COMBINING ABILITY ANALYSIS FOR YIELD AND ITS COMPONENTS IN SUNFLOWER (*HELIANTHUS ANNUUS* L.).

by

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A thesis submitted in partial fulfilment for the degree

of

MASTER OF SCIENCE

in Plant Breeding

in the

University of Nairobi

1988.

DECLARATION BY CANDIDATE

This thesis is my original work and has not been presented for a degree in any other university.

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This thesis has been submitted for examination with our approval as University supervisors.

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TO MY FATHER JUSTINE NAMUNYAKA

ACKNOWLEDGEMENTS

I wish to express my gratitude to my major supervisor Dr. A.P. Tyagi, and my second supervisor Dr. P.O. Ayiecho, of the Department of Crop Science, in the Faculty of Agriculture, University of Nairobi, for their very useful advice, guidance and encouragement during the course of this study. A lot of thanks to all members of staff, both academic and technical, for their help at the various stages of my study, and for making my stay at the University of Nairobi successful.

I am indeed grateful to the German Government (DAAD) and the University of Nairobi for the award of a two-year scholarship which enabled me to conduct this study.

I would like to thank the Directors of the National Plant Breeding station (NPBS), Njoro, and the National Dryland Farming Research Station, Machakos, for providing me with the land where part of the research was carried out. Many thanks to Miss Mabel Mahasi of the NPBS, for taking care of my experiments during the periods I was not at the station.

I am indebted to my parents for their continued encouragement and moral support. My sincere appreciation goes to my husband James for his material and moral support during the course of my work. I would like to thank my daughter Beatrice, who tolerated the loneliness during the time I was busy with my work. Finally, I extend my sincere gratitude to Mrs Jane Njeri Mbugua for her excellent work in typing this thesis.

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ABSTRACT

This study was undertaken to: (1) assess the combining ability of selected cultivars of sunflower for seed yield and earliness components, (ii) determine gene action for these components, and (iii) find out the association among all pairs of the characters.

The materials for the study consisted of three male parents namely; Shaba, Fedha and 026 used as testers; and five female parents namely: Amiata, Argentario, Gro 21. Smena and 090. They were used in a top cross. Crossing was carried out at the Field Station of the University of Nairobi, Kabete Campus - Nairobi, Kenya, during the short rainy season of 1986. The resulting fifteen crosses and the eight parents were grown in two row plots replicated three times in a randomized block design at three locations namely: Field Station, University of Nairobi, Kabete, National Dryland Farming Research Station Katumani - Machakos and National Plant Breeding Station Njoro - Nakuru. Individual plant observations on ten randomly selected plants from each plot were recorded for (i) number of days to flowering, (ii) number of days to maturity, (iii) stem diameter, (iv) stem height, (v) head diameter, (vi) diameter of the sterile head centre (vii) hundred seed weight,

(viii) number of empty seeds, (ix) husk percentage and (x) seed yield per plant.

The combining ability analysis revealed that the nature of gene action for number of days to flowering and maturity at Kabete and Katumani, seed yield at Kabete and number of empty seeds at Katumani was mainly non-additive, indicating the relative importance of hybrid varieties in the improvement of sunflower with respect to these traits at these locations. On the other hand, the rest of the traits at the three locations were predominantly under the influence of the additive gene action, implying that improvement of these traits at these locations could effectively be done by simple selection and/or recurrent selection.

Hybrid combinations 090 x 026, Argentario x Fedha, Gro 21 x Fedha, and Smena x Shaba showed good specific combining ability (SCA) for earliness at Kabete, while Amiata x 026 and Gro 21 x Fedha had good SCA for this trait at Katumani. Argentario x Shaba and Smena x Fedha appeared promising for further breeding work in the improvement of sunflower with respect to seed yield per plant in highlands of Kenya, due to their high although non-significant SCA effects obtained at Kabete.

Smena was a very good general combiner for seed yield at Katumani, and it also had significant positive general combining ability (GCA) for stem diameter, at Kabete and Njoro, and stem height at Kabete. Shaba showed high positive GCA for head diameter and 100-seed weight at Kabete. At Njoro, Gro 21 had significant positive GCA for 100-seed weight.

Both correlation coefficients and path coefficients indicated that the most important determinant of yield at Kabete and Katumani was head diameter. In addition, stem diameter, 100-seed weight and plant height at Kabete; and stem height and seed filling at Katumani also contributed positively to seed yield per plant. At Njoro, 100-seed weight and head diameter had the highest positive direct effect on seed yield per plant. At this location, number of empty seeds was found to strongly affect seed yield.

by diff. determinant of yield at diff. location.

CHAPTER 1

INTRODUCTION

In this time of rapidly growing world population, it is likely that the world will face a food shortage in near future (FAO, 1981). A number of countries are experiencing a food shortage especially proteins and edible oils (Macgregor,1970 and Rollier, 1970). Developing countries have a high rate of population growth and they will need to import proteins and edible oil, which in turn may result in a world shortage. An increased production of animal protein and animal fat would alleviate this problem of food shortage. However, food products from animals are usually expensive. Animal fat consumption also increases the incidence and frequency of atherosclerosis (clinical coronary heart diseases) because it contains a high amount of saturated fatty acids and cholesterol (Vergroessen, 1970). An alternative to animal fat is oil seed crops. Oil seed crops provide easily available and highly nutritious human and animal food. Most of the vegetable oils are polyunsaturated in nature and induce low levels of cholesterol (Weiss, 1983). Vergroessen (1970) reported that a number of drugs for the treatment of atherosclerosis cause troublesome side effects, yet the change in the type of dietary fat causes no unfavourable side effects.

Some of the edible oil seed crops are groundnuts, rape, mustard, sesame, linseed, safflower, niger, cottonseed, soyabean, Indian hemp, poppyseed, crambe, copra, palm, coconut and sunflower. Sunflower (Helianthus annuus L.) originated in the Mexico area of Southwest United States. It is a member of Compositae family, with the somatic chromosome number 2n= 34. Botanical varieties grown for seed are H. annuus var. macrocarpus (DC) CK 11; with H. annuus sub sp. lenticularis the nearest wild relative. There is also the 'weed' sunflower of Western North America, H. annuus sub sp. annuus which is grown mainly as an ornamental. Sunflower will cross easily with other related species, and the species most closely related to H. annuus is H. argrophyllus which is native to Texas. U.S.A

Sunflower is the most important crop in USSR and south eastern European countries. It is also grown in many parts of the world including USA, Argentina and Kenya (Haraldsson, 1970; Smith, 1970; Navolotsky and Buryakov, 1976; Acimovic, 1979;

Kloczowski and Horodyski, 1980 and Weiss, 1983). Among the annual oil seed crops grown in Kenya, sunflower has become the most important source of edible vegetable oil (Kiplagat, 1987). Pathak (1979) described it as the most efficient producer of high quality edible oil.

Oil is the most important economic component of sunflower seeds. Sunflower seed oil has increased faster in world importance than oil from any other source (Talley et al.; 1970 and Weiss, 1983). Jensma (1970) noted that the oil can be extracted with relatively simple, inexpensive and harmless equipment. The sunflower oil has 70% linoleic acid, 18% oleic acid, 6% palmitic acid, 4% stearic acid, and traces of Beheric acid (Weiss, 1983). The oil is rich in polyunsaturated fatty acids which make it an excellent dietary oil (Hayenga, 1970; Trotter and Givan, 1970 and Weiss, 1983). The absence or very low linolenic acid content give the oil stability properties. The high quality nature of the oil makes it highly attractive for use in several food products. For example, it is used as cooking oil (e.g. Frytol) or blended with other edible vegetable oils and fats and sold as shortening (kimbo), ghee (cowboy) or margarine (blue band). It is also used in the preparation of fried foods like potato chips, crisps, chicken, catfish etc. Sunflower seed oil is also used by the canning industry. Weiss (1983) reported that the sunflower oil is being extensively tested as fuel for diesel engines with satisfactory results. Petroleum and its derivatives are sold to agriculture to act as carriers or adjuvants for herbicides, fungicides and insecticides. Sunflower oil can be used instead of petroleum in such cases (Robinson, 1970). The sunflower oil has a number of uses in the paint industry (Weiss, 1983).

The residue left after the oil has been extracted is referred to as a meal. It is a high quality protein source for livestock (Lewis, 1970; Weiss, 1983 and Oil Crop Development (OCD), 1987). The high protein sunflower meal can also be incorporated into human food formulations, and can be combined with available inexpensive staples to develop nutritious enriched products (MacGregor, 1970 and Talley _et al_., 1970).

Threshed heads are directly fed to livestock and big size seed varieties are roasted for eating (Weiss, 1983 and OCD, 1987). Sunflower seeds are also acceptable as a nut substitute in bakery and confectionary products (MacGregor, 1970 and Talley _et al_., 1970). Seed hulls are used in livestock feeding (Lewis, 1970). Decorative privacy panels made from sunflower seed hulls have a great appeal to architects (MacGregor, 1970).

Yellow and purple dyes are extracted from florets or achenes of sunflower (Weiss, 1983). MacGregor (1970), Weiss (1983) and OCD (1987) described a number of functions of the stalk of the sunflower crop in the paper manufacturing industry, building industry, agriculture and as firewood.

Sunflower is cultivated in the dry soils as green manure or fodder (Ravagnan, 1970) and is also used for silage (Massey, 1970). Sunflower is popular with bees, leading to increased production of high quality honey.

Sunflower is considered more drought tolerant than most crops, and can therefore be grown in drought-prone areas and perform better than such crops as maize (OCD, 1987). This shows that sunflower might be a very suitable crop for Kenya, since more than 80% of Kenyan land is arid or semi-arid. Most of the edible oil used in Kenya has traditionally been imported from Malaysia (OCD, 1987). This is expensive in terms of scarce foreign exchange. It deprives Kenyan livestock farmers of the benefit of the cake (meal), and also deprives many Kenyans of employment.

Most of the applications mentioned have been studied not only from the point of practicability and feasibility, but also have been examined closely from the economic point of view, and are commercially acceptable (MacGregor, 1970). One difficulty encountered lies in the short supply of sunflowers. Weiss (1983) reported that an increase in sunflower seed yield can lead to more stable supplies and greater local demand. He stated that processing of large, regular supplies allows more economical factory utilization and a wider variety of products. One of the major steps towards increasing supply of sunflower is by plant improvement through research.

Sunflower is one of very few Compositae crops with which plant improvement has been concerned. The common objectives have been to improve the crop with respect to:- seed yield, oil content and quality, resistance to diseases and pests, resistance to lodging, drought tolerance, earliness, adaptation, protein content, uniformity in plant type and short plant type (Sudhakar and Seetharam, 1980; Kloczowski and Horodyski, 1980; Tyagi, 1985 and Riungu, 1987). Sunflower is a highly cross-pollinated crop and its improvement should emphasize the exploitation of heterozygosity. This necessitates the testing of combining ability for the germplasm to be used in the breeding programme. Sunflower is notably difficult to manipulate in crossing, although use of cytoplasmic male sterility and chemical sterilization have helped to facilitate the excercise (Sindagi et al., 1979 ; Sudhakar and Seetharam, 1980 and Felicity, 1981). Consequently, it has been necessary to rely on natural crossing to obtain the progenies required for tests of combining ability. Allard (1960) described four different types of tests of combining ability that can be made on progenies obtained by natural crossing, namely; open-pollinated progeny tests, poly-cross test, single cross test and top-cross test.

In the top-cross test, the seed upon which the test depends is obtained from selected individuals or clones that have been planted alternately with a single tester variety. The test-cross seed thus consists partly of top crosses to the variety and partly of intercrosses with the other selected clones. The proportion of top-crossed seed can be increased by increasing the number of plants of the tester variety grown relative to the number of plants of the selected clones. Top crosses are a satisfactory way of evaluating inbred lines for general combining ability, especially when trials are conducted in several seasons and at several locations. The efficiency of the method can be improved by using a good pollen producing line as the male parent or tester, and a highly self-sterile line as the female parent.

