THE UNIVERSITY OF ZAMBIA

GENETIC VARIABILITY AND STABILITY ANALYSIS IN SUNFLOWER

(*Helianthus annuus*, L.)

BY

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A THESIS

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DECLARATION

I, **MUNGUZWE HICHAAMBWA**, do hereby declare that this dissertation represents my ow work and that, to the best of my knowledge, it has not been previously submitted to this or an other university for the award of a degree.

Signed:____________________

Date: 12/1/95

APPROVAL

This dissertation of **MUNGUZWE HICHAAMBWA** 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

Information on genetic variability and stability of yield and yield components of sunflower in Zambia is lacking. The study was undertaken to determine the magnitude of yield; determine the relationships between yield and it's components; and estimate the heritability and stability of important traits in sunflower. Twenty five genotypes representing a random sample of the breeding populations in an on going sunflower improvement programme were grown in a 5 X 5 triple lattice design in 5 locations in the 1993/94 growing season. Data on kernel yield, kernel yield/head, oil content, oil yield, head diameter, stem diameter, plant population, plant height, average number of leaves/plant, number of days to 50% flowering, 1000 kernel weight and kernel % were collected and/or derived. The magnitude of yield was determined at harvesting. The relationship between yield and it's components was determined by path coefficient analysis. Presence of genetic variability was indicated by significant genetic variance. Heritability was estimated from variance components. Stability analysis was also done. The magnitude of kernel yield was found to be comparable with world averages though the average kernel yield of 1163 Kg/ha was below the country range of 1500 to 2000 Kg/ha) due to poor rains. High correlations between kernel yield and plant height ($r = 0.420^{**}$), stem diameter ($r = 0.589^{**}$) and kernel yield/head ($r = 0.658^{**}$) were observed but their direct effects on kernel yield were very small (-0.216, -0.154 and -0.189 respectively). However, their indirect effects were more positive mostly through head diameter (0.127, 0.174 and 0.141 respectively). Head diameter showed large direct effects on both kernel yield (0.311) and oil content (0.581). The direct effect of 1000 kernel weight on oil yield (0.173) was large relative to overall correlation ($r = 0.195^{**}$). The genetic variances for kernel yield, oil content, oil yield, head diameter, plant height, kernel yield/head and 1000 kernel weight were significant ($P \leq 0.05$). The broad sense heritability estimates for kernel yield ranged from 5.42% in Golden Valley to 33.01% in Monze; overall the estimate was 7.12%. For oil content the estimates ranged from 14.95% in Mt Makulu to 52.35% in Monze with an overall estimate of 11.43%. Similarly those of oil yield, plant height, stem diameter and 1000 kernel weight ranged from 8.36% in Golden Valley, 9.36% in Monze, 5.77% in Mt Makulu and 5.54% in Mt Makulu respectively to 26.78% in Monze, 61.96% in NIRS, 27.27% in Mt Makulu and 37.66% in Monze respectively with the overall estimate being 20.37%, 10.20%, 0.23%, and 2.51% respectively. For head diameter the estimate was 17.33% in Mt Makulu and 2.97% overall. Genotype X location interaction effects were significant for kernel yield, oil yield, 1000 kernel weight, stem diameter and plant height. Sunflower with respect to kernel and oil yield showed average ability to be consistent across locations. Overall the magnitude of yield was found to fall within an acceptable range with genetic variability being evident in the population. Head diameter alone could be a useful selection criterion for kernel yield and oil content; 1000 kernel weight for oil yield. Plant height and stem diameter together with head diameter could be useful indicators for early identification of elite lines with respect to kernel yield and oil content. Genetic variability for all traits studied was evident and the population was found to have average ability to perform consistently across environments.

DEDICATION

To my mother Namajala, son Ng'andu and wife Eliketa with lots of love.

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CHAPTER ONE

1.0 INTRODUCTION

Sunflower, *Helianthus annuus*, L., is grown mostly for the edible oil in the kernel which accounts for about 40% of it's weight. The refined oil is an excellent edible oil, being relatively low in the saturated fatty acids, palmitic and stearic. The absence of or very low linoleic acid content gives the oil excellent storage properties (Weiss, 1983). The meal that remains after oil extraction is a high quality protein source for livestock feeds though the high fibre content of the hull reduces it's nutritional value.

Historically, sunflower breeding has made important forward leaps with the development of high oil germplasm by Russian researchers between 1930 and 1960 (Martinez, 1989). This was further enhanced with the discovery of cytoplasmic male sterility and fertility restorer genes soon afterwards (Martinez, 1989; Weiss, 1983)). Since then it has been easier to develop hybrids thereby taking advantage of heterosis which led to increases in kernel yield in excess of 25% over open pollinated varieties. These hybrids not only gave high oil yield per hectare, but also provided for mechanised harvesting due to uniformity of the crop. Consequently sunflower has become an important crop among oil crops and presently ranks third at world level after soybean and oil palm (Martinez, 1989).

Reportedly, very little attention was paid to sunflower as a valuable source of protein and edible oils in Zambia until in the early 1970's when a sunflower improvement programme was initiated

(Ravagnan, 1974). The breeding programme adopted recurrent selection. This allowed a rapid detection of germplasm sufficiently reliable to deal with the immediate needs of the commercial kernel production, and the making of gene pools or populations with large genetic variability. From these populations it has been possible to isolate increasingly superior varieties from subsequent generations of selection.

According to Mwala *et al.* (1988), a total of 13 sunflower varieties had been released out of which 3 are currently being grown since the inception of the programme. These workers further reported that sunflower production in Zambia consequently increased from 124 metric tonnes in 1973 to about 30 000 metric tonnes in 1987; kernel yield increased from 1.5 metric tonnes to 2.5 metric tonnes per hectare while oil content increased from 32 to 40%.

Although this was a record increase in production, it still fell short of meeting the local crashing capacity (107 000 metric tonnes per year) of Zambia's two industrial processing plants (Mwala, *et al.*, 1988).

Presently the crop is increasingly becoming important especially among the Zambian small scale and emergent farmers, who produce about 95% of the total production (Eyland and Lubozhya, 1988). The crop is suitable for this sector because of its low input requirement. It is also a major raw material for the oil extracting industries in urban areas. One of the recently realised limiting factors to it's production has been the absence of improved varieties with desirable characteristics such as high oil yield and thin hulls. The continued use of recycled seed has aggravated the situation for small scale farmers and oil expellers as low oil content and low yield were evident.

The Research Branch of the Ministry of Agriculture Food and Fisheries has over the years consolidated the improvement programme which is still based on recurrent selection for good combining ability. According to Soukka (1990) an annual rate of increase in yield of approximately 10% over three cycles of recurrent selection has been achieved. However new tests and selection criteria can still be integrated into this original programme, to obtain simultaneous selection for oil yield enhancing characteristics and disease resistance. And in fact, as observed by Mwala *et al.* (1988), there may be need to produce varieties for large areas with specific and unique characteristics.

In addition kernel yield is a complex trait which is affected by a large number of factors which act alone or in combination. It is important that genetic information on this trait together with it's relationship with the other traits of the plant be known to develop appropriate selection criteria and to design efficient breeding programmes. The present study embarks in providing such information on yield and it's components in sunflower.

The overall goal of this study is to provide genetic information which would be useful in the current sunflower improvement programme. Specifically, the objectives are:

(1) to determine the magnitude of yield,

(2) to determine relationships between yield and it's components, and

(3) to estimate heritability and stability of important traits in sunflower.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Genetics of yield in sunflower

Grain yield in crops is determined primarily by the mass of the crop which, in turn, is determined by the quantity of radiation intercepted by the crop canopy (Hay and Walker, 1989). The crop canopy is determined by the genetic make up of the plants, the environmental effects and the interaction between the two (Falconer, 1960). These genetic and environmental components express their effects through their influence on the complex physiological and biochemical processes in the plant (Grant, 1975). Beard and Geng (1982) found significant genotypic effects in sunflower in response to planting date and the biological systems controlling the interrelationships between morphological, yield and oil characteristics. Most of the traits responsible for these effects are controlled mainly by additive gene action except for kernel yield on which partial dominance predominates with epistasis being minor for all traits (Miller *et al.*, 1980).

Several studies on sunflower (Visic, 1988; El - Mohandes, 1989; Samui and Goshc, 1988; Alessi *et al.*, 1977; Sultan *et al.*, 1988) have shown productivity to be affected by environmental factors like climate, fertiliser application, plant density, planting date and competition from weeds and diseases. Visic (1988) found relative humidity to be significantly related to kernel yield ($r = 0.397^{*}$) and head diameter ($r = 0.459^{*}$) and rainfall to be inversely related to oil yield ($r = - 0.551^{*}$). Nitrogen fertilisation has been found to increase crop canopy and kernel yield (El

- Mohandes, 1989; Samui and Goshc, 1988) while oil content is only increased when phosphorus is applied as well (Samui and Goshc, 1988). However, a balanced application of nitrogen, phosphorus and potassium gives the best kernel and oil yield (Sultan *et al.*, 1988). Plant population is inversely related to growth parameters as well as kernel and oil yield (El - Mohandes, 1989) but highest yields are achieved at optimum plant densities (Alessi *et al.*, 1977). As with nitrogen application, early planting favours crop canopy development and yield (Sultan *et al.*, 1988) where as late planting reduces oil content and days to 50 % flowering (Alessi *et al.*, 1977). Zemichael (1989) found sunflower yields to be reduced by 50 % after a full season competition with weeds. Visic (1988) working on white rot disease and other growth factors of sunflower found white rot of the head to adversely affect oil content ($r = -0.699^{**}$).

