1.4	–	–	–	–	–
20	–	11.6	–	10.1	–	–
21	–	2.0	–	0.6	–	–
22	–	–	–	43.0	–	–
23	4.0	–	–	1.4	–	–
24	23.6	8.6	–	10.5	–	–
25	–	6.0	38.1	2.0	–	–
26	3.0	4.6	–	–	1.2	–
27	–	–	4.9	–	3.2	–
28	–	–	4.9	–	40.8	–
29	–	–	–	–	–	–
30	–	–	–	–	–	–
31	–	–	–	–	–	–
Total	83.8	102.8	49.3	99.1	45.2	

Total rainfall received during the growing season = 380mm

Appendix . II. Rainfall data at Liempe farm in millimetres.

Days	December	January	February	March	April	May
1	-	-	1.6	-	-	-
2	-	12.5	-	1.3	-	-
3	-	2.0	-	21.0	-	-
4	-	-	16.4	-	-	-
5	1.3	-	-	-	-	-
6	-	-	-	-	-	-
7	-	-	-	-	-	-
8	3.8	-	7.0	-	-	-
9	-	6.7	-	-	-	-
10	-	-	-	-	0.2	-
11	-	5.3	-	-	-	-
12	-	-	-	5.4	3.4	-
13	-	-	-	3.7	-	-
14	0.3	1.6	-	1.3	-	-
15	-	-	-	0.2	-	-
16	6.8	-	0.8	4.0	-	-
17	-	3.0	3.1	4.3	-	-
18	17.5	1.1	-	-	-	-
19	-	14.6	-	-	-	-
20	14.4	15.8	-	5.0	-	-
21	14.7	-	-	6.7	-	-
22	0.2	8.3	-	0.6	-	-
23	2.9	6.9	-	27.3	-	-
24	-	15.0	-	3.7	-	-
25	3.0	8.0	21.6	2.1	-	-
26	-	-	4.0	-	-	-
27	1.0	-	3.0	24.0	-	-
28	15.4	-	-	0.5	9.6	-
29	1.2	-	0.8	-	9.9	-
30	-	-	-	-	-	-
31	-	-	-	26.3	-	4.0
Total	77.4	100.8	58.3	137.4	23.1	4.0

The rainfall presented above represent the rainfall distribution at the main airport. The instrument used at Liempe was accumulative type and the actual amount received was 340 mm.

Appendix .III. Rainfall data at Golden Valley in millimetres.

Days	December	January	February	March	April	May
1	–	–	22.5	10.5	1.5	–
2	–	13.5	–	–	–	–
3	–	6.0	–	–	–	–
4	–	–	trace	–	–	–
5	9.5	–	–	–	–	–
6	–	–	12.0	–	–	–
7	Trace	13.5	7.0	–	–	–
8	1.5	–	–	–	–	–
9	1.5	56.0	–	–	–	–
10	8.0	–	–	2.0	–	–
11	2.0	9.5	–	–	–	–
12	–	–	–	22.0	–	–
13	–	–	–	39.5	–	–
14	17.5	–	–	–	–	–
15	–	–	–	–	–	–
16	–	4.5	–	–	–	–
17	–	–	1.5	–	–	–
18	–	–	–	–	–	–
19	–	24.0	–	Trace	–	–
20	1.0	8.5	–	3.5	–	–
21	3.5	2.5	–	7.5	–	–
22	7.0	12.0	–	2.0	–	–
23	Trace	1.5	–	30.0	–	–
24	–	2.0	3.5	1.5	–	–
25	1.5	4.0	28.0	4.0	–	–
26		–	2.5	11.5	–	–
27	9.0	–	–	–	–	–
28	7.0	–	–	–	–	–
29	Trace	–	–	–	–	–
30	4.0	–	–	10.5	–	–
31	–	–	–	–	–	–
Total	65	157.5	77.0	145.0		

Total rainfall received during the growing season = 430mm

Appendix . IV. Rainfall data at Lusitu in millimetres.

Days	December	January	February	March	April	May
1	-	-	-	3.5	-	-
2	-	19.0	Trace	0.5	-	-
3	-	65.5	Trace	7.0	-	-
4	-	-	-	-	-	-
5	41.0	-	-	-	-	-
6	-	2.0	-	-	-	-
7	-	-	-	-	-	-
8	Trace	-	-	-	-	-
9	Trace	-	-	-	-	-
10	2.5	-	-	-	-	-
11	-	-	2.0	-	-	-
12	-	-	-	-	-	-
13	-	-	-	34.0	-	-
14	-	-	5.5	4.5	-	-
15	Trace	-	-	-	-	-
16	-	-	4.0	-	-	-
17	-	30.5	-	-	-	-
18	16.0	0.5	-	-	-	-
19	12.0	13.5	-	-	-	-
20	-	Trace	-	-	-	-
21	Trace	-	-	-	-	-
22	-	-	-	-	-	-
23	Trace	2.0	-	39.5	-	-
24	-	34.5	3.5	-	-	-
25	19.5	-	-	10.5	-	-
26	0.5	-	-	-	-	-
27	-	-	-	-	-	-
28	-	-	-	-	-	-
29	-	-	-	-	-	-
30	-	-	-	-	-	-
31	-	-	-	-	-	-
Total	91.5	167.5	15.0	99.5	0.0	0.5

Total rainfall received 195.5mm

Appendix . VI. Temperature data at Liempe farm in Degrees celsius.