Breeders have put a lot of emphasis on testing and selecting lines that can combine well in terms of yield, and oil content and quality. These are the most important aspects of the crop. These aspects are very difficult to assess with any degree of accuracy. They are the result of the interaction of several physiological and growth components of the plant (Alba and Greco, 1979). They are strongly conditioned by genotype-environmental interactions and by complex inheritance with other component characters (Allard, 1960). Thus, predisposing a breeding programme for these characters, it is necessary to have information on the most important contributing components which influence them as well as their system of interaction. The selection of lines and subsequent testing of these to determine their combining ability in combinations is an expensive and time consuming procedure. It would be advantageous to the plant breeder to know if some of the more easily measured agronomic features could be used in selection of lines with high combining ability.

Therefore the present study was undertaken to:-

(i) Find out the association among the yield and earliness characters in selected cultivars of sunflower, and to partition these correlations into direct and indirect effects so as to determine the most important character(s) for seed yield.

(ii) Assess the combining ability of these cultivars for yield and earliness components.

(iii) Determine gene action for the various characters in these cultivars so as to follow a breeding strategy most appropriate to develop an early maturing and high yielding variety of sunflower.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Combining ability and gene action.

Allard (1960) defined combining ability as the ability of an inbred to transmit desired character into the hybrid. He reported that the value of any inbred ultimately rests in its ability to produce superior hybrids in combination with other inbreds. Whether the two inbreds will combine well will depend on the capability of the two inbreds to supplement each other genetically. Simmonds (1979) noted that the advantage of combining abilities is that they provide an empirical summary of complex observations and a reasonable basis for predicting the performance of yet untested crosses. He added that all progeny-testing procedures depend upon the estimation of combining abilities.

Since sunflower is a cross-pollinated crop with high percentage of self incompatibility, both yield and fertility are reduced by inbreeding (Hayes *et al.*, 1955). This implies that an important aspect of sunflower breeding would be to exploit heterozygosity utilizing genetically diverse lines (Anand and Chandra, 1979). Thus, breeding procedures used in the improvement of the crop are the production of hybrids and synthetic varieties. Populations can also be improved by recurrent selection (Riungu, 1987). Production of hybrid varieties seems to be more advantageous and commonest due to their stability, high yielding potential and their uniformity (Ravagnan, 1970; Sindagi *et al*., 1979; Kloczowski and Horodyski, 1980; Felicity, 1981; Weiss, 1983; Kiplagat, 1987 and Riungu, 1987). All these breeding methods involve crossing of at least two parents in a breeding programme. Thus, one of the prerequisites in such a breeding programme would be the isolation of lines, as parents, with good combining ability from the germplasm collections. Certain cultivars are better combiners than others with respect to the various characteristics of the sunflower crop (Sindagi *et* al., 1979; Pathak, 1980, and Sudhakar and Seetharam, 1980). Therefore efficient detection of line performance in combinations is extremely important and this necessitates the testing of lines for their combining ability in crosses (Miller *et al*., 1980). Vranceanu (1970) and Volf *et al*. (1976) stated that the combining ability in sunflowers has to be tested both for seed yield and oil content in production of hybrids.

Mayo (1980) defined two forms of combining ability namely:-

- General combining ability (GCA). This is the average performance of a line or strain in a series of crosses.
- Specific combining ability (SCA). This refers to the deviation from performance predicted on the basis of GCA, when two individuals are involved in a single cross.

Most progeny testing procedures put greater emphasis on GCA (Simmonds, 1979). SCA is of utmost interest in hybrid breeding where the performance of a particular cross is critical (Mayo, 1980).

More often breeders are interested in knowing the behaviour of particular genes in populations. Mayo (1980) gave a detailed account of the partitioning of the phenotypic value of some metric trait for an individual into different components. The phenotypic value has components attributable to the influence of genes and to the influence of the environment. In the very simplest case, where genotype and environment do not interact, the phenotypic value is made up of a genotypic component plus an environmental deviation. In cases of more than one locus, the genotypic value consists of the additive, dominance and epistatic contributions to the metric values of a trait. The dominance and epistatic deviations constitute the non-additive components. Mayo (1980) also reported that the genotypic components can be partitioned in terms of combining ability, whereby GCA gives the measure of additive gene effects, while SCA gives the measure of non-additive gene effects.

The concept of combining ability is considered to be a landmark in the development of breeding procedures in some crops; it is helpful in selecting the elite parents to be used in breeding programs (Lal and Seth, 1981).

In sunflower a lot of research has been done involving studies on combining ability for various characteristics. In 1953, Russel demonstrated that some sunflower inbred lines differed significantly in combining ability with respect to days to flower. Sudhakar and Seetharam (1980) made observations on days to flowering and concluded that some lines were good combiners for the character. Similarly, studies by Pathak (1980) revealed that certain cultivars were better combiners than others with respect to days to flowering. The same study further showed that late flowering was dominant over early flowering. Alba and Porceddu (1977) analysed a total of 96 combinations involving six male-sterile lines and sixteen normal inbreds for flowering data. Results showed that five male sterile lines and five normal lines had high GCA values. Putt (1966) studied combining ability in sunflower with respect to time to bloom. The results showed that mean squares for GCA and SCA were significant, and the estimated components of variance for GCA and SCA were essentially the same in magnitude. Rao and Singh (1977) carried out studies which showed that the non-additive component was more important in the control of seventy five percent flowering. On the other hand, other workers concluded that GCA effects (additive component) were more important than SCA effects (non-additive component) in the control of days to flowering. For example studies by Dua (1979) showed that the additive genetic variance was relatively more stable than the non-additive with respect to number of days to flowering. Other studies revealed that additive genetic variance accounted for a major portion of the genetic variation, and epistasis was found to be a minor factor in the genetic variation of days to flowering (Miller _et al_., 1980). Rao (1980) observed that both additive and non-additive gene effects affected days to flowering; but variances for GCA exceeded those for SCA. Dua and Yadava (1982) concluded that additive and dominance gene effects were present for days to flowering, but additive was predominant.

Some sunflower inbred lines were found to be significantly different in combining ability with respect to days to maturity (Russel, 1953). Sudhakar and seetharam (1980) demonstrated that some sunflower lines were good combiners for days to seventy five percent maturity. Kovacik and Skaloud (1972) showed that the variances due to GCA were similar to variances due to SCA indicating equal importance of both additive and non-additive gene effects in the control of days to maturity. Studies by Putt (1966) showed that mean squares for GCA and SCA were significant for days to maturity, but the estimated components of GCA were greater than SCA. Similarly Dua and Yadava (1982) demonstrated that both additive and dominance gene effects were present for days to maturity with additive gene effects being more important. Rao and Singh (1977) and Dua (1979) reported that additive component was more important in the control of number of days to maturity.

Russel (1953) concluded that some sunflower inbred lines differed significantly with respect to stem diameter. Out of six male-sterile lines and sixteen normal inbred lines analysed for stem diameter, five male-sterile lines and five normal lines were found to have good GCA for stem diameter (Alba and Porceddu, 1977). Rao (1980) reported that GCA variances were higher than SCA variances for stem diameter. He also reported complementary epistasis for stem diameter. Studies by Dua and Yadava (1982) showed that both additive and dominance gene effects were present for stem diameter, with additive effects playing a more important role.

Pathak (1980) concluded that certain cultivars of sunflower were better combiners than others with respect to plant height. He also observed that tallness was dominant over shortness. Kovacik and Skaloud (1972; 1977) observed very big differences in GCA for plant height. Putt (1966) found that mean squares for GCA and SCA were significant for plant height, but the estimated components of GCA were less than SCA. Likewise, Dua (1979) found that the dominance component was more important in the control of plant height. Contrary to the above findings, Rao and Singh (1977) concluded that the additive component was more important than the non-additive component for plant height. Similarly, Miller et al. (1980) observed that the additive genetic variance accounted for a major portion of the genetic variation for plant height while epistasis was of minor importance. Studies by Rao (1980) also showed that GCA variances were higher than SCA variances for plant height. In 1982 Dua and Yadava also found that both additive and dominance gene effects were present for plant height, with the additive gene effects being predominant.

Russel (1953) found that some sunflower inbred lines differed significantly in combining ability with respect to head diameter. Similarly, Pathak (1980) found that certain sunflower cultivars were better combiners than others with respect to head diameter. He noted that small head size was dominant over large head size. In 1980, Sudhakar and Seetharam showed that some sunflower lines were good combiners for head diameter, and they could be used in crossing programmes and in the development of synthetic varieties. Alba and Porceddu (1977) observed five male-sterile lines and five normal inbreds to have good GCA for head diameter. Putt (1966) reported significant mean squares for GCA and SCA for head diameter in sunflower. He also observed that the estimated components of GCA were equal to the estimated components of SCA. Other workers, however, found that GCA effects were more important than SCA effects. Studies by Rao and Singh (1977) revealed that the additive genetic variance was more important than the non-additive genetic variance for head diameter. Similarly, Miller _et al_. (1980) concluded that the additive genetic variance accounted for a major portion of the genetic variation; epistasis was found to be a minor factor in the control of head diameter. Studies by Sindagi _et al_. (1979) indicated that the variances due to GCA were higher than the variances due to SCA, indicating a predominant role of the additive component for head diameter. The same studies further revealed that three crosses gave high SCA effects. Dua and Yadava (1982) found that the additive and non-additive gene effects were present for head diameter, but the additive component was predominant.

Sudhakar and Seetharam (1980) identified some sunflower lines as good combiners for seed filling. Studies by Sindagi _et al_. (1979) showed a number of female parents with good GCA for number of filled seeds per head, and many crosses with high SCA effects for the same character. The same study further demonstrated that the variances due to GCA were higher than the variances due to a SCA for this character.

Sudhakar and Seetharam (1980) reported that some sunflower lines were good combiners for 100-seed weight. Putt (1966) observed that mean squares for both GCA and SCA were significant for 1000-seed weight, and that the estimated components of GCA and SCA were equal. On the other hand Dua (1979) concluded that the dominance component was relatively more important with respect to 100-seed weight. Other studies showed that the GCA effects were more important than SCA effects in the control of seed weight. Rao and Singh (1977) found that the additive component was more important than the non-additive component for 1000-seed weight. Sindagi _et al_. (1979) demonstrated that the variances due to GCA were higher than the variances due to a SCA, indicating the predominant role of the additive component for 100-seed weight. The same study further showed that among the female parents, one proved to be a good general combiner for 100-seed weight, while three crosses gave high SCA effects for the same character. Miller _et al_. (1980) observed that the additive genetic variance accounted for a major portion of the genetic variation for 200-seed weight. Epistasis was found to be minor. Rao (1980) showed that GCA variances were higher than SCA variances for 1000-seed weight. Rao also observed substantial partial dominance for this character. Studies by Dua and Yadava (1982) also suggested the importance of both additive (predominant) and dominance gene effects for 100-seed weight.