Within the crop canopy, crop yield is dependent upon organs/components of the plant which are interdependent to a lesser or greater degree (Hay and Walker, 1989). Beard and Geng (1982) discovered from principal component and path analyses that there are four underlying components which can be defined for sunflower characters. The first component is closely associated with plant growth and development from planting to anthesis, and is the most important growth component in terms of the direct effect on kernel yield. They concluded that the characters measured at harvest are highly dependent on early growth.

Much yield component studies in sunflower have been done and results have varied from place to place (Fick, 1978). This is so because correlations of individual characters with yield depend on the group of genotypes and the environment under which they are being evaluated. These correlations can be used only as a general guide in selection for high yield. Kandil and El - Mohandes (1987) working in 8 environments found head diameter to be a good indicator of head yield with correlation coefficients ranging from 0.399^{*} to 0.870^{**}.

In a path coefficient analysis of sunflower Marinkovic and Skoric (1988) found, although the magnitudes were not reported, highly significant correlation between kernel yield on one hand and plant height , kernel length, width, husk content and thickness on the other. A non significant positive correlation was found between kernel yield and average number of leaves per plant while that between number of days to flower though also non significant was negative. But the number of days to flower had highly significant correlations with plant height, number of leaves per plant and kernel length. These workers further reported that plant height was positively correlated to husk content and highly significantly correlated to number of leaves per plant, kernel length and width.

Tyagi (1988) found sunflower kernel yield to be negatively correlated to days to maturity. But Kovacik and Skaloud (1972) found yield per head to have a highly significant positive correlation with number of days to flowering ($r = 0.6163^{**}$). The number of days to flowering may be related to days to maturity but there can be genotypic differences in the time taken from flowering to maturity (Fick, 1978). Kovacik and Skaloud (1972) further reported positive and significant correlations between yield per head and 1000 kernel weight ($r = 0.2484^{*}$), head diameter ($r = 0.9136^{**}$) and plant height ($r = 0.6190^{**}$), and a non significant positive correlation with oil content ($r = 0.1819$). Oil content had a non significant negative correlation with 1000 kernel weight ($r = -0.1426$), a significant and non significant positive correlation with days to flowering ($r = 0.2027^{*}$) and plant height ($r = 0.0421$) respectively. Head diameter was not significantly correlated (positive) to 1000 kernel weight ($r = 0.1573$) but had highly significant correlations with number of days to flowering ($r = 0.5521^{**}$). And negative highly significant correlations were found between 1000 kernel weight on one hand and number of days to flowering ($r = -0.2251^{*}$) and plant height ($r = -0.3689^{**}$) on the other.

Other studies have been conducted with similar or different results. For instance, Soltani and Arshi (1988) and Marjanac (1988), contrary to Kovacik and Skaloud (1972), found significant positive relationships between oil content and 1000 kernel weight.

2.2 Heritability

Heritability is the proportion of observed variability which is due to heredity, the remainder being due to environmental causes (Allard, 1960). In other words, it is a measure of the degree to which a phenotype is genetically influenced and, therefore, the degree to which it can be modified by phenotypic selection (Gardner and Snustad, 1984).

Broad sense heritability which is the ratio of the genotype to phenotype can be estimated from multi - locational trials, and such estimates provide information on the magnitudes of genetic and environmental variation in the population (Dudley and Moll, 1969). The characterisation of such variation in yield and yield components in plant populations is needed in designing the most appropriate breeding programme (Robinson *et al.*, 1949). However, heritability is not a concept that can be applied to a trait in general, but only to a trait in a particular population, in a particular set of environments (Gregorius, 1977; Gardner and Snustad, 1984).

Much genetic variability for yield and yield components occurs in sunflower (Ado *et al.,* 1988). Because of the importance of the environmental effects, heritability of kernel yield is relatively low compared to other agronomic traits (Fick, 1978). Kloconski (1975) is reported by Fick (1978) to have found 18% as broad sense heritability on a single plant basis for yield as compared to a range of 22 to 49% for plant height, 1000 kernel weight, oil content, hull percentage and head diameter. He further reports that Shabana in 1974 reported a relatively high broad sense heritability of 69% for kernel yield among individual plants, an estimate that was similar to those of oil content and 1000 kernel weight, but was considerably less than the estimates for leaf area, days to 50% flowering, umber of leaves per plant, plant height and number of kernels per head.

Working on genotypes of F1 hybrid combinations, Kovacik and Skaloud (1972) found high broad sense heritability estimates of 74.61% for head diameter, 63.99% for number of days to 50% flowering, 82.00% for 1000 kernel weight ad 96.28% for final plant height. They found a relatively low estimate of 44.26% for oil content which is lower than the estimate (72%) found by Fick (1975).

Generally, estimates of heritability of the major yield components of umber of kernels per head and kernel weight were higher than those for kernel yield in many studies suggesting that selection for increased kernel yield through selection of yield components may have a value as a breeding procedure (Fick, 1978).

2.3 Stability

Stability of a genotype is defined as its ability to avoid substantial fluctuations in performance over a range of environments with above average yields and below average variance (Saaed and Francis, 1983). To estimate stability Eberhart and Russell (1966) proposed the linear regression coefficient of the genotype means on environmental indices and deviations from the regressions. They described a stable genotype as one with a regression coefficient close to unity and with deviations from the regressions as small as possible.

Stability of yield performance of sunflower over environments also is apparently under genetic control (Fick, 1978). According to Fick and Zimmer (1976) in Fick (1978) yield stability of sunflower can be attained with genetically homogeneous single cross hybrids as well as with heterogeneous cultivars or populations. However, Giriraj *et al.* (1988) found inbred lines to be of lower stability than populations where as the performance of three way and double cross hybrids was found to be similar.

Many sunflower yield stability studies have reported significant genotype, environment and genotype X environment interaction effects (Ugaro *et al.*, 1988; Tian - ping, 1988 and Giriraj *et al.*, 1988) implying that it is possible to select genotypes suited to closely defined ecological areas or those that are adapted to a wide range of environments. In all these studies, stability was generally inversely related to kernel yield and oil content.

In Zambia, Mwala and Lepoint (1988) carried out an analysis of experimental data from field experiments conducted at five locations over three years (1983 - 1985) with twenty five genotypes to identify and characterise stable varieties of sunflower in the Zambian environment in order to select breeding populations with wider adaptability. Though it was difficult to reconcile in this study the three concepts of stability, (namely the genotypic mean, regression coefficient and the deviations from the regression), due to the multiplicity of the stress factor in Zambia ad the unpredictability of the environmental index, stability analysis was seen as a useful tool in the breeding programme when a wide rage of environments is considered for the cultivation of a crop, as is the case in Zambia.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Design

Twenty five genotypes representing a random sample of the breeding population in an on going sunflower improvement programme were, during the 993/94 season, grown in 5 X 5 triple lattice design with 4 replications in 5 locations at Monze, National Agricultural Irrigation Research Station (NIRS) in Mazabuka, Mt Makulu Research Station in Lusaka, Golden Valley in Chisamba and Kabwe. Monze ad NIRS fall in a low rainfall zone (Region Ib) while Mt Makulu, Golden Valley and Kabwe fall in a medium rainfall zone (Region II). Their micro climates in terms of temperatures and soil types are also different. The planting dates ad soil types are shown in Table 1. The genotypes used and their origins are presented in Table 2.

Each plot had six rows plated 75 cm apart with 15 stations 30 cm apart. Four seeds were planted per station and these were thinned to one when the plants were about 10 cm high. Basal dressing fertiliser was applied at the rate of 20 Kg/ha nitrogen, 40 Kg/ha phosphorus as P_2O_5 and 20 Kg/ha potassium as K_2O and top dressing fertiliser at 34 Kg/ha nitrogen as ammonium nitrate. One row on either end of the lots were discarded to leave a harvest area of 3.0 X 3.4 m^2.

Table 1: Planting dates and soil types at each of the 5 locations

Location	Planting Date	Soil Type
Monze	19/12/93	Slightly leached, medium to slightly acid, red to reddish clayey derived from basic rocks, often in admixture with acid rocks (Veldkamp, 1987)
NIRS	17/12/93	Calcareous silt loams to sandy clay loams developed from alluvium (Msoni and Mulenga, 1992)
Mt Makulu	24/12/93	Deep and well drained sandy loams (Lee, 1968)
Golden Valley	30/12/93	Imperfect to poorly drained cracking fine clays over recent alluvium (Mulenga, 1992)
Kabwe	31/12/93	Flat imperfectly drained soils with a bleached layer of coarse sand at the top (Haugbton, 1974)

Table 2: The origins of the genotypes used in the study

Treatment/Genotype	Origin
CH 311, CH 336, CH 301	Commercial hybrid varieties
F43, F31-1, F50, F31-3-1, F468-2, F458-3, F427-3, F40, F41, F418-2, A4-5(3), PV8(4), A4-3(5)	Mt Makulu experimental lines
XTM7, XTM8, XTM10, XTM13, XTM14, XTM15, XTM16	Tanzanian populations
XUM7, XU10	University of Zambia inbred lines

3.1 Observations

The following observations were made per plot:

(1) Kernel yield

This was the average weight of kernels harvested per plot converted to Kg/ha and kernel yield per head.

(2) Oil Content

A random sample of the harvested kernels from each plot was analysed by nuclear magnetic resonance. The oil content was also converted to oil yield in Kg/ha for analysis.