Days	December	January	February	March	April	May
1	30(15)	30(14)	31(17)	32(20)	31(18)	23(12)
2	31(16)	31(17)	31(19)	31(18)	30(17)	25(12)
3	31(18)	27(17)	31(18)	30(19)	28(15)	29(13)
4	33(18)	27(18)	28(18)	27(18)	28(14)	29(13)
5	32(21)	28(16)	30(17)	29(18)	29(14)	30(13)
6	26(18)	29(17)	28(17)	31(17)	27(15)	29(14)
7	27(16)	30(17)	28(17)	31(17)	29(14)	28(12)
8	31(16)	30(17)	29(16)	32(16)	28(14)	28(12)
9	28(19)	28(16)	29(17)	34(19)	29(14)	29(13)
10	29(19)	30(18)	30(16)	32(18)	28(16)	28(13)
11	25(18)	26(18)	29(17)	32(18)	30(19)	26(15)
12	30(18)	28(16)	31(17)	31(18)	30(17)	25(12)
13	30(19)	31(15)	33(17)	28(18)	29(15)	25(14)
14	31(20)	33(17)	34(17)	27(19)	29(13)	26(11)
15	31(17)	32(18)	34(18)	30(20)	29(12)	26(11)
16	28(20)	33(18)	32(18)	28(17)	30(13)	26(12)
17	30(18)	31(18)	32(19)	29(17)	30(15)	26(12)
18	29(19)	29(19)	31(19)	29(18)	31(16)	26(12)
19	27(19)	32(18)	32(17)	31(16)	30(14)	27(11)
20	27(17)	25(18)	32(17)	30(19)	30(15)	27(13)
21	25(17)	29(18)	32(17)	30(19)	30(15)	28(11)
22	26(18)	32(18)	33(17)	30(19)	28(15)	28(11)
23	25(19)	29(19)	34(17)	28(21)	27(14)	28(10)
24	30(18)	29(18)	35(18)	27(18)	29(15)	28(13)
25	30(18)	25(19)	28(19)	28(18)	29(16)	30(12)
26	28(19)	27(18)	32(17)	25(18)	30(15)	29(12)
27	27(18)	27(15)	29(18)	28(19)	31(18)	28(13)
28	25(18)	28(15)	31(18)	27(18)	32(19)	28(12)
29	27(18)	30(18)	32(18)	29(17)	27(19)	26(13)
30	28(17)	31(17)		29(18)	23(17)	24(13)
31	29(15)	31(17)		29(18)		18(14)
Mean	29(18)	29(17)	31(17)	29(18)	29(15)	27(12)

Figures in brackets are minimum temperatures.

Appendix . VII. Temperature data at Lusitu and Masstock in Degrees celsius.

Days	December	January	February	March	April	May
1	36(25)	37(22)	35(24)	39(25)	36(23)	29(16)
2	38(23)	32(23)	35(24)	38(25)	36(24)	30(17)
3	38(27)	32(22)	34(24)	37(23)	34(23)	35(18)
4	39(26)	31(21)	32(23)	32(22)	32(22)	34(16)
5	34(25)	33(22)	37(23)	34(24)	35(22)	34(17)
6	29(22)	34(23)	36(23)	36(23)	33(23)	33(17)
7	32(22)	31(26)	36(23)	38(24)	35(21)	32(17)
8	34(23)	35(23)	32(24)	38(24)	34(21)	32(18)
9	33(25)	32(24)	36(22)	39(25)	33(22)	32(18)
10	25(25)	35(23)	37(22)	37(25)	33(21)	33(21)
11	31(24)	31(25)	28(26)	30(26)	36(25)	31(23)
12	34(24)	34(22)	36(23)	31(23)	35(24)	30(23)
13	37(27)	36(21)	39(22)	35(24)	35(24)	30(23)
14	37(27)	38(21)	39(22)	33(23)	36(22)	30(17)
15	35(26)	31(26)	40(26)	29(23)	33(21)	31(17)
16	36(26)	38(23)	31(23)	34(24)	36(19)	28(19)
17	37(26)	35(24)	32(25)	34(24)	34(23)	31(19)
18	35(27)	32(22)	37(25)	34(24)	36(25)	31(17)
19	26(22)	35(29)	39(23)	36(24)	35(21)	31(14)
20	26(24)	27(22)	38(27)	33(24)	36(20)	31(15)
21	33(24)	33(23)	37(24)	31(26)	35(20)	32(15)
22	34(24)	31(23)	39(25)	33(25)	34(24)	32(15)
23	31(25)	27(25)	40(26)	26(26)	33(23)	33(14)
24	34(25)	33(23)	39(26)	31(23)	32(25)	31(16)
25	33(26)	27(22)	29(22)	29(23)	35(24)	33(16)
26	26(20)	31(23)	40(22)	29(23)	35(26)	32(16)
27	31(22)	31(21)	37(26)	31(23)	36(26)	31(19)
28	33(24)	35(20)	39(24)	33(25)	34(26)	31(18)
29	31(22)	36(22)	39(24)	34(23)	29(25)	30(18)
30	35(23)	37(23)		36(23)	25(19)	31(18)
31	36(21)	35(230		35(23)		23(21)
Total	33(24)	33(23)	36(24)	34(24)	34(23)	31(18)

Figures in brackets are minimum temperatures.

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