It was demonstrated that some sunflower inbred lines differed significantly in combining ability with respect to seed yield (Russel, 1953). Sudhakar and Seetharam (1980) also reported that some sunflower lines were good combiners for seed yield per plant. Pathak (1980) concluded that certain sunflower cultivars were better combiners than others with respect to seed yield per plant. He further noted that low seed yield was dominant over high seed yield. In 1978, Rozhkova studied the GCA of 64 varieties and various inbred lines for yield. Twenty varieties showed high GCA for this trait. In a different study, Rozhkova (1978) reported that which one 19% of the varieties studied had a high GCA for yield; three testers proved sufficient to determine the GCA of the varieties studied. Anashchenko and Rozhkova (1974) studied thirty nine varieties of sunflower for combining ability for seed yield. The best GCA was shown by a variety from Australia; good SCA was shown by four Soviet varieties, one variety from Iraq and one from Romania. Alba and Porceddu (1977) identified five male sterile lines and five normal lines with good GCA for seed yield per plot. The GCA of short-stemmed inbreds was determined by top-crosses with two tall and two short varieties; high GCA for seed yield was shown by four inbreds and one short tester (Alekseev et al., 1979). Burlov and Buntovskii (1978) observed that the GCA of eight lines for seed yield per hectare depended more on environmental conditions. The study further identified two lines with high GCA for seed yield and these were regarded as the most promising for further breeding work. Putt (1966) found that the mean squares for GCA and SCA were significant for seed yield. However, the estimated components of GCA were less than SCA indicating that non-additive gene action was more important than additive gene action for seed yield per plant. Studies by Kovacik and Skaloud (1972) also indicated that the ratio of the variability components of GCA to SCA was 1: 9.64 for seed yield per head, suggesting that for this character, suitable hybrids rather than parental lines should be selected. The same study also revealed large differences in GCA for this character. Similarly Dua (1979) concluded that the dominance component (SCA) in the case of yield per plant was relatively more important than the additive component (GCA). The results contrary to the above as regards combining ability studies for seed yield have also been reported by a number of workers. For example, Sudhakar (1979) concluded that the additive genetic variance was more important than the non-additive for seed yield. In 1979, Sindagi _et al_. observed that variances due to a GCA were higher than the variances due to a SCA for seed yield per plant. The same study showed that out of the eleven female parents, two were good combiners for seed yield per plant; and three crosses gave higher SCA for the character. Miller _et al_. (1980) reported significant dominance variance for sunflower seed yield. However, the additive gene action was more important since the additive genetic variance accounted for a major portion of the genetic variation. Rao (1980) observed that GCA variances were higher than SCA variances for seed yield. However, partial dominance and complementary epistasis occurred for the character. Work by Furedi and Frank (1981) revealed that GCA effects were higher than SCA effects for achene yield per plot in sunflower; three lines out of the ten were significantly superior in GCA. Dua and Yadava (1982) reported the presence of additive and dominance gene effects for seed yield per plant. They noted that the additive component was more important.

2.2 Correlations.

Correlations may be purely environmental or a compound of environmental and genetic components. Simmonds (1979) noted that genetic correlations arise from linkages that have not reached equilibrium and from pleiotrophy; the latter being far more important. He also indicated that correlations are common and have to be taken account of in plant breeding.

Natali and Jam (1970) observed that the correlation coefficients of seed yield with plant height, growth period and 100 seed weight were positive and significant. Studies by Kovacik and Skaloud (1972) showed that plant height and number of days to flowering were positively correlated with seed yield; while husk percentage was positively correlated with diameter of the head. Oka and Campos (1976) reported a positive and significant phenotypic correlation between plant height and number of days to flowering. Skorpik (1974) reported a positive correlation between the weight of plant parts above the ground for fifteen day old plants and 100-seed weight. He also noted two types of hybrids by correlation analysis; a tall, late, high-yielding, small-seeded type, and short early low-yielding, small seeded type. Skoric (1974) reported that height in sunflower significantly affected seed yield per hectare. Pathak (1974) observed that seed yield per plant showed highly significant and positive correlations with head diameter, 100-seed weight, 100-kernel weight, plant height, stem diameter and 100-husk weight, in decreasing order. Kovacik and Skaloud (1976) reported that husk content showed significant correlations with head diameter and seed yield per head. Results from Russian varieties of sunflower showed that the most important traits influencing seed yield were 100-seed weight, seed number per head and plant height in that order (Shabana, 1977). Saadat _et al_. (1977) reported positive correlation between head diameter and 1000 seed weight and a negative correlation between 1000 seed weight and the proportion of empty seeds in two superior sunflower mutants. Singh _et al_. (1977) concluded that when selecting for increased seed yield emphasis should be given to seed weight and head diameter. Correlation and regression coefficients reported by Ayyasamy _et al_. (1977) indicated that head diameter had the most significant effect on seed yield of sunflower. Asawa _et al_. (1977) concluded that plant height and filling percentage in seeds were the most important characters governing variability in seed yield. Varshney and Singh (1977) showed that seed yield was positively correlated with days to 75% maturity, height, head diameter and 1000-seed weight. Zali et al. (1977) found a positive correlation between seed yield and head diameter. Chandra and Anand (1977) showed that yield was phenotypically and genotypically positively correlated with plant height, stem diameter (below the fourth leaf and at mid-height), head diameter and 100-seed weight. The results further showed that the diameter of the sterile centre was negatively correlated with stem thickness. Results by Anand and Chandra (1979) suggested strong and positive correlation between seed yield and plant height, and between head diameter and seed weight. Alba and Greco (1979) made observations on head diameter, plant height at maturity, days to flowering, seed yield, thousand seed weight and thousand kernel weight. The phenotypic correlations showed the important influence of head diameter, 1000-kernel weight, days to flowering, plant height and 1000-seed weight. Giriraj et al. (1980) obtained positive correlations between seed yield and 100-seed weight, plant height and head diameter, in decreasing order. Dua (1979) concluded that plant height, stem diameter and head diameter had the greatest effects on seed yield in sunflower. Pathak (1980) also observed that seed yield and head size were strongly correlated with each other. Maturity and stem height were also associated with each other. Correlation studies by Lakshmanaiah (1980) indicated that seed yield was positively associated with head diameter, 100-seed weight, seed filling, plant height and stem girth. Velkov (1980) observed that correlation coefficients between yield and its components was highest between seed yield and head diameter. Simple correlation coefficients by Beard and Geng (1982) indicated that 200-seed weight was important in determining seed yield in sunflower. The same study further indicated that size of the plant had a strong negative simple correlation with seed yield. Dedio (1982) found that 1000-seed weight was highly negatively correlated will hull content. Tyagi (1985) demonstrated that seed yield was positively associated with plant height, head diameter and 100-seed weight, in that order. The study also revealed a high and significant correlation between plant height and head diameter.

2.3 Path analyses.

Correlation coefficients, sometimes, may be misleading and conclusions based on them alone may not be so reliable. Therefore Wright (1921) suggested path coefficient analysis which helps to partition the genotypic and/or phenotypic correlations into direct and indirect effects on a given character. The indirect effects influence a character through other traits. This method was first demonstrated by Dewey and Lu (1959) in crested wheat grass; and since then, it has been successfully used by other researchers on various crop plants.

Varshney and Singh (1977) found that plant height, head diameter and seed filling directly affected seed yield, while maturity and 1000-seed weight affected seed yield indirectly via plant height, in sunflower. The direct effect of maturity on seed yield was negative. Path coefficient analysis in sunflower by Chandra and Anand (1977) showed that stem diameter at mid-height had a strong positive direct effect on yield; while height, stem diameter below the fourth leaf and 100% flowering showed negative direct associations with yield. Alba and Greco (1979) observed that the maximum direct effect on seed yield of sunflower was by head diameter, followed by 1000-kernel weight and plant height. Thousand seed weight and days to flowering had negative direct effects on yield. The highest indirect effect on seed yield was that of days to flowering through head diameter. Studies by Giriraj _et al_. (1980) revealed a maximum direct effect of seed weight, plant height and head diameter on seed yield in sunflower. Lakshmanaiah (1980) observed that head diameter had the greatest positive direct effect on seed yield. Velkov (1980) concluded that head diameter had the major effect on achene yield, but 1000-achene weight also had an important effect via head diameter. Studies by Beard and Geng (1982) clearly indicated the importance of 200 seed weight in contributing to seed yield. The results further demonstrated that early growth had an important direct effect on seed yield, while size of the plant negatively affected seed yield through 200-seed weight. Path coefficient analysis by Tyagi (1985) revealed that head diameter had the highest direct effect on seed yield. Plant height had a negative direct effect on yield and up to a large extent contributed indirectly via head diameter. Hundred seed weight also had a negative direct effect on yield, but contributed positively via head diameter.

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials.

Eight open-pollinated sunflower varieties obtained from the National Plant Breeding Station (NPBS) Njoro, Kenya were used as parents in a top cross test in this study. The varieties and some of their characteristics given in the NPBS Annual Reports (1980 to 1986), are as follows:

Table 1. Names of the eight varieties used for the study and some of their characteristics

Variety	Gro 21	026	Amiata	090	Smena	Argentario	Shaba	Fedha
Origin	USA	USA	Italy	USA	Italy	Italy	USA	USA
Seed yield (kg/ha)	1110	1414	1440	1251	1348	1412	1536	1551
Oil percentage	38.3	38.4	37.5	39.1	38.0	38.9	37.7	38.9
Kernel percentage	75.5	70.6	72.9	71.0	71.4	64.7	69.8	69.7
1000 seed wt(g)	59.5	65.0	70.7	72.4	79.8	75.0	92.1	99.2
Head diameter (cm)	15.0	12.0	14.0	16.0	17.0	19.0	24.3	19.0
Flowering days	86	94	92	81	88	88	88	88
Maturity days	136	136	133	126	122	130	130	129
Height (m)	1.8	1.6	1.7	1.5	2.0	1.8	1.6	1.8

3.2 Top Cross Test

Fedha, Shaba and 026 were used as the male parents (testers) while Argentario, Amiata, Gro 21, Smena and 090 were used as female parents (lines). The top cross was carried out at the Field Station of the Faculty of Agriculture, University of Nairobi, Kabete Campus, Kenya, during the October rains of 1986. Three different isolated sites were used for top crosses. One tester was used for each site. At each site, two rows of each of the female parents (lines) were grown alternately with single rows of the tester. To increase the proportion of pollen from the testers, three guard rows of the tester were planted on each side of the block, at each site. Spacing was 75 cm between rows and 30 cm between plants. Three seeds were planted per hill. These were thinned to one plant per hill two weeks later. Weeding was done using a hand hoe and irrigation was done twice due to lack of enough rains.

At the onset of flowering, before the individual florets in the inflorescence opened, heads of five plants from each parent at each site were covered with paper bags to obtain selfed seeds of the parents. The rest of the plants were allowed to open-pollinate, which resulted in five crosses from each site and a total of fifteen crosses from the three sites. After seed set, the heads of all plants were covered with paper bags to avoid bird damage.

After maturity, heads of the selfed plants and the crossed females were harvested, dried, threshed and winnowed separately. The seeds from the different plants, belonging to the same cross were thoroughly mixed. The selfed seeds belonging to the same parent from the different sites were also thoroughly mixed.

3.3 Evaluation of the twenty-three genotypes.

During the March rains of 1987, the fifteen crosses, together with the eight parents were grown in a randomized complete block design, with three replications. Two rows of each genotype were planted in each replication. Spacing was maintained at 75 cm between rows and 30 cm between plants. Three seeds were planted per hill. The plants were thinned to two per hill two weeks after planting. Each row consisted of ten plants after thinning. The trial was conducted at three locations in Kenya, namely:

- The Field Station of the Faculty of Agriculture, Kabete Campus, of the University of Nairobi.
- National Dryland Farming Research Station, Katumani - Machakos.
- National Plant Breeding Station, Njoro.

Information on rainfall and temperatures for the three locations during the growing season is given in Appendix I.

Hand weeding was done at each location. Irrigation was done at Katumani and Njoro because the rainfall was not enough at the two locations. Shortly after seedset, the heads of the plants were covered with paper bags to prevent bird damage.

From each row, five plants were randomly selected for data collection. Thus, from each replication, ten plants were sampled for each genotype. Data were recorded on the following parameters.