(3) 1000 kernel weight

(4) Head size per plant measured as the diameter at physiological maturity

(5) Mature plant height measured as the height from the soil surface to the beginning of the droop of the head at physiological maturity

(6) Number of days from planting to 50% flowering at Mt Makulu Research Station only

(7) Number of leaves per planted measured at 50% flowering at Mt Makulu only

(8) Husk/kernel percentage

(9) Stem diameter measured at the base at physiological maturity

(10) Number of heads per plot converted to plat population/ha to indicate genotypic ability to establish good crop stands.

For characteristics (4) to (9) an average of ten random observations per plot from within the harvest area was used as a measure for the appropriate parameter.

3.2 Data analysis

(1) The above observations were analysed for correlation with kernel yield, oil content and oil yield, and amongst themselves, as per Little and Hill (1978). Path coefficient analysis of the parameters was also done following the method used by Singh and Chaudhary (1977) to determine their direct ad indirect effects on kernel yield, oil content and oil yield.

(2) Locational ad across location analysis of variance using M-stat computer software (Nissen, 1982) programme for kernel yield, oil content and all other measurements was done. Presence of genetic variability was indicated by the significance of genetic variances. The relative magnitudes of genetic and environmental variances were indicated by broad sense heritability estimates. The broad sense heritability estimates were calculated from variance components. The analyses of variance were carried out as shown in Table 3 and 4.

Table 3: Form of analysis of variance of data at each location

Source	df	Expected Mean Squares
Replications	(r - 1)	$\sigma^2_e + g\sigma^2_r$
Genotypes	(g - 1)	$\sigma^2_e + r\sigma^2_g$
Blocks (adj.)	r(b - 1)	$\sigma^2_e + \sqrt{g}\, r\sigma^2_b$
Effective error	$(\sqrt{g} - 1)(r\sqrt{g} - \sqrt{g} - 1)$	σ^2_e

$\sigma^2_e = Me$

$\sigma^2_b = (Mb - Me)/r\sqrt{g}$

$\sigma^2_g = (Mg - Me)/r$

$\sigma^2_r = (Mr - Me)/g$

Table 4: Expected mean squares from combined analysis of data across locations

Source	df	Expected Mean Squares	F Test
Location (L)	l - 1	$\sigma^2_e + r\sigma^2_{gl} + l\sigma^2_{gr} + gr\sigma^2_l$	Ml/(Mlr + Mgr - Me)
Replications (R)	r - 1	$\sigma^2_e + r\sigma^2_{gl} + l\sigma^2_{gr} + gl\sigma^2_r$	Mr/(Mlr + Mgr - Me)
L X R	(l - 1)(r - 1)	$\sigma^2_e + g\sigma^2_{lr}$	Mlr/Me
Genotypes (G)	g - 1	$\sigma^2_e + r\sigma^2_{gl} + l\sigma^2_{gr} + lr\sigma^2_g$	Mg/(Mgl + Mgr - Me)
G X L	(g - 1)(l - 1)	$\sigma^2_e + r\sigma^2_{gl}$	Mgl/Me
G X R	(g - 1)(r - 1)	$\sigma^2_e + l\sigma^2_{gr}$	Mgr/Me
Error	(g - 1)(r - 1) (l - 1)	σ^2_e	Me

Note: The block effect is pooled into error.

σ^2_e = Me

σ^2_{gr} = (Mgr - Me)/l

σ^2_{gl} = (Mgl - Me)/r

σ^2_g = (Mg - Mgl - Mgr + Me)/lr

σ^2_{lr} = (Mlr - Me)/g

σ^2_r = (Mr - Mgr -Mlr + Me)/gl

σ^2_L = (ML - MGL - MLR + ME)/GR

(3) Stability analysis of genotypes with respect to kernel yield and oil yield was conducted following the method of Eberhart and Russell (1966). The model is:

$$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$$

where

Y_{ij} is the mean of the ith genotype at the jth environment (i= 1,2,3,.....v and j = 1,2,3,.....n)

μ_i is the ith genotype mean over all environments

β_i is the regression coefficient that measures the response of the ith genotype to varying environments

I_j is the environmental index, estimated as the environmental mean minus the overall mean, and

δ_{ij} is the deviation from the regression of the ith genotype at the jth environment.

The third stability parameter, mean squared deviation from regression (S2d), was estimated as:

$$S^2_d = [\Sigma\delta_{ij}/l - 2] - Se^2/r$$

where l is the number of locations, and

Se^2/r is the estimate of pooled error.

The hypothesis that the genotypic regressions are not different from 1 was tested by the t test:

$t = (b_i - 1)/\sqrt{(MSE/SII)}$

where:

b_i is the regression coefficient of the ith genotype

MSE is the error mean square of the regression

SII is the variance of the environmental index, and

$df = l - 2$.

The hypothesis that the deviation from regression for each genotype is not different from 0 was tested by:

$F = (\sum\delta_{ij}/l - 2)/\text{pooled error}$

with df $l - 2$ and $(g - 1)(r - 1)(l - 1)$ for numerator and denominator respectively.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Magnitude of Yield and its Components

The rain season started well in all the locations as shown in Appendix 1. The soil moisture was adequate for germination and crop establishment at planting time in December, 1993. This resulted in good crop stands. However there was no rainfall in Golden Valley after December. As a result, further crop development depended on stored soil moisture leading to poor yields. In Monze, rainfall stopped too early and this affected the final stages of crop development. Though the rainfall amount at NIRS was less, it was better distributed and enabled achievement of higher yields. Mt Makulu is the only site which had reasonable rainfall after March, 1994. The dry weather towards the end of the season favoured termite damage which resulted in extensive lodging in all sites except Mt Makulu. The mean kernel yield of 1163 Kg/ha is less than the normal research average of 1500 - 2000 Kg/ha (Anonymous, 1992). This is attributed to low rainfall amount in Golden Valley, poor rainfall distribution in Monze and low fertility status of the soils (Hougbton, 1974) in Kabwe. The mean yields in NIRS and Mt Makulu fall within the normal range. The other traits were less affected by this variation in rainfall and soil types and their values compare well with world average values which range from 30 to 60 mm for stem diameter; 100 to 300 cm for plant height; 100 to 300 mm for head diameter; and are over 50 g for 1000 kernel weight; and 25 to 48% for oil content (Weiss, 1983). Fick (1978) reports slightly different values of 50 to over 500 cm for stem length; 10 - 100 mm for stem diameter; 8 - 70 leaves per plant; 30 - 110 days from emergence to initiation of flowering; 60 - 750 mm for head diameter; and 40 - 200 g for 1000 kernel weight.

Table 5: Correlation coefficients among yield and yield components of 25 sunflower genotypes grown in 5 locations in the 1993/94 season (data unbalanced)

TRAITS	Kern.	1000 wt	Yld/Hd	50% Fl+	No. lvs+	Hd Dia	Plt Ht	Stem Di	Plt Popn	Oil cont.	Oil
Yield	-0.106	0.045	0.658**	-0.224	0.205	0.343**	0.420**	0.589**	-0.019	-0.097	0.982**
Oil	-0.101	0.195**	0.666**	-0.194	0.200	0.343**	0.404**	0.566**	-0.047	0.029	
Oil cont.	0.102	0.321**	-0.038	-0.193	-0.086	0.374**	-0.214	0.024	-		
Plt Popn	-0.247	-	-	0.267*	0.264	-	-0.089	-			
Stem Di	0.201**	-0.128	0.611**	-0.178	0.155	0.559**	0.511**				
Plt Ht	0.106*	-0.129	0.328**	0.206	0.356**	0.408**					
Hd Dia	0.021	0.239**	0.453**	-	-0.180						
No. lvs	-0.044	-0.243	-0.051	0.047							
50% Flr	0.066	-0.066	-0.132								
Yld/Hd	0.012	0.326**									
1000 wt	-										

* and ** denote significance at 5% and 1% levels of probability respectively

+ denotes that observations were only taken at Mt Makulu Research Station

Observations for 1000 kernel wt and kernel percentage were only taken at 3 locations only correlated to plant population ($r = 0.264^{*}$) and head diameter ($r = -0.389^{**}$).

The results of the path coefficient analysis of kernel yield are shown in Table 6. The direct effects on kernel yield of stem diameter (-0.154), plant height (-0.216), and kernel yield per head (0.189) are small and even negative in spite of their large correlation coefficients ($r = 0.589^{**}$, $r = 0.420^{**}$ and $r = 0.658^{**}$ respectively). This implies that direct selection for kernel yield through these traits would not be effective. If these traits are to be a basis for selection, then they must be considered in relation with the other traits through which they have large indirect effects on kernel yield. Oil yield (1.218) and head diameter (0.311) are the only traits with large direct effects relative to their respective correlation coefficients ($r = 0.982^{**}$ and $r = 0.343^{**}$). Direct selection through these traits would be effective. Oil yield being a product of kernel yield and oil content which are both influenced by many factors, the reliability of this trait in a selection criteria can not be ascertained. The coefficient of determination was 1.046.

Table 7 shows the results of the path coefficient analysis of oil content. Only head diameter has a large direct effect (0.581) on oil content relative to the correlation coefficient ($r = 0.374^{**}$). Plant population and 1000 kernel weight have small direct effects in spite of their large and significant correlation coefficients ($r = -0.239^{**}$ and $r = 0.321^{**}$ respectively). However their indirect effects through head diameter (-0.209 and 0.139 respectively) are relatively large. Thus these traits in combination with head diameter would be useful in a selection criteria. But the

Table 6: Results of path coefficient analysis of kernel yield of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

Type of effect	Path Coefficient
Effect of oil yield on kernel yield	
Overall correlation	0.982**
Direct effect	1.218
Indirect effect via oil content	-0.007
Indirect effect via plant population	0.011
Indirect effect via stem diameter	-0.087
Indirect effect via plant height	-0.087
Indirect effect via head diameter	0.107
Indirect effect via No. of leaves/plant	0.018
Indirect effect via days to 50% flowering	-0.023
Indirect effect via kernel yield/head	-0.126
Indirect effect via 1000 kernel weight	-0.041
Indirect effect via kernel %	0.001
Effect of oil content on kernel yield	
Overall correlation	-0.097
Direct effect	-0.254
Indirect effect via oil yield	0.035
Indirect effect via plant population	0.054
Indirect effect via stem diameter	-0.004
Indirect effect via plant height	0.046
Indirect effect via head diameter	0.116
Indirect effect via No. of leaves/plant	-0.008
Indirect effect via days to 50% flowering	-0.023
Indirect effect via kernel yield/head	0.007
Indirect effect via 1000 kernel weight	-0.068
Indirect effect via kernel %	-0.001
Effect of plant population on kernel yield	
Overall correlation	-0.019
Direct effect	-0.228
Indirect effect via oil yield	-0.057
Indirect effect via oil content	0.061
Indirect effect via stem diameter	0.063
Indirect effect via plant height	0.019
Indirect effect via head diameter	-0.112
Indirect effect via No. of leaves/plant	0.024
Indirect effect via days to 50% flowering	0.032
Indirect effect via kernel yield/head	0.116
Indirect effect via 1000 kernel weight	0.063

Indirect effect via kernel %	0.001
Effect of stem diameter on kernel yield	
Overall correlation	0.589^{**}
Direct effect	-0.154
Indirect effect via oil yield	0.689
Indirect effect via oil content	-0.006
Indirect effect via plant population	0.093
Indirect effect via plant height	-0.111
Indirect effect via head diameter	0.174
Indirect effect via No. of leaves/plant	0.014
Indirect effect via days to 50% flowering	-0.021
Indirect effect via kernel yield/head	-0.116
Indirect effect via 1000 kernel weight	0.027
Indirect effect via kernel %	-0.001
Effect of plant height on kernel yield	
Overall correlation	0.420^{**}
Direct effect	-0.216
Indirect effect via oil yield	0.492
Indirect effect via oil content	0.054
Indirect effect via plant population	0.020
Indirect effect via stem diameter	-0.079
Indirect effect via head diameter	0.127
Indirect effect via No. of leaves/plant	0.032
Indirect effect via days to 50% flowering	0.025
Indirect effect via kernel yield/head	-0.062
Indirect effect via 1000 kernel weight	0.027
Indirect effect via kernel %	-0.001
Effect of head diameter on kernel yield	
Overall correlation	0.343^{**}
Direct effect	0.311
Indirect effect via oil yield	0.418
Indirect effect via oil content	-0.095
Indirect effect via plant population	0.082
Indirect effect via stem diameter	-0.086
Indirect effect via plant height	-0.088
Indirect effect via No. of leaves/plant	-0.016
Indirect effect via days to 50% flowering	-0.047
Indirect effect via kernel yield/head	-0.086
Indirect effect via 1000 kernel weight	0.050
Indirect effect via kernel %	0.000
Effect of No. of leaves/plant on kernel yield	
Overall correlation	0.205
Direct effect	0.090
Indirect effect via oil yield	0.244

Indirect effect via oil content	0.022
Indirect effect via plant population	-0.060
Indirect effect via stem diameter	-0.024
Indirect effect via plant height	-0.077
Indirect effect via head diameter	-0.056
Indirect effect via days to 50% flowering	0.006
Indirect effect via kernel yield/head	0.010
Indirect effect via 1000 kernel weight	0.050
Indirect effect via kernel %	0.000
Effect of days to 50% flowering on kernel yield	
Overall correlation	-0.224
Direct effect	0.120
Indirect effect via oil yield	-0.236
Indirect effect via oil content	0.049
Indirect effect via plant population	-0.061
Indirect effect via stem diameter	0.027
Indirect effect via plant height	-0.045
Indirect effect via head diameter	-0.121
Indirect effect via No. of leaves/plant	0.004
Indirect effect via kernel yield/head	0.025
Indirect effect via 1000 kernel weight	0.014
Indirect effect via kernel %	0.000
Effect of kernel yield/head on kernel yield	
Overall correlation	0.658**
Direct effect	-0.189
Indirect effect via oil yield	0.811
Indirect effect via oil content	0.010
Indirect effect via plant population	0.139
Indirect effect via stem diameter	-0.094
Indirect effect via plant height	-0.071
Indirect effect via head diameter	0.141
Indirect effect via No. of leaves/plant	-0.005
Indirect effect via days to 50% flowering	-0.016
Indirect effect via 1000 kernel weight	-0.069
Indirect effect via kernel %	-0.000
Effect of 1000 kernel weight on kernel yield	
Overall correlation	0.045
Direct effect	-0.211
Indirect effect via oil yield	0.238
Indirect effect via oil content	-0.082
Indirect effect via plant population	0.068
Indirect effect via stem diameter	0.020
Indirect effect via plant height	0.028
Indirect effect via head diameter	0.074

Indirect effect via No. of leaves/plant	-0.022
Indirect effect via days to 50% flowering	-0.008
Indirect effect via kernel yield/head	-0.062
Indirect effect via kernel %	0.001
Effect of kernel % on kernel yield	
Overall correlation	-0.106
Direct effect	-0.005
Indirect effect via oil yield	0.123
Indirect effect via oil content	-0.026
Indirect effect via plant population	0.056
Indirect effect via stem diameter	-0.031
Indirect effect via plant height	-0.023
Indirect effect via head diameter	0.007
Indirect effect via No. of leaves/plant	-0.004
Indirect effect via days to 50% flowering	-0.008
Indirect effect via kernel yield/head	-0.002
Indirect effect via 1000 kernel weight	0.038

** denotes significance at 1% level of probability

Table 7: Results of path coefficient analysis of oil content of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

Type of effect	Path Coefficient
Effect of kernel yield on oil content	
Overall correlation	-0.097
Direct effect	-8.337
Indirect effect via oil yield	8.177
Indirect effect via plant population	0.004
Indirect effect via stem diameter	-0.405
Indirect effect via plant height	0.153
Indirect effect via head diameter	0.199
Indirect effect via No. of leaves/plant	-0.043
Indirect effect via days to 50% flowering	0.092
Indirect effect via kernel yield/head	0.109
Indirect effect via 1000 kernel weight	-0.059
Indirect effect via kernel %	0.013
Effect of oil yield on oil content	
Over all correlation	0.029
Direct effect	8.327
Indirect effect via kernel yield	-8.187
Indirect effect via plant population	0.009
Indirect effect via stem diameter	-0.389
Indirect effect via plant height	0.147
Indirect effect via head diameter	0.199
Indirect effect via No. of leaves/plant	-0.042
Indirect effect via days to 50% flowering	0.080
Indirect effect via kernel yield/head	0.111
Indirect effect via 1000 kernel weight	-0.257
Indirect effect via kernel %	0.031
Effect of plant population on oil content	
Overall correlation	-0.039**
Direct effect	-0.194
Indirect effect via kernel yield	0.158
Indirect effect via oil yield	-0.329
Indirect effect via stem diameter	0.281
Indirect effect via plant height	-0.032
Indirect effect via head diameter	-0.209
Indirect effect via No. of leaves/plant	-0.055
Indirect effect via days to 50% flowering	-0.110
Indirect effect via kernel yield/head	-0.101
Indirect effect via 1000 kernel weight	0.393

Indirect effect via kernel %	0.021
Effect of stem diameter on oil content	
Overall correlation	0.024
Direct effect	-0.687
Indirect effect via kernel yield	-4.911
Indirect effect via oil yield	4.713
Indirect effect via plant population	0.079
Indirect effect via plant height	0.186
Indirect effect via head diameter	0.325
Indirect effect via No. of leaves/plant	-0.032
Indirect effect via days to 50% flowering	0.073
Indirect effect via kernel yield/head	0.101
Indirect effect via 1000 kernel weight	0.169
Indirect effect via kernel %	0.008
Effect of plant height on oil content	
Overall correlation	0.214
Direct effect	0.364
Indirect effect via kernel yield	-3.502
Indirect effect via oil yield	3.364
Indirect effect via plant population	0.017
Indirect effect via stem diameter	-0.351
Indirect effect via head diameter	0.237
Indirect effect via No. of leaves/plant	-0.074
Indirect effect via days to 50% flowering	-0.085
Indirect effect via kernel yield/head	0.054
Indirect effect via 1000 kernel weight	0.170
Indirect effect via kernel %	0.019
Effect of head diameter on oil content	
Overall correlation	0.374**
Direct effect	0.581
Indirect effect via kernel yield	-2.860
Indirect effect via oil yield	2.856
Indirect effect via plant population	0.070
Indirect effect via stem diameter	-0.384
Indirect effect via plant height	0.149
Indirect effect via No. of leaves/plant	0.037
Indirect effect via days to 50% flowering	0.160
Indirect effect via kernel yield/head	0.075
Indirect effect via 1000 kernel weight	-0.315
Indirect effect via kernel %	0.005
Effect of No. of leaves/plant on oil content	
Overall correlation	-0.086
Direct effect	-0.208
Indirect effect via kernel yield	-1.709