1. Number of days to 50% flowering. A head was considered flowered on the day when the inflorescence had opened wide enough to expose all the florets inside it.
2. Number of days to maturity. A plant was considered mature on the day when all the leaves on it turned yellow.

3. Stem diameter in centimeters (cm) at maturity. The stem diameter was taken at three points on the plant namely; the top, at mid-height and at the bottom (just near the ground level). The average of the three values was regarded as the stem diameter.

4. Stem height (cm) at maturity. Stem height was taken as the distance from the ground level up to the attachment of the head.

5. Head diameter (cm). This was measured across the head at maturity.

6. Diameter (cm) of the sterile head centre at maturity. This was measured from the centre of the head towards periphery up to filled seeds.

7. Seed yield in grams (g) per plant.

8. Hundred seed weight (g).

With parameters no. 7 and 8, observations,were made after harvesting, drying, threshing, thorough winnowing and sun-drying of the seeds to about twelve percent moisture. Care was taken to exclude any empty seeds, which could be detected by slight pressing of the seed between fingers to feel whether it was empty or filled.

9. Number of empty seeds per plant. This consisted of the empty seeds in the sterile centre and from elsewhere in the head.

10. Husk percentage. Hundred seeds were dried to constant weight; the husks from the seeds were removed by hand and also weighed. The husk percentage was obtained by dividing the weight of husks by the weight of the hundred seeds, and then multiplying by hundred.

3.4 Statistical analysis.

The average values of the ten sampled plants were used for statistical analysis. Data from each location was analysed separately. For each location, data analysis for randomized complete block design was carried out as suggested by Panse and Sukhatme (1964), considering b blocks and t treatments.

The model for this analysis of variance was:-

$$Y_{ij} = \mu + Ti + B_j + E_{ij}; \quad i = 1, 2, \text{-----}, t. \quad j = 1, 2, \text{-----}, b.$$

Where: Y_{ij} = Observation corresponding to the i^{th} treatment in the j^{th} block.

μ = General mean.

T_i = i^{th} treatment effect.

B_j = j^{th} block effect.

E_{ij} = Error term.

Assumptions of the model:

a) E_{ij}'s are independent random variables which are normally distributed with mean zero and constant variance.

b) $\Sigma\hat{T}_i = \Sigma\hat{B}_j = 0$

Based on the above model, the ANOVA table was as shown below.

Table 2. Analysis of variance for the randomised complete block design.

Source	d.f.	s.s.
Treatment	$t - 1$	$\frac{\sum_{i=1}^{t} T_i^2}{b} - \frac{G^2}{tb}$
Blocks	$b - 1$	$\frac{\sum_{j=1}^{b} B_j^2}{t} - \frac{G^2}{tb}$
Error	$(t-1)(b-1)$	By subtraction from total sum of squares
Total	$(tb) - 1$	$\sum_{i=1}^{t}\sum_{j=1}^{b} Y_{ij}^2 - \frac{G^2}{tb}$

Where G = The Grand total = all the t treatments summed over all the blocks.

The combining ability analyses were done in accordance with the procedures described by Singh and Chaudhary (1977). This analysis was done for each location separately. The model for this analysis as given by Kempthone (1969) was as shown below:

$$Y_{ijk} = \mu + m_i + f_{ij} + \ell_{ijk} \; ; \quad i = 1,2,\ldots\ldots m$$
$$j = 1,2\ldots\ldots f.$$

where Y_{ijk} = Observed performance of a cross between j^{th} female parent and i^{th} male parent, corresponding to the k^{th} offspring.

μ = General mean.

m_i = male parent effect.

f_{ij} = effect of the j^{th} female parent crossed to the i^{th} male parent.

ℓ_{ijk} = experimental error effect.

Assumption of the above model:-

$$\Sigma(mi) = \Sigma(f_{ij}) = \Sigma(\ell_{ijk}) = 0.$$

Based on the above model, the treatment sums of squares for each location were partitioned as below:-

Table 3. Analysis of variance showing the partitioning of the treatment sums of squares.

Source	d.f.	s.s.
Treatments	t-1	$\frac{\Sigma\Sigma C_{ij}^2 + \Sigma\Sigma P_{ii}^2}{b} - \frac{G^2}{tb}$
Parents	p-1	$\frac{\Sigma\Sigma P_{ii}^2}{b} - \frac{G_p^2}{pb}$
Crosses	c-1	$\frac{\Sigma\Sigma C_{ij}^2}{b} - \frac{G_c^2}{cb}$
Parents vs crosses	1	By subtraction from treatment sums of squares
Lines	L-1	$\frac{\Sigma\Sigma x_{i..}^2}{bT} - \frac{G_c^2}{cb}$
Testers	T-1	$\frac{\Sigma\Sigma x_{.j.}^2}{bL} - \frac{G_c^2}{cb}$
Lines x Testers	(L-1)(T-1)	Sums of squares due to crosses minus sums of squares due to lines and due to testers.

L = number of lines (female parents)

T = number of testers (male parents)

P = number of parents

C = number of crosses

Gp = Grand total for parents

Gc = Grand total for crosses.

xi.. = Marginal total for i^{th} female

x.j. = Marginal total for j^{th} male.

C_{ij} = the observation for j^{th} female mated to i^{th} male.

Pii = the observation for i^{th} parent.

Estimation of combining ability effects for each location was done as follows:-

$$g_L = \frac{xi..}{Tb} - \frac{Gc}{LTb}$$

$$g_T = \frac{x.j.}{Lb} - \frac{Gc}{LTb}$$

$$S_{ij} = \frac{Cij}{b} - \frac{xi..}{Tb} - \frac{x.j.}{Lb} + \frac{Gc}{LTb}.$$

Where: g_L = the GCA of a line.

g_T = the GCA of a tester.

S_{ij} = SCA of the cross between j^{th} female and i^{th} male parent.

Correlation coefficients among the various parameters were computed as described by Gouldon (1954).

The correlation coefficients were subjected to significance test at $P = 0.05$. Path coefficient analysis was carried out following a method used by Dewey and Lu (1959),taking the yield as the effect, and all the other characters as possible causes.

CHAPTER 4

RESULTS

4.1 Gene action.

Combining ability analysis of variance for yield components and maturity characters are presented in Tables 4, 5 and 6 for Kabete, Katumani and Njoro respectively.

Number of days to flowering:

The general combining ability (GCA) mean squares were higher than the specific combining ability (SCA) mean squares at all the three sites. However, at Kabete and Katumani, the SCA mean squares were highly significant while the GCA mean squares were non-significant. None of the mean squares at Njoro were significant for number of days to flowering.

Number of days to maturity:

At Kabete and Katumani, the SCA mean squares were greater than the GCA mean squares. At both locations, SCA mean squares were significant, while GCA mean squares were non-significant. At Njoro, none of the mean squares were significant. However, the GCA mean squares were slightly higher than the SCA mean squares at the location.

Table 4. Mean squares from combining ability analysis of variance for seed yield, its components and maturity traits in sunflower at Kabete.

Source of variation	df	Days to flowe-ring	Days to matu-rity	Stem dia-meter	Stem height	Head dia-meter	Dia-meter of ste-rile centre	No. of empty seeds	100 seed weight	Husk per-centage	Seed yield per plant
Lines (GCA)	4	68.0	121.1	0.153	725.5	3.119	0.181	1899.9	0.587	6.23	604.5
Testers (GCA)	2	120.9	117.7	0.060	270.7	7.257*	0.124	3186.8	1.545*	0.13	223.8
Lines x Testers (SCA)	8	62.7**	173.1**	0.090	210.4	1.391	0.197	1290.7	0.244	3.30	313.0*
Error	44	5.9	30.9	0.076	160.2	2.204	0.893	743.1	0.237	3.17	141.3

*, ** = Significant at 5% and 1% level of probability respectively.

Table 5. Mean squares from combining ability analysis of variance for seed yield, its components and maturity traits in sunflower at Katumani.

Source of variation	df	Days to flowe-ring	Days to maturity	Stem dia-meter	Stem height	Head dia-meter	Diameter of ste-rile centre	No. of empty seeds	100 seed weight	Husk percen-tage	Seed yield per plant
Lines (GCA)	4	30.78	14.30	0.009	115.0	2.828	0.158	5.578	0.068	3.898	315.3
Testers (GCA)	2	11.58	5.13	0.248*	424.8	0.865	0.461	4.131	0.178	5.053	93.3
Lines x Testers (SCA)	8	26.02**	19.63*	0.045	146.3	3.699	0.224	24.051	0.129	3.887	287.2
Error	44	6.06	8.24	0.045	138.2	2.162	0.336	38.265	0.192	4.055	200.4

*, ** = Significant at 5% and 1% level of probability respectively.

Table 6. Mean squares from combining ability analysis of variance for seed yield, its components and maturity traits in sunflower at Njoro.

Source of variation	df	Days to flowe-ring	Days to maturity	Stem dia-meter	Stem height	Head dia-meter	Diameter of ste-rile centre	No. of empty seeds	100 seed weight	Husk per-centage	Seed yield per plant
Lines (GCA)	4	5.856	5.756	0.312	338.6	2.957	0.171	146.2	7.771**	118.8	483.8
Testers (GCA)	2	9.867	18.156	0.393	492.4	2.454	0.224	46.2	1.242	398.6*	766.0
Lines x Testers (SCA)	8	2.756	12.572	0.189	118.3	2.780	0.112	130.4	1.042	85.3	382.7
Error	44	3.604	7.528	0.189	160.8	3.937	0.138	39.8	2.504	95.2	339.1

*, ** = Significant at 5% and 1% level of probability respectively.

Stem diameter:

The analysis of variance for combining ability revealed that GCA mean squares were higher than the SCA mean squares at all the three locations for stem diameter. At Katumani the GCA mean squares (testers) were significant.

Stem height:

At all the three locations, the analysis of variance for combining ability showed that the GCA mean squares were higher than the SCA mean squares. The ratio of GCA mean squares (mean squares for testers plus mean squares for lines) to SCA mean squares was about 4:1 at Kabete and Katumani, and 7:1 at Njoro. However, none of the mean squares were significant at any of the locations.

Head diameter:

At Kabete, the analysis of variance for combining ability showed that GCA mean squares (testers) were significant, while SCA mean squares were non-significant. The analysis further revealed that at the same location, the ratio of GCA mean squares to SCA mean squares was about 8:1 for this trait. At Katumani and Njoro, all the mean squares were non-significant. The ratio of GCA mean squares to SCA mean squares was about 2:1 at Njoro, and 1:1 at Katumani.

Diameter of the sterile head centre:

At the three locations, the GCA mean squares were slightly greater than the SCA mean squares for the diameter of the sterile head centre. All the mean squares were non-significant.

Number of empty seeds:

The analysis of variance for combining ability showed that at the three locations, all the mean squares were non-significant for number of empty seeds. The GCA mean squares were greater than the SCA mean squares at Kabete and Njoro, while the opposite was true at Katumani.

Hundred seed weight:

The analysis of variance for combining ability for 100-seed weight showed highly significant GCA mean squares (lines) at Njoro, and significant GCA mean squares (testers) at Kabete. The mean squares at Katumani were non-significant. The ratio of GCA mean squares to SCA mean squares was about 9:1 at Kabete and Njoro, and 2:1 at Katumani.

Husk percentage:

The GCA mean squares were higher than the SCA mean squares at all the three locations. In addition, the GCA mean squares (testers) were significant at Njoro. No other mean squares were significant for the trait at the locations.

Seed yield per plant:

At the three locations, the GCA mean squares were greater than the SCA mean squares for seed yield per plant. At Kabete, the SCA mean squares were significant, while the GCA mean squares were non-significant. At Njoro and Katumani, none of the mean squares were significant.

4.2 General combining ability effects.

The general combining ability (GCA) effects for yield components and maturity characters are presented in Tables 7, 8 and 9 for Kabete, Katumani and Njoro locations respectively.

Days to flowering:

At all the three locations, Smena had highly significant positive GCA effects for number of days

Table 7. General combining ability effects of the parents for seed yield, its components and maturity traits in sunflower at Kabete.

Parents	Days to flowering	Days to maturity	Stem diameter	Stem height	Head diameter	Diameter of sterile centre	No. of empty seeds	100 seed weight	Husk percentage	Seed yield per plant
Lines										
Amiata	-1.898*	-1.594	-0.057	1.975	0.451	-0.103	17.646	0.122	-0.155	-2.754
Argentario	0.946	0.393	0.136	1.464	-0.429	0.193	-5.276	-0.093	1.461**	-0.835
Gro 21	-0.554	-0.484	-0.023	-11.858**	-0.422	-0.074	-6.224	0.141	-0.407	-4.290
Smena	4.235**	5.816**	0.214*	12.586**	0.808	0.109	11.887	0.235	-0.308	14.21**
090	-2.731**	-4.129*	0.001	-4.169	-0.880*	-0.124	-18.032*	-0.403**	-0.593	-6.329
Testers										
026	0.953	2.209	-0.073	-4.782	-0.563	-0.064	-12.927*	-0.293*	-0.031	-4.095
Shaba	-3.194**	-3.151*	0.039	3.338	0.777*	-0.039	15.797*	0.343**	0.102	3.579
Fedha	2.180**	0.942	0.033	1.444	-0.216	0.104	-2.874	-0.049	-0.073	0.517
Standard errors										
GCA effects-line	0.810	1.852	0.092	4.219	0.495	0.315	9.087	0.162	0.593	3.963
GCA effects-tester	0.627	1.435	0.071	3.268	0.383	0.244	7.039	0.126	0.459	3.07
GCA-dif.bet. lines	1.145	2.619	0.130	5.966	0.700	0.445	12.851	0.229	0.839	5.604
GCA-dif.bet. testers	0.887	2.029	0.100	4.621	0.542	0.345	9.954	0.178	0.650	4.341

*,** = Significantly different from zero at 5% and 1% level of probability respectively.

Table 8. General combining ability effects of the parents for seed yield, its components and maturity traits in sunflower at Katumani.

Parents	Days to flowering	Days to maturity	Stem diameter	Stem height	Head diameter	Diameter of sterile centre	No. of empty seeds	100-seed weight	Husk percentage	Seed yield per plant
Lines										
Amiata	-1.764*	0.200	-0.032	-4.293	-0.345	-0.087	0.300	-0.113	-0.106	-2.197
Argentario	0.569	-0.244	0.002	2.848	-0.333	0.068	0.644	-0.052	0.881	-5.528
Gro 21	1.658*	1.311	0.035	-1.350	0.422	-0.170	-1.356	0.035	0.194	-0.378
Smena	1.691*	0.733	0.026	4.468	0.767	0.168	0.367	0.115	-0.953	10.042*
090	-2.153**	-2.000*	-0.031	-1.674	-0.511	0.021	0.044	0.015	-0.016	-1.940
Testers										
026	0.436	0.133	0.008	1.018	0.095	0.200	0.600	0.015	-0.639	0.477
Shaba	-1.011	-0.640	-0.132*	-5.757*	-0.273	-0.126	-0.227	0.101	0.495	-2.698
Fedha	0.576	0.507	0.124*	4.739	0.178	-0.074	-0.373	-0.115	0.143	2.221
Standard errors										
GCA effects-line	0.821	0.957	0.071	3.919	0.490	0.193	2.062	0.146	0.671	4.718
GCA effects tester	0.636	0.741	0.055	3.036	0.380	0.150	1.597	0.113	0.520	3.655
GCA-dif.bet. lines	1.161	1.353	0.100	5.542	0.693	0.273	2.916	0.206	0.949	6.673
GCA-dif.bet. testers	0.898	1.048	0.077	4.293	0.537	0.212	2.259	0.160	0.735	5.169

*,** = Significantly different from zero at 5% and 1% level of probability respectively.

Table 9. General combining ability effects of the parents for seed yield, its components and maturity traits in sunflower at Njoro.

Parents	Days to flowering	Days to maturity	Stem diameter	Stem height	Head diameter	Diameter of sterile centre	No. of empty seeds	100-seed weight	Husk percentage	Seed yield per plant
Lines										
Amiata	-1.022	-0.733	-0.120	3.164	0.120	-0.163	-3.884*	-0.802*	5.842*	1.209
Argentario	-0.244	1.156	-0.181	2.320	0.453	0.167	-2.339	0.142	-3.124	4.220
Gro 21	-0.133	-0.067	0.008	-10.791**	-0.480	0.047	0.993	1.542**	-2.969	2.609
Smena	1.200*	0.379	0.302*	4.164	0.609	-0.121	-1.242	0.336	-0.047	4.831
090	0.200	-1.133	-0.009	1.142	-0.702	0.069	6.471**	-0.547	0.298	-12.869*
Testers										
026	-0.400	-1.111	-0.157	3.964	-0.149	0.134	0.162	-0.189	-0.964	-6.793
Shaba	-0.533	0.022	0.167	-6.569*	0.458	-0.029	-1.829	0.331	-4.604*	7.453
Fedha	0.933*	1.330*	-0.01	2.604	-0.309	-0.105	1.668	-0.142	5.569*	-0.660
Standard errors										
GCA effects-line	0.633	0.915	0.145	4.227	0.661	0.124	2.102	0.528	3.252	6.139
GCA effects-tester	0.490	0.708	0.112	3.275	0.512	0.096	1.628	0.409	2.519	4.755
GCA-dif.bet. lines	0.895	1.293	0.205	5.978	0.935	0.175	2.972	0.746	4.600	8.681
GCA-dif.bet. testers	0.693	1.002	0.159	4.631	0.725	0.136	2.302	0.578	3.563	6.725

*,** Significantly different from zero at 5% and 1% level of probability respectively.

to flowering. The highest value was obtained at Kabete, followed by Njoro. Fedha also had highly significant positive GCA for the trait at Kabete and Njoro, while Gro 21 had a significant positive GCA at Katumani only. At Kabete, populations shaba, 090 and Amiata showed significant negative GCA effects for this trait, in a decreasing order. 090 and Amiata also showed significant negative GCA effects at Katumani. None of the parents showed significant negative GCA effects for the number of days to flowering at Njoro.

Number of days to maturity:

At Kabete, 090 and Shaba showed significant negative GCA effects for the trait, while Smena had highly significant positive GCA effect for this trait. The population 090 showed significant negative GCA at Katumani while Fedha had positive GCA for this trait at Njoro.

Stem diameter:

At Kabete and Njoro, Smena showed significant positive GCA effects for this character, while at Katumani, Fedha and Shaba showed significant positive and negative GCA effects respectively.

Stem height:

At Kabete, Smena showed highly significant positive GCA effects for stem height, while at Kabete and Njoro, Gro 21 showed highly significant negative GCA effects for this trait. Similarly, Shaba had significant negative GCA effects at Njoro and Katumani.

Head diameter:

At Kabete, 090 showed significant negative GCA effects for head diameter. At the same location, Shaba showed significant positive GCA effects for this trait. All the GCA effects at Katumani and Njoro were non-significatn for this trait.

Diameter of the sterile head centre:

At all the three locations, all the GCA effects for this character were non-significant.

Number of empty seeds per head:

Significant negative GCA effects were recorded for 090 and 026 while Shaba had significant positive GCA effects for the number of empty seeds at Kabete. At Njoro, Amiata and 090 had significant negative and positive GCA effects respectively for this trait.

The GCA effects at Katumani were non-significant.

Hundred seed weight:

At Kabete, 090 and 026 had significant negative GCA effects, while Shaba had highly significant positive GCA effects for 100-seed weight. At Njoro, Gro 21 and Amiata showed significant positive and negative GCA effects respectively for this character. None of the GCA effects for this trait were significant at Katumani.

Husk percentage:

At Kabete, Argentario showed highly significant positive GCA effects for husk percentage. At Njoro, significant positive GCA effects were recorded for Amiata and Fedha, while significant negative GCA effects were recorded for Shaba for this trait. The GCA effects for this trait at Katumani were non-significant.

Seed yield per plant:

At Kabete, Smena showed highly significant positive GCA effects for seed yield per plant. The same line had significant positive GCA for this trait at Katumani. At Njoro, 090 showed significant negative GCA for the seed yield per plant.

4.3 Specific combining ability effects.

The specific combining ability (SCA) effects for yield components and maturity characters are presented in Tables 10,11 and 12.

Number of days to flowering:

The greatest number of significant SCA effects for the number of days to flowering was recorded at Kabete. At Kabete, the crosses Gro 21 x Fedha, 090 x 026, Smena x Shaba and Argentario x Fedha showed significant negative SCA effects for days to flowering in that order. At the same location, Smena x Fedha, Gro 21 x 026 and 090 x Shaba showed highly significant positive SCA effects for this trait in that order. At Katumani, Gro 21 x Fedha had highly significant negative SCA effects, while Gro 21 x 026 and Smena x Fedha showed significant positive SCA for this character. The SCA effects for number of days to flowering at Njoro were non-significant.

Number of days to maturity:

With respect to this character, the crosses tended to behave in a way very similar to number of days to flowering. At Kabete, the combinations Smena

Table 10. Specific combining ability effects of the crosses for seed yield, its components and maturity traits in sunflower at Kabete.

Crosses	Days to flowering	Days to maturity	Stem diameter	Stem height	Head diameter	Diameter of sterile centre	No. of empty seeds	100-seed weight	Husk percentage	Seed yield per plant
Amiata x 026	-0.042	0.802	-0.099	-2.429	0.185	-0.097	-11.906	0.238	-0.797	-3.273
Argentario x 026	1.514	4.147	0.116	-1.051	0.269	-0.173	-0.884	-0.163	0.764	-2.245
Gro 21 x 026	4.547**	3.091	0.043	-2.262	0.045	-0.012	7.564	-0.137	0.522	3.223
Smena x 026	-1.242	-1.443	-0.007	1.393	-0.775	0.448	-12.481	-0.105	0.550	4.220
090 x 026	-4.776**	-6.598*	-0.054	4.349	0.280	-0.169	17.705	0.167	-1.035	-1.925
Amiata x Shaba	-1.962	-5.338	0.019	2.385	-0.551	0.018	12.370	-0.274	0.877	-5.927
Argentario x Shaba	1.461	4.007	0.044	4.062	0.285	0.198	12.458	0.124	-1.309	11.394
Gro 21 x Shaba	0.761	3.384	0.161	7.818	0.568	0.059	13.795	0.453	0.366	7.299
Smena x Shaba	-4.528**	-8.316**	-0.229	-14.527*	-0.322	-0.427	-17.938	-0.021	0.253	-13.918*
090 x Shaba	4.271**	6.262*	0.007	0.252	0.023	0.156	-20.586	-0.283	-0.185	1.151
Amiata x Fedha	2.004	4.535	0.081	0.045	0.368	0.079	-0.464	0.034	-0.078	9.198
Argentario x Fedha	-2.973*	-8.153**	-0.160	-3.01	-0.552	-0.021	-11.576	0.039	0.546	-9.151
Gro 21 x Fedha	-5.306**	-6.476*	-0.203	-5.555	-0.612	-0.047	-21.361	-0.318	-0.886	-10.522
Smena x Fedha	5.771**	9.757**	0.237	13.133*	1.098	-0.023	30.418*	0.125	-0.802	9.698
090 x Fedha	0.504	0.336	0.047	-4.611	-0.301	0.013	2.980	0.116	1.223	0.773
Standard errors										
SCA effects	1.403	3.208	0.159	7.307	0.857	0.546	15.739	0.281	1.027	6.864
SCA-dif.bet. crosses	1.984	4.537	0.224	10.334	1.212	0.772	22.258	0.397	1.453	9.707

*, ** = Significantly different from zero at 5% and 1% level of probability respectively.