Indirect effect via oil yield	1.665
Indirect effect via plant population	-0.051
Indirect effect via stem diameter	-0.107
Indirect effect via plant height	0.130
Indirect effect via head diameter	-0.105
Indirect effect via days to 50% flowering	-0.019
Indirect effect via kernel yield/head	-0.008
Indirect effect via 1000 kernel weight	0.320
Indirect effect via kernel %	0.005
Effect of days to 50% flowering on oil content	
Overall correlation	-0.193
Direct effect	-0.412
Indirect effect via kernel yield	1.868
Indirect effect via oil yield	-1.615
Indirect effect via plant population	-0.052
Indirect effect via stem diameter	0.122
Indirect effect via plant height	0.075
Indirect effect via head diameter	-0.226
Indirect effect via No. of leaves/plant	-0.010
Indirect effect via kernel yield/head	-0.022
Indirect effect via 1000 kernel weight	0.087
Indirect effect via kernel %	-0.008
Effect of kernel yield/head on oil content	
Overall correlation	-0.038
Direct effect	0.166
Indirect effect via kernel yield	-5.486
Indirect effect via oil yield	5.546
Indirect effect via plant population	0.118
Indirect effect via stem diameter	-0.420
Indirect effect via plant height	0.119
Indirect effect via head diameter	0.263
Indirect effect via No. of leaves/plant	0.011
Indirect effect via days to 50% flowering	0.054
Indirect effect via 1000 kernel weight	-0.430
Indirect effect via kernel %	0.020
Effect of 1000 kernel weight on oil content	
Overall correlation	0.321**
Direct effect	-1.318
Indirect effect via kernel yield	-0.375
Indirect effect via oil yield	1.624
Indirect effect via plant population	0.058
Indirect effect via stem diameter	0.088
Indirect effect via plant height	-0.047
Indirect effect via head diameter	0.139

Indirect effect via No. of leaves/plant	0.050
Indirect effect via days to 50% flowering	0.027
Indirect effect via kernel yield/head	-0.054
Indirect effect via kernel %	0.022
Effect of kernel % on oil content	
Overall correlation	0.102
Direct effect	-0.121
Indirect effect via kernel yield	0.884
Indirect effect via oil yield	-0.841
Indirect effect via plant population	0.048
Indirect effect via stem diameter	-0.138
Indirect effect via plant height	0.039
Indirect effect via head diameter	0.012
Indirect effect via No. of leaves/plant	0.009
Indirect effect via days to 50% flowering	-0.027
Indirect effect via kernel yield/head	0.002
Indirect effect via 1000 kernel weight	0.236

** denote significance at 1% level of probability

effectiveness of plant population can not be ascertained since it is largely a function of management. The coefficient of determination was 1.462.

Table 8 presents the results of the path coefficient analysis of oil yield. Only kernel yield has a large direct effect (0.867) on oil yield relative to the correlation coefficient ($r = 0.982^{**}$). Direct selection for oil yield through kernel yield should therefore be effective. Although stem diameter, plant height and head diameter have large correlation coefficients with oil yield ($r = 0.566^{**}$, $r = 0.404^{**}$ and $r = 0.343^{**}$ respectively) their direct effects (0.113, 0.159 and -0.235 respectively) are small. However, their indirect effects through kernel yield (0.510, 0.364 and 0.297 respectively) are large. The direct effect of oil content on oil yield (0.196) is large but the correlation coefficient ($r = 0.029$) is small and insignificant. Selection for oil yield can be achieved directly through selection for kernel yield and indirectly through selection for head diameter, plant height and stem diameter.

Table 8: Results of path coefficient analysis of oil yield of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

Type of effect	Path Coefficient
Effect of kernel yield on oil yield	
Overall correlation	0.982**
Direct effect	0.867
Indirect effect via oil content	-0.019
Indirect effect via plant population	-0.003
Indirect effect via stem diameter	0.067
Indirect effect via plant height	0.067
Indirect effect via head diameter	-0.031
Indirect effect via No. of leaves/plant	-0.013
Indirect effect via days to 50% flowering	0.017
Indirect effect via kernel yield/head	0.073
Indirect effect via 1000 kernel weight	0.008
Indirect effect via kernel %	-0.008
Effect of oil content oil yield	
Overall correlation	0.029
Direct effect	0.196
Indirect effect via kernel yield	-0.084
Indirect effect via plant population	-0.036
Indirect effect via stem diameter	0.003
Indirect effect via plant height	-0.034
Indirect effect via head diameter	-0.088
Indirect effect via No. of leaves/plant	0.006
Indirect effect via days to 50% flowering	0.015
Indirect effect via kernel yield/head	-0.004
Indirect effect via 1000 kernel weight	0.056
Indirect effect via kernel %	0.001
Effect of plant population oil yield	
Overall correlation	-0.047
Direct effect	0.150
Indirect effect via kernel yield	-0.016
Indirect effect via oil content	-0.047
Indirect effect via stem diameter	-0.046
Indirect effect via plant height	-0.014
Indirect effect via head diameter	0.085
Indirect effect via No. of leaves/plant	-0.017
Indirect effect via days to 50% flowering	-0.021
Indirect effect via kernel yield/head	-0.068
Indirect effect via 1000 kernel weight	-0.052

Indirect effect via kernel %	-0.001
Effect of stem diameter oil yield	
Overall correlation	0.566**
Direct effect	0.113
Indirect effect via kernel yield	0.510
Indirect effect via oil content	0.005
Indirect effect via plant population	-0.062
Indirect effect via plant height	0.081
Indirect effect via head diameter	-0.131
Indirect effect via No. of leaves/plant	-0.010
Indirect effect via days to 50% flowering	0.014
Indirect effect via kernel yield/head	0.068
Indirect effect via 1000 kernel weight	-0.022
Indirect effect via kernel %	-0.000
Effect of plant height oil yield	
Overall correlation	0.404**
Direct effect	0.159
Indirect effect via kernel yield	0.364
Indirect effect via oil content	-0.042
Indirect effect via plant population	-0.013
Indirect effect via stem diameter	0.058
Indirect effect via head diameter	-0.096
Indirect effect via No. of leaves/plant	-0.023
Indirect effect via days to 50% flowering	-0.016
Indirect effect via kernel yield/head	0.036
Indirect effect via 1000 kernel weight	-0.022
Indirect effect via kernel %	-0.000
Effect of head diameter oil yield	
Over all correlation	0.343**
Direct effect	-0.235
Indirect effect via kernel yield	0.297
Indirect effect via oil content	0.073
Indirect effect via plant population	-0.054
Indirect effect via stem diameter	0.063
Indirect effect via plant height	0.065
Indirect effect via No. of leaves/plant	0.012
Indirect effect via days to 50% flowering	0.030
Indirect effect via kernel yield/head	0.050
Indirect effect via 1000 kernel weight	0.041
Indirect effect via kernel %	-0.000
Effect of No. of leaves/plant on oil yield	
Overall correlation	0.200
Direct effect	-0.065
Indirect effect via kernel yield	0.178

Indirect effect via oil content	-0.017
Indirect effect via plant population	0.040
Indirect effect via stem diameter	0.018
Indirect effect via plant height	0.057
Indirect effect via head diameter	0.042
Indirect effect via days to 50% flowering	-0.004
Indirect effect via kernel yield/head	-0.006
Indirect effect via 1000 kernel weight	-0.042
Indirect effect via kernel %	-0.000
Effect of days to 50% flowering on oil yield	
Over all correlation	-0.194
Direct effect	-0.077
Indirect effect via kernel yield	-0.194
Indirect effect via oil content	-0.038
Indirect effect via plant population	0.040
Indirect effect via stem diameter	-0.020
Indirect effect via plant height	0.033
Indirect effect via head diameter	0.091
Indirect effect via No. of leaves/plant	-0.003
Indirect effect via kernel yield/head	-0.015
Indirect effect via 1000 kernel weight	-0.011
Indirect effect via kernel %	0.000
Effect of kernel yield/head on oil yield	
Overall correlation	0.666**
Direct effect	0.111
Indirect effect via kernel yield	0.570
Indirect effect via oil content	-0.007
Indirect effect via plant population	-0.092
Indirect effect via stem diameter	0.069
Indirect effect via plant height	0.052
Indirect effect via head diameter	-0.106
Indirect effect via No. of leaves/plant	0.003
Indirect effect via days to 50% flowering	0.010
Indirect effect via 1000 kernel weight	0.056
Indirect effect via kernel %	-0.001
Effect of 1000 kernel weight on oil yield	
Overall correlation	0.195**
Direct effect	0.173
Indirect effect via kernel yield	0.039
Indirect effect via oil content	0.063
Indirect effect via plant population	-0.045
Indirect effect via stem diameter	-0.015
Indirect effect via plant height	-0.021
Indirect effect via head diameter	-0.056

Indirect effect via No. of leaves/plant	0.016
Indirect effect via days to 50% flowering	0.005
Indirect effect via kernel yield/head	0.036
Indirect effect via kernel %	-0.001
Effect of kernel % on oil yield	
Overall correlation	-0.101
Direct effect	0.005
Indirect effect via kernel yield	-0.092
Indirect effect via oil content	0.020
Indirect effect via plant population	-0.037
Indirect effect via stem diameter	0.023
Indirect effect via plant height	0.017
Indirect effect via head diameter	-0.005
Indirect effect via No. of leaves/plant	0.003
Indirect effect via days to 50% flowering	-0.005
Indirect effect via kernel yield/head	0.001
Indirect effect via 1000 kernel weight	-0.031

** denote significance at 1% level of probability

The strong relationship between kernel yield and oil yield ($r = 0.982^{**}$) is due to the use of kernel yield as one of the factors to estimate oil yield, where as stem diameter, plant height, head diameter and kernel yield per head are an indication of plant vigour and in turn crop productivity. The grand mean yield is less than the normal research average (Anonymous, 1992). The poor performance was attributed to poor rains as discussed above. Though sunflower is considered to be drought tolerant, water deficit affects growth and yield (Guiducci, 1988). However, in such stress conditions leaf number, 1000 kernel weight and oil content are usually the more weakly affected (Velkov, 1988). This could be the reason for low correlation coefficients between these traits and kernel yield.