Table 11. Specific combining ability effects of the crosses for seed yield, its components and maturity traits in sunflower at Katumani.

Crosses	Days to flowering	Days to maturity	Stem diameter	Stem height	Head diameter	Diameter of sterile centre	No. of empty seeds	100-seed weight	Husk percentage	Seed yield per plant
Amiata x 026	-1.236	-3.333*	-0.062	-3.688	-0.738	-0.237	-2.067	0.024	0.302	-8.197
Argentario x 026	-0.536	-0.356	0.220	4.571	0.066	-0.092	-1.111	-0.004	-0.815	3.534
Gro 21 x 026	4.742**	3.289*	-0.035	0.303	1.845*	0.340	4.689	0.153	-0.028	13.787*
Smena x 026	-2.091	0.267	-0.026	0.554	0.016	0.184	0.233	-0.237	0.875	-0.103
090 x 026	-0.880	0.133	-0.096	-9.740	-1.189	-0.185	-1.744	0.063	-0.335	-9.021
Amiata x Shaba	1.078	1.707	0.031	-0.296	0.476	0.399	2.060	0.022	0.768	5.705
Argentario x Shaba	-0.089	1.018	-0.073	1.613	0.734	0.067	2.416	0.010	-1.192	2.576
Gro 21 x Shaba	0.222	-0.138	-0.072	-8.712	-1.124	-0.264	-3.884	0.153	0.655	-11.108
Smena x Shaba	-1.278	-2.693	0.070	0.226	-0.482	-0.183	0.027	-0.090	-0.685	-7.094
090 x Shaba	0.067	0.107	0.044	7.168	0.395	-0.018	-0.618	0.210	0.455	9.921
Amiata x Fedha	0.158	1.627	0.031	3.984	0.262	-0.162	0.007	-0.046	-1.070	2.493
Argentario x Fedha	0.624	-0.662	-0.147	-6.184	-0.800	0.026	-1.304	-0.007	2.007*	-6.110
Gro 21 x Fedha	-4.964**	-3.151*	0.107	0.408	-0.722	-0.076	-0.804	-0.000	-0.627	-2.680
Smena x Fedha	3.369*	2.427	-0.044	-0.780	0.466	-0.001	-0.260	0.326	-0.190	7.197
090 x Fedha	0.813	-0.240	0.053	2.572	0.794	0.213	2.362	-0.274	-0.120	-0.901
Standard errors										
SCA effects	1.421	1.657	0.122	6.788	0.849	0.335	3.571	0.253	1.163	8.172
SCA-dif. bet.crosses	2.010	2.344	0.173	9.599	1.200	0.473	5.051	0.357	1.644	11.557

*,** = Significantly different from zero at 5% and 1% level of probability respectively.

Table 12. Specific combining ability effects of the crosses for seed yield, its components and maturity traits in sunflower at Njoro.

Cross	Days to flowering	Days to maturity	Stem diameter	Stem height	Head diameter	Diameter of sterile centre	No. of empty seeds	100-seed weight	Husk percentage	Seed yield per plant
Amiata x 026	-0.379	-0.888	0.107	-5.364	1.760	-0.061	-0.170	0.022	4.398	-0.596
Argentario x 026	-0.489	0.333	-0.249	0.147	-0.673	0.183	-1.640	0.311	3.931	7.693
Gro 21 x 026	0.067	0.089	-0.038	5.258	-0.540	0.208	-4.358	-0.089	-2.891	0.338
Smena x 026	1.067	1.086	0.101	-0.364	0.238	-0.180	-6.424*	0.522	-4.280	-6.384
090 x 026	-0.267	-0.136	0.079	0.324	-0.784	-0.150	12.593**	-0.767	-1.158	-1.051
Amiata x Shaba	0.756	1.533	-0.150	8.036	-0.747	-0.083	2.337	0.402	-7.629	5.191
Argentario x Shaba	-0.022	-2.356	0.194	5.347	0.253	-0.037	-0.537	-0.642	1.804	-18.620*
Gro 21 x Shaba	0.533	0.089	0.201	-7.209	0.653	-0.053	1.382	-0.342	5.449	0.724
Smena x Shaba	-0.133	1.867	-0.356	-5.831	-0.502	-0.027	2.931	0.002	-0.473	16.369
090 x Shaba	-1.122	0.333	0.022	-0.342	0.342	0.199	-6.112	0.580	0.849	-3.664
Amiata x Fedha	-0.378	-1.242	0.043	-2.671	-1.013	0.144	-2.167	-0.424	3.231	-4.596
Argentario x Fedha	0.511	1.113	0.054	-8.493	0.420	-0.146	2.177	0.331	-5.736	10.927
Gro 21 x Fedha	-0.600	0.012	-0.251	1.951	-0.113	-0.155	2.977	0.431	-2.558	-1.062
Smena x Fedha	-0.933	-2.200	0.254	6.196	0.264	0.207	3.493	-0.524	4.753	-9.984
090 x Fedha	1.400	0.356	-0.101	0.018	0.442	-0.049	-6.481*	0.187	0.309	4.716
Standard errors										
SCA effects	1.096	1.584	0.251	7.322	1.146	0.215	3.640	0.914	5.633	10.633
SCA-dif.bet.crosses	1.550	2.240	0.355	10.355	1.620	0.304	5.148	1.292	7.967	15.037

*,** = Significantly different from zero at 5% and 1% level of probability respectively.

x Shaba, Argentario x Fedha, 090 x 026 and Gro 21 x Fedha had significant negative SCA effects for the days to maturity in that order. On the other hand, Smena x Fedha and 090 x Shaba had significant positive SCA effects for this trait at Kabete. At Katumani, crosses Amiata x 026 and Gro 21 x Fedha had significant negative SCA effects, while Gro 21 x 026 showed significant positive SCA effects for number of days to maturity. At Njoro, the SCA effects for this trait were low and non-significant.

<u>Stem diameter</u>:

At all the three locations, all the SCA effects for this character were low and non-significant.

<u>Stem height</u>:

The only significant SCA effects for stem height were obtained at Kabete for the crosses Smena x Fedha and Smena x Shaba which were positive and negative SCA effects respectively. At Katumani and Njoro, all crosses showed non-significant SCA effects for this trait.

<u>Head diameter</u>:

At Katumani, only Gro 21 x 026 showed significant positive SCA effects for head diameter. The rest of the SCA effects for this trait at Katumani, and at the other two locations were non-significant.

Diameter of the sterile head centre:

The SCA effects for this trait at all the three locations were non-significant.

Number of empty seeds per head:

At Kabete, Smena x Fedha had significant positive SCA effects for this trait. No cross showed significant SCA effects for number of empty seeds at Katumani. At Njoro, 090 x 026 showed highly significant positive SCA, while 090 x Fedha and Smena x Fedha had significant negative SCA effects for this trait.

Hundred seed weight:

At the three locations, all the SCA effects for 100-seed weight were non-significant.

Husk percentage:

The only significant SCA effects for this character were recorded at Katumani for Argentario x Fedha with a positive SCA value.

Seed yield per plant:

At Kabete, Smena x Shaba showed significant negative SCA effects for seed yield per plant. The crosses Argentario x Shaba and Smena x Fedha showed high, though non-significant positive SCA effects for this trait at Kabete. At Katumani, Gro 21 x 026 had significant positive SCA effects for seed yield per plant, while at Njoro, Argentario x Shaba showed significant negative SCA effects for this character.

4.4 Correlation coefficients.

Correlation coefficients among yield components and maturity traits at Kabete, Katumani and Njoro are presented in Tables 13, 14 and 15. At Kabete, head diameter had the highest correlation coefficient ($r = 0.803$) with seed yield per plant; this was followed by stem diameter, 100-seed weight, stem height and number of days to maturity in that order. At Katumani, the head diameter also had the highest correlation coefficient ($r = 0.904$) with seed yield per plant. This was followed by number of empty seeds and 100-seed weight. At Njoro, 100-seed weight and head diameter were significantly positively correlated with seed yield per plant, with relatively low correlation coefficient values of 0.307 and 0.305 respectively.

Table 13. Correlation coefficients among yield, its components and maturity traits in sunflower at Kabete.

Characters	Seed yield per plant	No. of days to flowering	No. of days to maturity	Stem diameter	Stem height	Head diameter	Diameter of sterile centre	No. of empty seeds	100 seed weight
No. of days to flowering	0.051								
No. of days to maturity	0.306*	0.666**							
Stem diameter	0.646**	0.015	0.212						
Stem height	0.522**	-0.039	0.075	0.752**					
Head diameter	0.803**	-0.225	0.113	0.745**	0.624**				
Diameter of sterile centre	0.231	0.125	0.185	0.090	0.140	0.057			
No. of empty seeds	0.287	-0.062	0.129	0.226	0.201	0.352*	0.274		
100-seed weight	0.531**	-0.177	0.100	0.416**	0.300*	0.625*	0.201	0.402**	
Husk percentage	-0.231	-0.113	- 0.010	-0.352*	-0.267	-0.228	0.105	-0.029	-0.206

*, ** = Significant at 5% and 1% level of probability respectively.

Table 14. Correlation coefficients among yield, its components and maturity traits in sunflower at Katumani.

Characters	Seed yield per plant	No. of days to flowering	No. of days to maturity	Stem diameter	Stem height	Head diameter	Diameter of sterile centre	No. of empty seeds	100-seed weight
No. of days to flowering	0.032								
No. of days to maturity	-0.006	0.679**							
Stem diameter	0.135	0.240	0.359*						
Stem height	0.216	0.382**	0.252	0.450**					
Head diameter	0.904**	0.071	0.017	0.222	0.172				
Diameter of sterile centre	0.275	0.334*	0.405**	0.311*	0.212	0.344*			
No. of empty seeds	0.512**	0.037	-0.023	0.065	0.188	0.567**	0.617**		
100-seed weight	0.505**	-0.236	-0.338*	-0.180	-0.136	0.379**	-0.176	0.088	
Husk percentage	0.012	0.126	0.050	0.098	0.189	0.062	0.132	0.032	-0.300*

*, ** = Significant at 5% and 1% level of probability respectively.

Table 15. Correlation coefficients among yield, its components and maturity traits in sunflower at Njoro.

Characters	Seed yield per plant	No. of days to flowering	No. of days to maturity	Stem diameter	Stem height	Head diameter	Diameter of sterile centre	No. of empty seeds	100-seed weight
No. of days to flowering	0.121								
No. of days to maturity	0.036	0.149							
Stem diameter	0.265	0.150	0.175						
Stem height	-0.068	0.265	-0.192	0.069					
Head diameter	0.305*	0.246	0.140	0.557**	0.278				
Diameter of sterile centre	-0.194	-0.163	-0.096	-0.119	0.029	-0.182			
No. of empty seeds	-0.333*	0.065	0.083	0.099	0.087	0.084	-0.037		
100-seed weight	0.307	0.335*	0.075	0.274	-0.057	0.309*	-0.229	0.168	
Husk percentage	0.034	0.018	0.075	-0.017	-0.089	0.004	0.098	-0.126	-0.252

*, ** = Significant at 5% and 1% level of probability respectively.

At this location, the number of empty seeds was significantly negatively correlated ($r = -0.333$) with seed yield per plant.