4.3 Genetic variability and stability of important traits in sunflower

4.3.1 Genetic variability and heritability

The mean squares from the locational analysis of variance of kernel yield are shown in Table 9. The genotypic effect was highly significant in Monze ($P < 0.01$), significant at NIRS ($P < 0.05$) and Mt Makulu ($P < 0.05$) and insignificant in Golden Valley and Kabwe. Table 10 shows the variance components and broad sense heritability estimates of kernel yield at each of the 5 locations. The genetic variances were secondary to error variances in determining phenotypic variance while the replication and block variances were tertiary to the error and genetic variances in all locations. The estimated broad sense heritability ranged from 33.01% in Monze to 5.42% in Golden Valley. The environmental value had a significant influence on genotypic expressivity and it's correlation coefficient with broad sense heritability estimate of 0.758 is significant ($P < 0.05$). Table 11 shows the combined analysis of variance of kernel yield data

Table 9: Mean squares, coefficient of variation and environmental values from locational analysis of variance of kernel yield of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

	Mean Squares				
Source of variation	Monze	NIRS	Mt Makulu	G/Valley	Kabwe
Replication	1514489	434593	388753	200389	4408
Genotypes	299740**	587931*	416528*	42773	132074
Blocks	244954	407591	253936	31304	72740
Effective error	80185	312280	192903	35525	184544
$\bar{CV}$	21.58%	22.10%	26.68%	50.11%	46.45%
Environmental Value	1312	1507	1696	376	925

* and ** denote significance at 5% and 1% levels of probability respectively

Table 10: Variance components and broad sense heritability estimates of kernel yield of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

	Variance components				
Source of variation	Monze	NIRS	Mt Makulu	G/Valley	Kabwe
Replication	57372	4893	7834	6595	0+
Genotypes	73185**	91884*	74542*	2416	0+
Blocks	10984	6354	4069	0+	0+
Effective error	80185	312280	192903	35525	184544
Broad sense h^2	33.01%	22.12%	26.68%	5.42%	-
Environmental Value	1312	1507	1696	376	925

* and ** denote significance at 5% and 1% levels of probability respectively

+ denotes negative variances of which the most realistic value is zero.

across locations. The genotypic and location effects were highly significant at $P < 0.01$ while the genotype X location interaction effect was only significant at $P < 0.05$. The genotypic variance (34709^{**}) was secondary in importance to location variance (254831^{**}) in determining phenotypic variance. The large location variance is attributed to very low kernel yields in Golden valley and Kabwe. The broad sense heritability estimate from the pooled analysis of data is 7.12%.

The mean squares from location wise analysis of variance of oil content are presented in Table 12. The genotypic effect was significant in all locations except Golden valley. The environmental value ranged from 28.35% in Mount Makulu to 38.53% in Monze. Although Golden Valley had insignificant genotypic effect, it's environmental value (34.31) is higher and the coefficient of variation (7.37%) lower than that of Mount Makulu (28.35 and 10.65% respectively). The variance components and broad sense heritability estimates of oil content at each location are shown in Table 13. The estimated heritability is highest in Monze (52.35%) followed by Kabwe (49.33%) then NIRS (21.16%) and Mount Makulu (14.95%). Table 14 shows the combined analysis of variance of oil content data. The location and genotypic effects were significant where as that of the genotype X location interaction was not. The broad sense heritability was estimated as 11.43%.

Table 11: Mean Squares, variance components and broad sense heritability estimated from combined analysis of variance of kernel yield of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

Source of Variation	Mean Square	Variance	Heritability
Location (L)	19626115**	254831**	
Genotypes (G)	779925**	34709**	7.12%
G X L	203561*	16762*	
Pooled error	153274	153274	
Coefficient of Variation 33.97%			

* and ** denote significance at 5% and 1% levels of probability respectively

Table 12: Mean squares, coefficient of variation and environmental values from locational analysis of variance of oil content of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

	Mean Squares				
Source of variation	Monze	NIRS	Mt Makulu	G/Valley	Kabwe
Replication	40.460	34.766	73.875	19.731	5.780
Genotypes	18.010**	11.940*	15.284*	9.363	17.594**
Blocks	5.280	9.718	6.481	2.026	2.066
Effective error	2.920	5.990	9.113	10.334	4.488
CV	4.44%	6.56%	10.65%	7.37%	35.89%
Envntal Value	38.53	37.28	28.35	34.31	35.89

* and ** denote significance at 5% and 1% levels of probability respectively

Table 13: Variance components and broad sense heritability estimates of oil content of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

	Variance components				
Source of variation	Monze	NIRS	Mt Makulu	G/Valley	Kabwe
Replication	1.50	1.15	2.59	0.38	0.00+
Genotypes	5.03**	1.98*	2.06*	0.00+	4.37**
Blocks	0.16	0.25	0.00+	0.00+	0.00+
Effective error	2.92	5.99	9.11	10.33	4.49
Broad sense h^2	52.35%	21.16%	14.95%	-	49.33%
Environmental Value	38.53	37.28	28.35	34.31	35.89

* and ** denote significance at 5% and 1% levels of probability respectively

+ denotes negative variance estimates the most realistic value being 0.

Table 14: Mean Squares, variance components and broad sense heritability estimated from combined analysis of variance of oil content of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

Source of Variation	Mean Square	Variance	Heritability
Location (L)	1183.695**	15.306**	
Genotypes (G)	49.149**	2.919**	11.43%
G X L	5.737	0.000+	
Pooled error	6.158	6.158	
Coefficient of Variation	7.12%		

* and ** denote significance at 5% and 1% levels of probability respectively

+ denotes negative variance estimate of which the most realistic value is 0.

The locational analysis of variance of oil yield is presented in Table 15. Oil yield, a product of kernel yield and oil content, did not show a genetic variability picture related to either of the two traits. The genotypic effect was only significant in Monze. However, with regard to variance components (Table 16), Monze had the highest heritability estimate (26.78%) followed by NIRS (18.73%), Mt Makulu (17.48%) and Golden Valley (8.36%). The combined analysis of variance of oil yield in Table 17 shows significant location, genotypic and genotype X location interaction effects. There was inconsistent differential response of the genotypes to the environment in the 5 locations. The error variance (21365) was tertiary in importance to location and genotypic variances (250708^{**} and 72688^{**}) in determining phenotypic variability. Genetic variance accounted for about 20.37% of the total variance as indicated by the broad sense heritability estimate.

Similar analyses were done for yield components and the results are shown in Appendices 2 to 5. Genetic variation was generally evident in these traits as well. Genotypic expressivity in this case was also influenced by the environment though the degree was less than that on kernel yield. Head diameter seemed to be the most affected by adverse weather since the dry spell occurred during the reproductive stage of the crop's growth. Genetic variation in this trait was consequently only significant in Mt Makulu which had adequate moisture at the time of head development. All these traits except stem diameter showed significant genetic variation from in the combined analysis. Genotype X location interaction effect was significant for 1000 kernel weight, plant height, stem diameter and plant population.

Table 15: Mean squares, coefficient of variation and environmental values from locational analysis of variance of oil yield of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

	Mean Squares				
Source of variation	Monze	NIRS	Mt Makulu	G/Valley	Kabwe
Replication	303482	94410	62387	31314	1094
Genotypes	42149**	86099	34840	5129	17250
Blocks	38729	71540	30889	4475	13468
Effective error	13131	49575	20380	3780	23722
CV	22.90%	40.00%	30.91%	47.12%	47.55%
Environmental Value	500	557	462	130	324

** denote significance at 1% level of probability

Table 16: Variance components and broad sense heritability estimates of oil yield of 25 sunflower genotypes grown in 5 locations in 1993/94.

	Variance components				
Source of variation	Monze	NIRS	Mt Makulu	G/Valley	Kabwe
Replication	11614	1793	1680	1101	0+
Genotypes	9672**	12175	4820	450	0+
Blocks	1706	1464	701	46	0+
Effective error	3131	49575	20380	3780	23722
Broad sense h^2	26.78%	18.73%	17.48%	8.36%	-
Environmental Value	500	557	462	130	324

** denotes significance at 1% level of probability

+ denotes negative variance estimates the most realistic value being 0.

Table 17: Mean Squares, variance components and broad sense heritability estimated from combined analysis of variance of oil yield of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

Source of Variation	Mean Square	Variance	Heritability
Location (L)	2188035**	250708**	
Genotypes (G)	81860**	72688**	20.37%
G X L	28475*	2370*	
Pooled error	21365	21365	
Coefficient of Variation	37.04%		

* and ** denote significance at 5% and 1% levels of probability respectively

Crop performance in terms of kernel yield was poor especially in Golden Valley and Kabwe due to unfavourable weather especially during the reproductive stage of the crop's growth. These two sites did not show significant genotypic effects and were characterised by low environmental values and high coefficients of variation. This is in agreement with Asay and Johnson (1990) who found that generally the expression of genetic variability among breeding material is known to be reduced by drought and that experimental error reflected by the coefficient of variation becomes substantially larger. Consequently genetic variances and broad sense heritability estimates are remarkedly reduced.