At Kabete, stem diameter was highly significantly ($P = 0.01$) positively correlated with stem height, head diameter and 100-seed weight, and also significantly ($P = 0.05$) but negatively associated with husk percentage (Table 13). Also recorded at this location, were highly significant positive correlation coefficients between stem height and head diameter; head diameter and 100-seed weight; number of empty seeds and 100-seed weight; and number of days to maturity and number of days to flowering. There were also fairly weak but significant positive correlation coefficients between head diameter and number of empty seeds; and stem height and 100-seed weight.

At Katumani (Table 14) number of days to flowering was significantly positively correlated with number of days to maturity, stem height and diameter of the sterile head centre; while number of days to maturity was positively correlated with stem diameter and diameter of the sterile head centre, but negatively correlated with 100-seed weight. At this location, there were highly significant positive correlation coefficients between stem diameter and stem height, head diameter and number of empty seeds, diameter of the sterile centre and number of empty seeds; and head diameter and 100-seed weight. There were also fairly weak but significant associations between stem diameter and diameter of the sterile head centre, head diameter and diameter of the sterile head centre; and 100-seed weight and husk percentage.

At Njoro (Table 15) 100-seed weight was positively associated with number of days to flowering and head diameter. There was also a strong positive association between head diameter and stem diameter.

4.5 Path coefficients.

Direct and indirect effects of yield components and maturity traits on seed yield per plant at Kabete, Katumani and Njoro are presented in Tables 16 , 17 , and 18.

At Kabete (Table 16) the maximum positive direct effect on seed yield per plant was shown by head diameter (0.839). The rest of the direct effects were quite small and less than 0.100, with the exception

Table 16. Path coefficients (direct effects underlined) of yield components and maturity traits on seed yield in sunflower at Kabete.

Characters	Effect via								
	No. of days to flowering	No. of days to maturity	Stem diameter	Stem height	Head diameter	Diameter of sterile centre	No. of empty seeds	100-seed weight	Husk percentage	Phenotypic correlation with yield
No. of days to flowering	0.155	0.057	0.000	-0.001	-0.189	0.021	0.004	-0.002	0.005	0.051
No. of days to maturity	0.103	0.085	0.000	0.002	0.095	0.031	-0.007	0.001	0.000	0.306*
Stem diameter	0.002	0.018	-0.002	0.022	0.625	0.015	-0.013	0.006	0.016	0.646**
Stem height	-0.006	0.006	-0.002	0.029	0.524	0.024	-0.011	0.004	0.012	0.522**
Head diameter	-0.035	0.010	-0.001	0.018	0.839	0.010	-0.020	0.009	0.010	0.803**
Diameter of sterile centre	0.019	0.016	0.000	0.004	0.048	0.070	-0.016	0.003	-0.005	0.231
No. of empty seeds	-0.01	0.011	0.000	0.006	0.295	0.047	-0.057	0.006	0.001	0.287
100-seed weight	-0.027	0.009	-0.001	0.009	0.524	0.034	-0.023	0.014	0.009	0.531**
Husk percentage	-0.018	-0.001	0.001	-0.008	-0.191	0.018	0.002	-0.003	-0.046	-0.231

Table 17. Path coefficients (direct effects underlined) of yield components and maturity traits on seed yield in sunflower at Katumani.

Characters	Effect via									
	No. of days to flowering	No. of days to maturity	Stem diameter	Stem height	Head diameter	Diameter of sterile centre	No. of empty seeds	100-seed weight	Husk percentage	Phenotypic correlation with yield
No. of days to flowering	-0.083	0.070	-0.023	0.057	0.057	0.004	0.000	-0.052	0.002	0.032
No. of days to maturity	-0.056	0.103	-0.034	0.037	0.014	0.005	0.000	-0.075	0.000	-0.006
Stem diameter	-0.020	0.037	-0.094	0.067	0.180	0.004	0.000	0.040	0.001	0.135
Stem height	-0.032	0.026	-0.042	0.148	0.139	0.003	0.002	-0.030	0.002	0.216
Head diameter	-0.006	0.002	-0.021	0.025	0.809	0.344	0.006	0.084	0.000	0.904**
Diameter of sterile centre	-0.028	0.042	-0.029	0.031	0.278	0.012	0.006	-0.039	0.002	0.275
No. of empty seeds	-0.003	-0.002	-0.006	0.028	0.459	0.007	0.010	0.020	0.000	0.512**
100-seed weight	0.020	-0.035	0.017	-0.020	0.307	-0.002	0.001	0.222	-0.004	0.505**
Husk percentage	-0.010	0.005	-0.009	0.028	0.050	0.002	0.000	-0.067	0.013	0.012

Table 18. Path coefficient (direct effects underlined) of yield components and maturity traits on seed yield in sunflower at Njoro.

Characters	Effect via									
	No. of days to flowering	No. of days to maturity	Stem diameter	Stem height	Head diameter	Diameter of sterile centre	No. of empty seeds	100-seed weight	Husk percentage	Phenotypic correlation with yield
No. of days to flowering	<u>0.000</u>	-0.005	0.018	-0.024	0.049	0.017	-0.025	0.091	0.001	0.121
No. of days to maturity	0.000	<u>-0.034</u>	0.021	0.018	0.028	0.010	-0.032	0.020	0.006	0.036
Stem diameter	0.000	-0.006	<u>0.120</u>	-0.006	0.110	0.012	-0.039	0.074	-0.001	0.265
Stem height	0.000	0.007	0.008	<u>-0.092</u>	0.055	-0.003	-0.034	-0.015	0.007	-0.068
Head diameter	0.000	-0.005	0.067	-0.026	<u>0.198</u>	0.019	-0.033	0.084	0.000	0.305*
Diameter of sterile centre	0.000	0.003	-0.014	-0.003	-0.036	<u>-0.104</u>	0.014	-0.062	0.007	-0.194
No. of empty seeds	0.000	-0.003	0.012	-0.008	0.017	0.004	<u>-0.391</u>	0.046	-0.009	-0.333*
100-seed weight	0.000	-0.003	0.033	0.005	0.061	0.024	-0.066	<u>0.271</u>	-0.019	0.307*
Husk percentage	0.000	-0.003	-0.002	-0.008	0.001	- 0.010	0.049	-0.068	<u>0.075</u>	0.034

of number of days to flowering (0.155). The direct effects of number of empty seeds, husk percentage and stem diameter were negative, while the rest were positive.

At Katumani (Table 17) the maximum positive direct effect on seed yield per plant was also shown by head diameter. This was followed by 100-seed weight, stem height and number of days to maturity in that order; but these were quite small direct effects, compared to that of head diameter. The rest of the direct effects were negligible with stem diameter and number of days to flowering negative, and the others positive.

The direct effects obtained at Njoro (Table 18) were of relatively low magnitude compared to those obtained at Kabete and Katumani. The maximum positive direct effect at Njoro was shown by 100-seed weight (0.271) followed by head diameter (0.198). On the other hand, the maximum negative direct effect was obtained for number of empty seeds (-0.391).

At Kabete (Table 16), stem diameter, 100 seed weight and stem height showed positive indirect effects on seed yield per plant through head diameter. The rest of the indirect effects at this location were of low magnitude. At Katumani (Table 17), number of empty seeds, 100-seed weight and diameter of the sterile head centre had positive indirect effects on seed yield per plant through head diameter, in that order. At this location, head diameter also had a positive indirect effect through diameter of the sterile head centre. The rest of the indirect effects on seed yield per plant at Katumani were negligible. Most of the indirect effects at Njoro (Table 18) were very small, although the indirect effect of stem diameter via head diameter tended to be a bit higher than the others.

CHAPTER 5

DISCUSSION

5.1 Gene action

Number of days to flowering.

The significance of the SCA mean squares and the non-significance of the GCA mean squares at Kabete and Katumani (Tables 4 and 5) showed that non-additive gene effects were responsible for the variability of this trait among the crosses at the two locations. This indicates that development of early flowering sunflower varieties at these locations can best be achieved by use of early maturing crosses. These results are similar to those obtained by Rao and Singh (1977), but differ from those of Putt (1966) who found equal importance of both the additive and non-additive gene effects for number of days to flowering. The fact that the GCA mean squares were about six times greater than the SCA mean squares at Njoro (Table 6) indicated the relative importance of the additive component in the control of number of days to flowering at this location, although none of these mean squares were significant. This in turn implies that at Njoro, the trait can be improved by use of suitable parents that can be obtained by simple progeny testing and selection. Dua (1979) and Miller *et al.*

(1980) also concluded that the additive gene effects were more important than the non-additive gene effects in the control of number of days to flowering.

Number of days to maturity.

The fact that the SCA mean squares were significant and more than the GCA means squares at Kabete and Katumani (Tables 4 and 5) clearly demonstrated that number of days to maturity was primarily under the control of non-additive gene effects. Consequently the development of early maturing sunflowers at these locations can best be done by use of hybrid varieties. Kovacik and Skaloud (1972) demonstrated equal importance of both additive and non-additive gene effects in the control of number of days to maturity; while Putt (1966) and Dua and Yadava (1982) found both gene effects important, but additive predominant. At Njoro, GCA mean squares were slightly more than the SCA mean squares (Table 6). This showed that at this location, the additive gene effects were probably more important than the non-additive gene effects. These results have some similarity with results obtained by Putt (1966) and Dua and Yadava (1982). This also shows that gene effects are location dependent and at Njoro early maturing open-pollinated varieties of sunflower can be developed through simple and/or recurrent selection.

Stem diameter.

At all the three locations, the GCA mean squares were greater than the SCA mean squares (Tables 4, 5 and 6). This indicates that at all the three locations, the additive gene effects were more important than the non-additive gene effects in the manifestation of variability among the crosses for stem diameter. This implies that development of sunflower varieties with suitable stem diameter can easily be achieved by simple selection. The results of this study on the nature of gene action with respect to stem diameter are in close agreement with results obtained by Rao (1980) and Dua and Yadava (1982).

Stem height.

Since GCA mean squares were much higher than the SCA mean squares at the three locations (Tables 4, 5 and 6), the nature of gene action for stem height at these locations was mainly additive. Therefore, improvement of the trait at the locations can easily be achieved by simple selection. These results are contrary to the findings of Putt (1966) and Dua (1979), but are similar to those of Rao and Singh (1977), Miller *et al*. (1980)

and Rao (1980).

Head diameter.

The significance of GCA mean squares at Kabete (Table 4), and the higher values of GCA mean squares compared to SCA mean squares at Kabete and Njoro (Table 6) indicated that the additive component was more important than the non-additive component in contributing to the variability of head diameter at these two locations. Thus, selection as a means of improving this trait at Kabete and Njoro would be effective, and specific combinations of many parents would not have to be tested in order to find the best cultivars. These results on gene action are in close agreement with findings of Rao and Singh (1977), Miller et al., 1980 and Sindagi et al. (1979). At Katumani (Table 5) the equality of GCA and SCA mean squares suggests equal importance of both additive and non-additive gene effects in the control of head diameter at this location. The breeding strategy most appropriate in the improvement of head size at Katumani would be selection of superior segregates in early generations, and later intensified selection in advanced generations. Putt (1966) also found equal importance of additive and non-additive gene effects in the control of head diameter, but unlike in this study, both the GCA and SCA mean squares were significant.

Diameter of the sterile head centre.

The higher GCA mean square values than the SCA mean squares values at all the three locations implied that at the three locations, the nature of gene action for this trait was mainly additive. Consequently, development of sunflower varieties with a small sterile head centre can easily be achieved by simple selection methods at the three locations.

Number of empty seeds per head.