All in all, the kernel yield results show that genetic variability exists in the population. However the proportion of genetic variance to the total variance as reflected by the broad sense heritability estimate is low. This is attributed to moisture stress during the season which affected productivity. It can not be ascertained whether the low heritability estimate is due to an appreciable amount of fixation due to selection pressure in this trait in the breeding population. Other studies have found heritability estimates for sunflower kernel yield ranging from 18% to 80% depending on populations and the environment under which the estimates were made (Fick, 1978).

Oil content seemed to be more affected by moisture stress than kernel yield. The better overall performance in Golden valley than in Mt Makulu could be attributed to differences in soil types and inherent fertility levels since according to Weiss (1988) phosphorus is known to increase kernel oil content and nitrogen to reduce it. In addition the presence of sulphur fumes in Mt

Makulu could have favoured production of sulphur containing amino acids rather than fatty acids. Even the broad sense heritability estimate of oil content did not seem to be influenced by the environmental value. The correlation coefficient of 0.384 between the environmental value and the broad sense heritability estimate is not significant. The insignificant genotype X location interaction effect means that the relative performance of the genotypes in all the 5 locations was essentially the same. The broad sense heritability estimate of 11.43% is much lower than that obtained by Visic (1988) which ranged from 78 to 90% since the populations and environments involved are different. However, this estimate is higher than that of kernel yield reported in the previous section. Oil content has been reported to have higher heritability estimates than kernel yield (Fick, 1978). Oil yield showed an interaction of kernel yield and oil content though the resulting effect could not be related to either of the two.

4.3.2 Stability

The significant location and genotype X location interaction effects in kernel and oil yield justifies the necessity of testing the genotypes at multiple locations in this sunflower improvement programme. It implies that the genotypes responded quite differently in the different locations. Table 18 shows the genotypic mean kernel yields and the environmental values at each location. It is clear from the mean separation that the relative rankings of the means at each location is different.

Table 18: The mean kernel yield of 25 sunflower genotypes grown in 5 locations in 1993/93 season

No. Genotype	Mean Seed Yield/Location				
	Monze	NIRS	Mt Makulu	G/Valley	Kabwe
1. F43	1275b-d	1775ab	1743a-c	416a	998a
2. F31-1	1520a-d	1327a-d	1452bc	638a	993a
3. F31-3-1	1343a-d	1694a-c	1598a-c	402a	1273a
4. CH 311	1154cd	1683a-c	2084ab	497a	1121a
5. CH 336	1286b-d	817c-e	1909ab	460a	833a
6. CH 301	1656a-c	1513a-c	2068ab	525a	1066a
7. F468-2	1242b-d	1902ab	1274cd	423a	1140a
8. F458-3	1063d-f	1301a-e	1783a-c	333a	820a
9. F427-3	1402a-d	1975ab	1698a-c	194a	744a
10. F40	1580a-c	1638a-c	2172ab	571a	1342a
11. F41	1686ab	2100a	1709a-c	271a	746a
12. F418-2	1441a-d	1534a-c	2295a	308a	921a
13. F50	1202a-d	1902ab	1668a-c	367a	1138a
14. XTM7	1370a-d	1528a-c	1846a-c	426a	907a
15. XTM8	1408a-d	1158bc-e	1422c	288a	591a
16. XTM10	1636a-c	1851ab	1421c	507a	1082a
17. XTM13	1231b-d	2048ab	1900a-c	258a	938a
18. XTM14	1562a-c	1383a-c	1244cd	246a	864a
19. XTM15	1467a-d	1199a-e	1507bc	478a	944a
20. XTM16	1761a	1622ab	1706a-c	290a	760a
21. XUM7	671fg	420de	1126cd	283a	520a
22. XUM10	382g	397e	669d	316a	680a
23.A4-5(3)	1423a-d	1467a-c	2078ab	379a	1155a
24.PV8(4)	920ef	1820a-c	1233cd	157a	892a
25.A4-3(5)	1118c-f	1631a-c	1550bc	374a	657a
Environ. Val.	1312	1507	1646	376	925
CV	21.58%	37.17%	26.67%	50.11%	46.45%
Grand Mean	1163				

- Means at the same location with the same letter are not significantly different at 5% level of probability according to Duncan's Multiple Range Test.

The adjusted lattice design means were used to test for stability of the genotypes by the model of Eberhart and Russell (1966). The resulting mean, regression coefficient, mean squared deviations and the coefficient of determination of the regression are shown in Table 19.

Table 20 shows the genotypic mean oil yields and environmental values at each location and Table 21 the overall genotypic oil yield means, regression coefficients, mean squared deviations from the regressions and the coefficient of determination of the regressions.

In both cases about 92% of the genotypic means are not significantly different from the grand mean with the remainder having less than average performance. The regression coefficients of the genotypes for both kernel and oil yield are not significantly different from but below 1 except for one genotype. Similarly, the deviations from the regressions are also not significantly different from 0 except for 2 genotypes for kernel yield and 3 genotypes for oil yield. According to Eberhart and Russell (1966), a stable variety is one with above average performance, unity regression coefficient and zero mean squared deviations from regression. This implies that the population has average ability to yield consistently across the locations.

Table 19: The mean kernel yield, regression coefficient (b), mean squared deviations (S^2_d) and coefficient of determination of regression (R^2) of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

No. Genotype	#Mean	b	S^2_d	R^2
1. F43	1241ab	1.08	0.05	0.93
2. F31-1	1186ab	0.67	0.08	0.77
3. F31-3-1	1262ab	0.95	0.12	0.82
4. CH 311	1308ab	1.11	0.21	0.78
5. CH 336	1061ab	0.84	0.61	0.36
6. CH 301	1366ab	1.11	0.12	0.86
7. F468-2	1196ab	0.87	0.40	0.51
8. F458-3	1060ab	1.01	0.11	0.85
9. F427-3	1202ab	1.37	0.17	0.87
10. F40	1460a	1.10	0.12	0.86
11. F41	1302ab	1.40	0.24	0.79
12. F418-2	1300ab	1.38	0.22	0.84
13. F50	1255ab	1.09	0.19	0.79
14. XTM7	1215ab	1.08	0.03	0.97
15. XTM8	973b	0.93	0.17	0.76
16. XTM10	1299ab	0.93	0.25	0.67
17. XTM13	1275ab	1.37	0.19	0.86
18. XTM14	1060ab	0.92	0.26	0.65
19. XTM15	1119ab	0.77	0.11	0.77
20. XTM16	1228ab	1.23	0.21++	0.82
21. XUM7	604c	0.45	0.26	0.25
22. XUM10	489c	0.12*	0.13++	0.02
23.A4-5(3)	1300ab	1.15	0.15	0.85
24.PV8(4)	1004b	1.02	0.45	0.57
25.A4-3(5)	1066ab	1.03	0.12	0.85
Mean	1163	1.00		

* denotes b is significantly different from 1 at 5% level of probability.

++ denotes S^2_d is significantly different from 0 at 1% level of probability.

# denotes values followed by the same letter are not significantly different from each other at 5% level of probability according to Duncan's Multiple Range Test

The coefficient of determination shows what proportion of the total variance for each genotype was due to regression.

Table 20: The mean oil yield of 25 sunflower genotypes grown in 5 locations during 1993/93 season

	Mean Oil Yield/Location				
No. Genotype	Monze	NIRS	Mt Makulu	G/Valley	Kabwe
1. F43	490b-e	673a	512a	134a	340a
2. F31-1	587a-c	455a	366a	221a	333a
3. F31-3-1	502b-e	612a	435a	139a	444a
4. CH 311	459bc-e	652a	536a	175a	426a
5. CH 336	513a-e	309a	594a	167a	315a
6. CH 301	612a-c	540a	575a	167a	375a
7. F468-2	463c-f	691a	325a	134a	384a
8. F458-3	377ef	462a	462a	99a	268a
9. F427-3	500b-e	673a	463a	57a	243a
10. F40	515a-e	552a	547a	184a	445a
11. F41	626ab	797a	528a	97a	255a
12. F418-2	497b-e	506a	656a	90a	289a
13. F50	474dc-e	713a	460a	115a	368a
14. XTM7	537a-e	559a	547a	148a	337a
15. XTM8	573a-d	460a	413a	91a	224a
16. XTM10	636ab	682a	427a	178a	416a
17. XTM13	467bc-e	771a	503a	86a	319a
18. XTM14	596a-c	488a	320a	175a	312a
19. XTM15	537a-e	429a	389a	157a	336a
20. XTM16	697a	573a	484a	104a	185a
21. XUM7	265fg	164a	314a	102a	203a
22. XUM10	156g	142a	202a	113a	246a
23.A4-5(3)	618a-c	600a	624a	135a	424a
24.PV8(4)	383def	738a	379a	59a	350a
25.A4-3(5)	456bc-e	672a	502a	136a	258a
Environ. Val.	500	557	462	130	324
CV	22.90%	40.00%	30.91%	47.12%	47.55%
Grand Mean	395				

- Means at the same location with the same letter are not significantly different at 5% level of probability according to Duncan's Multiple Range Test.

Table 21: The mean oil yield, regression coefficient (b), mean squared deviations (S^2_d) and coefficient of determination of regression (R^2) of 25 sunflower genotypes grown in 5 locations in 1993/94 season.

No. Genotype	#Mean	b	S^2_d	R^2
1. F43	430a	1.16	2386	0.92
2. F31-1	393a	0.67	7566	0.49
3. F31-3-1	426a	0.97	4421	0.80
4. CH 311	450a	0.98	4502	0.80
5. CH 336	380a	0.67	21936	0.19
6. CH 301	454a	1.03	3929	0.83
7. F468-2	394a	1.00	14945	0.52
8. F458-3	334ab	0.86	15752	0.85
9. F427-3	387a	1.38	2686	0.93
10. F40	449a	0.86	16890	0.83
11. F41	461a	1.60	19790	0.88
12. F418-2	408a	1.15	15348	0.64
13. F50	426a	1.20	4087	0.82
14. XTM7	426a	1.04	12303	0.94
15. XTM8	352a	1.05	19099	0.76
16. XTM10	468a	1.11	12005	0.79
17. XTM13	429a	1.39	13771	0.80
18. XTM14	378a	0.82	12410	0.51
19. XTM15	370a	0.75	11116	0.69
20. XTM16	409a	1.36	83840++	0.69
21. XUM7	209bc	0.30	8350	0.14
22. XUM10	172c	0.05*	81808++	0.00
23.A4-5(3)	480a	1.19	3809	0.88
24.PV8(4)	382a	1.24	11197	0.61
25.A4-3(5)	405a	1.17	154633++	0.81
Mean	395	1.00		

* denotes b is significantly different from 1 at 5% level of probability.

++ denotes S^2_d is significantly different from 0 at 1% level of probability.

# denotes values followed by the same letter are not significantly different from each other at 5% level of probability according to Duncan's Multiple Range Test

The coefficient of determination shows what proportion of the total variance for each genotype was due to regression.

CHAPTER FIVE

5.0 CONCLUSIONS

The magnitudes of yield and it's components in this sunflower breeding population are comparable to world averages though some variations exist due to differences in genotypes and the environment.

The relationships between yield and it's components show that the main determinants of kernel yield, oil content and oil yield are head diameter, plant height, stem diameter and 1000 kernel weight. Selection for oil yield can be achieved directly through kernel yield and 1000 kernel weight. Head diameter would be effective selection criterion for both kernel yield and oil content. Plant height and stem diameter together with head diameter could be useful indicators for early identification of elite lines with respect to both kernel yield and oil content.

Genetic variability in yield and it's components (except stem diameter) exists in this population. The broad sense heritability estimates are low due to unfavourable weather. It can not be ascertained whether the low heritability estimates indicated that an appreciable amount of fixation in the traits studied had taken place in this population.

The population has average ability to yield consistently across the locations with respect to kernel and oil yield.

These results can only be taken as tentative due to the use of limited seasons and/or locations but it is important that such information be available to improve the efficiency of the sunflower breeding programme. It is suggested that the experiment be repeated for at least another season to have more conclusive results.

CHAPTER SIX

6.0 REFERENCES

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APPENDICES

Appendix 1: Monthly rainfall (mm) for Monze, NIRS, Mt Makulu, Mt Makulu, Golden Valley and Kabwe in the 1993/94 season.

	Location				
Month	Monze	NIRS	Mt Makulu	G/Valley	Kabwe
July, 1993	1.8	-	-	-	-
August	2.0	-	-	-	-
September	101.3	-	-	-	0.9
October	134.3	-	11.1	-	15.6
November	218.8	149.1	119.7	81.1	106.7
December	115.8	77.9	126.0	91.7	87.1
January, 1994	31.8	172.1	243.1	-	277.5
February	6.0	136.5	127.8	-	196.0
March	-	20.3	2.7	-	2.7
April	-	-	21.9	-	0.6
May	-	-	-	-	-
June	-	-	-	-	-
Total	620.3	555.9	667.6	172.8	671.5

Appendix 2: Mean squares, heritability estimate and coefficient of variation of average number of leaves per plant and days to 50% flowering from analysis of variance of 25 sunflower genotypes grown at Mt Makulu in 1993/94 season.

	Mean Squares	
Source	No.of Leaves	Days to 50% Flowering
Replications	31.373	18.893
Genotypes	14.669*	9.443**
Blocks	7.534	3.760
Effective Error	6.671	2.970
Broad sense h^2	25.68%	37.09%
CV	10.00%	2.26%

* and ** denote significance at 5% and 1% levels of probability respectively

Appendix 3: Mean squares, broad sense heritability, environmental value and coefficient of variation of head diameter, plant population, plant height and stem diameter of 25 sunflower genotypes grown in 5 locations in the 1993/94 season

			Parameter Mean Square			
Location	Source of Variation	df	Head Diameter	Plant Population	Plant Height	Stem Diameter
Monze	Replications	2	1.33	110510815.00	1122.98	29.64
	Genotypes	24	310.22	131125599.00**	726.61	42.03
	Blocks	12	345.78	92982121.00	392.45	29.71
	Error	36	499.48	4222490.00	549.39	28.38
	Heritability		-	74.62	9.36	13.76
	Environmental Value		124.00	29398.00	180.00	21.16
	CV (%)		18.04	22.10	13.01	25.32
NIRS	Replications	2	2173.69	273400483.00	2040.00	75.89
	Genotypes	24	298.65	173212185.00**	2297.19**	29.20*
	Blocks	12	381.12	40810047.00	448.02	27.71
	Error	36	368.69	43520620.00	326.69	15.26
	Heritability		-	45.06	61.96	20.06
	Environmental Value		143.00	23216.00	216.00	28.79
	CV (%)		13.61	28.42	8.36	13.57
Mt Makulu	Replications	2	1652.92	280201179.00	1342.31	6.24
	Genotypes	24	380.59*	116537320.00**	1098.00*	12.28**
	Blocks	12	288.61	72412336.00	797.34	5.58
	Error	36	209.36	54574700.00	562.07	5.77
	Heritability		17.33	24.17	22.68	27.27
	Environmental Value		118.00	34825.00	198.00	28.20
	CV (%)		12.25	21.21	11.97	8.52
Golden Valley	Replications	2	426.97	6379034.00	369.33	13.01
	Genotypes	24	254.49	186386979.00*	574.67	7.68
	Blocks	12	252.70	75581473.00	469.98	14.61
	Error	36	261.47	9590033.00	404.89	11.32
	Heritability		0.00	80.82	12.15	0.00
	Environmental Value		109.00	41518.00	182.00	11.85
	CV (%)		14.80	23.59	11.90	28.39
Kabwe	Replications	2	202.08	171661988.00	829.00	0.49
	Genotypes	24	233.02	68615260.00	702.00	11.81
	Blocks	12	351.06	55223789.00	294.00	8.32
	Error	36	251.43	49866263.00	483.54	12.57
	Heritability		-	10.19	12.77	-
	Environmental Value		102.00	40323	141.00	11.33
	CV (%)		15.50	17.55	15.64	31.28

* and ** denote significance at 5% and 1% level of probability respectively

Appendix 4: Mean squares, broad sense heritability, environmental value and coefficient of variation of kernel %, 1000 kernel weight and kernel yield/head of 25 sunflower genotypes grown in 5 locations in the 1993/94 season

		Parameter Mean Square			
Location	Source of Variation	df	Kernel %	1000 Kernel Weight	Kernel Yield/Head
Monze	Replications	2	4.68	173.46	2299.22
	Genotypes	24	32.61**	125.53**	422.51**
	Blocks	12	3.41	29.49	144.27
	Error	36	3.17	41.23	165.41
	Heritability		75.14	37.66	25.47
	Environmental Value		66.38	66.31	46.26
	CV (%)		2.71	9.68	27.80
NIRS	Replications	2	na	na	535.58
	Genotypes	24	na	na	866.91
	Blocks	12	na	na	687.06
	Error	36	na	na	784.40
	Heritability		na	na	3.39
	Environmental Value		na	na	70.12
	CV (%)		na	na	39.94
Mt Makulu	Replications	2	32.68	1602.17	1994.12
	Genotypes	24	26.29	103.25	440.00
	Blocks	12	8.81	84.19	199.58
	Error	36	12.49	66.31	143.59
	Heritability		25.70	4.54	30.86
	Environmental Value		67.86	57.62	49.11
	CV (%)		5.21	14.13	24.40
Golden Valley	Replications	2	na	na	74.44
	Genotypes	24	na	na	18.63
	Blocks	12	na	na	20.13
	Error	36	na	na	21.60
	Heritability		na	na	-
	Environmental Value		na	na	9.23
	CV (%)		na	na	50.33
Kabwe	Replications	2	11.55	69.03	529.80
	Genotypes	24	47.01**	71.09*	309.57
	Blocks	12	2.45	16.68	287.23
	Error	36	9.20	33.94	302.51
	Heritability		61.51	25.95	0.75
	Environmental Value		57.56	62.54	24.32
	CV (%)		4.64	9.32	71.51

* and ** denote significance at 5% and 1% level of probability respectively
na denotes data not available

Appendix 5: Mean squares, broad sense heritability and coefficient of variation of yield components from combined analysis of variance of 25 sunflower genotypes grown in 5 locations in 1993/94 season

	Source of Variation					
	Location (L)	Genotypes (G)	G X L	Error	Heritability	CV (%)
df	2	24	96	192		
Trait						
Head Diameter	17952.91**	447.30*	269.75	332.16	2.97	15.29
1000 Kernel Wt	52019.24**	235.25**	89.15	80.30	2.51	19.50
Plant Height	58659.74**	2862.68**	656.39*	474.41	10.20	11.87
Stem Diameter	5379.65**	18.33	21.24*	16.12	0.23	19.81
Kernel %	34328.02**	71.72**	14.34	9.46	1.34	3.87
Plant Popn	4497029242**	8344329088**	9399580	57101174	13.97	22.27
Kernel Yd/Hd	41653.28**	852.04**	296.20	273.49	3.97	41.54

* and ** denotes significance at 5% and 1% level of probability respectively