At Kabete and Njoro, the GCA mean squares were greater than the SCA mean squares, suggesting that the additive component was more important than the non-additive component in contributing to the variability of this trait at these two locations. Contrary to the above, the ratio of mean squares at Katumani (Table 5) indicated that the non-additive gene action was more important than the additive gene action in controlling this character. Therefore, the breeding strategy most appropriate in developing sunflower with few empty seeds at Kabete and Njoro would be simple selection, while at Katumani hybrid varieties would serve the purpose. In many cases, the number of empty seeds may reflect the extent of seed filling. Sindagi et al. (1979) concluded that the additive gene effects were more important than the non-additive gene effects in controlling seed filling. Thus, his results on gene action have some similarity with the results of this study obtained at Kabete and Njoro, but are contrary to those obtained at Katumani.

Hundred seed weight.

The significance of the GCA mean squares and non-significance of the SCA mean squares at Kabete and Njoro (Tables 4 and 6); and the high ratios of GCA:SCA mean squares for this trait at all the three locations suggested that the variability attributable to additive gene effects was much higher than the variability attributable to non-additive gene effects. Consequently, at all the three locations, selection of elite parents, as a breeding strategy in the improvement of the character will be very effective. The results of this study on gene action for 100-seed weight are similar to those of Rao and Singh (1977), Sindagi *et al*. (1979) and Miller *et al*. (1980); but differ from the findings of Putt (1966) and Dua (1979).

Husk percentage.

The fact that the GCA mean squares were greater than the SCA mean squares at all the three locations (Tables 4, 5 and 6) shows that husk percentage was mainly controlled by additive gene effects at Kabete, Katumani and Njoro. Therefore, simple selection would be effective in developing sunflowers with low husk percentage and this will be most effective at Njoro where the GCA mean squares were significant.

Seed yield per plant.

At Kabete (Table 4), the analysis of variance for combining ability revealed significant SCA mean squares but non-significant GCA mean squares, suggesting the relative importance of the non-additive gene effects in the manifestation of variability among crosses for seed yield per plant at this location. Thus, hybrid varieties would be an effective breeding strategy in developing high yielding sunflowers at Kabete. These results are in close agreement with work by Putt (1966), Kovacik and Skaloud (1972) and Dua (1979). At Katumani and Njoro (Tables 5 and 6) the high ratio of GCA to SCA mean squares revealed that the variability attributable to additive gene effects was greater than the variability attributable to non-additive gene effects. This implies that at the two locations, development of high yielding sunflower varieties can be achieved easily through simple selection of high yielding parents. A number of workers also found the additive component to be more important than the non-additive component in the control of seed yield (Sudhakar, 1979; Sindagi *et al*., 1979; Miller *et al*., 1980; Rao, 1980 and Fured and Frank, 1981).

5.2 General combining ability effects.

Number of days to flowering.

At Kabete, Shaba, 090 and Amiata were good general combiners for early flowering in that order, while Smena and Fedha showed high general combining ability for lateness (Table 7). At Katumani (Table 8) 090, followed by Amiata were the best general combiners for early flowering. At this location, Smena and Gro 21 were poor general combiners for earliness. Since the analysis of variance for combining ability showed this character to be under the influence of non-additive gene action at the two locations (Tables 4 and 5), selection of any of the above lines as a means of improving the trait will not be successful at Kabete and Katumani. At Njoro (Table 9) Smena and Fedha showed high GCA for lateness. Thus, these two parents should be excluded from breeding programmes leading to early flowering sunflowers at Njoro, because the nature of gene action showed that at this location (Table 6), simple selection can be a successful breeding strategy in breeding early flowering sunflower varieties. This study showed that the parents differed significantly in GCA with respect to the number of days to flowering, and some lines were found to have very good GCA for this trait. Similar results were obtained by other workers (Russel, 1953; Sudhakar and Seetharam, 1980 and Pathak, 1980). Sindagi *et al*. (1979) observed that out of the fourteen lines, only one had significant GCA for number of days to flowering.

Number of days to maturity.

090 and Shaba had high GCA for early maturity at Kabete while Smena showed high GCA to late maturity at this location (Table 7). At Katumani, 090 showed good GCA for early maturity (Table 8). However, none of these parents can be selected or rejected on the basis of the GCA effects, because the nature of gene action for the trait at these two locations indicated that selection of elite parents will not result into quick response to selection, and hence will result into poor progress as far as improving the trait at the two locations is concerned. Fedha showed high GCA for late maturity at Njoro (Table 9). Since the nature of gene action for this trait at Njoro (Table 6) was mainly additive, which in turn shows quick response to simple selection, Fedha should not be selected for use in breeding programmes aiming at earliness at

Njoro. It may be selected for breeding late maturing varieties with high yield. The results of this study showed significant differences among the various parents used, with respect to GCA for maturity days. Similarly, some earlier workers concluded that different sunflower lines differed significantly in combining ability with respect to this trait (Russel, 1953 and Sudhakar and Seetharam, 1980).

Stem diameter.

At Kabete and Njoro (Tables 7 and 9) Smena showed high GCA for stem diameter. At Katumani (Table 8) Fedha showed high GCA for this trait. The nature of gene action at the three locations indicated that selection would be an effective breeding strategy in improving this trait, thus, Smena would be a good parent in breeding programmes aiming at increasing stem girth, at Kabete and Njoro, while Fedha would serve the same purpose at Katumani. Shaba would result into small stem diameters at Katumani, because of its significant negative GCA for this trait. Russel (1953) and Alba and Porceddu (1977) identified a number lines with good GCA for stem diameter among the gerplasm studied. However, the present study revealed relatively few parents with significant GCA effects for this trait.

Stem height.

Smena's positive GCA for stem height at Kabete (Table 7) showed that Smena, selected as an elite parent, can give offsprings with tall stems. At Njoro and Kabete. Selection of Gro 21 as a parent will result in short stem sunflowers due to its significant negative GCA at these two locations. Shaba will also behave in a similar way at Katumani and Njoro (Tables 8 and 9). These results showed that some of the parents used for the study were better combiners than other with respect to stem height. Similar results were also obtained by Pathak (1980). However Sindagi et al. (1979) studied fourteen parents and identified none with significant GCA effects for stem height.

Head diameter.

Due to the high GCA:SCA mean squares ratio for head diameter at Kabete (Table 4) and the positive GCA for Shaba for this trait, Shaba selected as a male parent in breeding strategies aiming at increasing head size is likely to produce segregates with bigger head diameter. 090 should not be included in sunflower breeding programmes, because of its negative GCA for this trait at Kabete. This study showed Shaba to be a good combiner for head diameter at Kabete. Sudhakar and

Seetharam (1980) also showed that some sunflower lines were good combiners for head diameter, and they could be used in crossing programmes and in the development of synthetic varieties. Similarly, Sindagi et al. (1979) studied fourteen parents and observed that among the females, one was a good general combiner for head diameter. Pathak (1980) also concluded that certain sunflower cultivars were better combiners than others with respect to head diameter. Contrary to the above findings, no parent showed significant GCA for this trait at Katumani and Njoro (Tables 8 and 9).

Diameter of the sterile head centre.

None of the parents showed significant GCA for this trait at all the three locations (Tables 7 , 8 and 9). It appeared that environment influenced the parents to the degree that any genetic differences that controlled GCA for the diameter of the sterile head centre could not be identified.

Number of empty seeds per head.

With respect to number of empty seeds, 090 and 026 were good female and male parents respectively because of their significant negative GCA for the trait at Kabete (Table 7). On the other hand, Shaba was discouraging because of its highly significant positive GCA for this trait at Kabete. In a similar manner, Amiata was a good female parent, whereas 090 was unfit for selection as a parent in the improvement of this trait at Njoro (Table 9). Normally, the number of empty seeds should give the extent of seed filling. Sudhakar and Seetharam (1980) identified some sunflower lines as good combiners for seed filling. Sindagi et al. (1979) observed that out of the fourteen lines studied, thirteen had highly significant GCA effects for number of filled seeds per head; the four had negative GCA effects, while the rest were positive. However, the present study showed few parents with significant GCA effects for number of empty seeds at Kabete and Njoro, and no parent with significant GCA effects for this trait at Katumani.

Hundred seed weight.

At Kabete, Shaba showed the best GCA for 100-seed weight (Table 7). Since the nature of gene action at this location (Table 4) revealed that simple selection would help in improving this character, selection of Shaba as a male parent in improving 100-seed weight is likely to be promising. At this location, 026 and 090 would not be good parents due to their negative GCA effects for this character. Gro 21 proved to be a very good general combiner for 100-seed weight at Njoro

(Table 9). Therefore its selection in improving this character is likely to give good results. At this location, Amiata proved to be a poor parent to contribute for 100-seed weight due to its negative GCA effects for this trait. The results obtained at Kabete and Njoro indicated that the parents were significantly different in GCA for 100-seed weight, some parents were good and others were poor general combiners for this trait. Sudhakar and Seetharam (1980) also reported that some sunflower lines were good combiners for 100-seed weight. On the other hand, Sindagi et al. (1979) obtained no parent with significant GCA for 100-seed weight, among the fourteen parents studied; although he reported that one of the male parents was found to be the best general combiner for this trait. His results are similar to the results obtained in this study at Katumani, where non of the parents showed significant GCA effects for this trait.

Husk percentage.

At Kabete (Table 7) Argentario showed a high GCA for husk percentage. Therefore, using it as a female parent at this location is most likely to result into high husk percentage. Similarly, Amiata and Fedha had high positive GCA for this trait at Njoro (Table 9) making them less suitable parents. However, Shaba appeared a suitable male parent because of its negative GCA for this character at Njoro. This study showed that certain parents were better combiners than others with respect to husk percentage at Kabete and Njoro. Similar conclusions were drawn by Sindagi et al. (1979) and Pathak (1980). However, at Katumani, none of the GCA effects for any parent was significantly different from zero.

Seed yield per plant.

At Kabete and Katumani (Tables 7 and 8) Smena had high positive GCA for seed yield per plant. The nature of gene action at Kabete (Table 4) suggested that simple selection will not result into high yielding sunflowers. Therefore selection of Smena as a female parent may not result into high yielding sunflowers. At Katumani (Table 5) the ratio of GCA to SCA showed that selection might be a promising breeding strategy in improving seed yield. Hence, selection of Smena as a female parent for this location is likely to produce encouraging results. 090 was very unsuitable for Njoro, because of its significant negative GCA (Table 9) at this location. This study indicated that Smena was a better combiner than other parents for seed yield per plant at Kabete and Katumani, while 090 was shown to be a poor general combiner compared to other parents at Njoro. Other workers also concluded that certain sunflower varieties were better combiners than others with respect to this trait (Russel, 1953; Anashchenko and Rozhkova, 1974; Alba and Porceddu, 1977; Sudhakar and Seetharam, 1980; Pathak, 1980 and Furedi and Frank, 1981). Kovacik and Skaloud (1972) reported large differences, among the lines studied, in GCA for seed yield in sunflower. Contrary to their study, the present study revealed small differences in GCA for this trait. This was evidenced by the fact that with the exception of Smena at Kabete and Katumani and 090 at Njoro, all the parents showed GCA effects that were not significantly different from zero for seed yield per plant. This kind of behaviour could be attributed to the great influence of the environment on the parents to the extent that any genetic differences that controlled GCA for this trait could not be identified among the lines. This confirms reports by Allard (1960) that seed yield in plants is strongly conditioned by the environment. Burlov and Buntovskii (1978) observed that the GCA of eight lines for seed yield per hectare in sunflower depended more on environmental conditions than on any other factor.

In general, this study revealed that high performing parents for the various traits did not always result in high GCA for the respective traits. This is in line with reports by Hayes _et al_. (1955) saying that high yielding lines can result into low yielding crosses due to the poor GCA of these lines. On the other hand Pathak (1980) concluded that high yielding lines were in general good general combiners, during studies on the evaluation of some sunflower cultivars for combining ability in top-crosses.

5.3 Specific combining ability effects.

Number of days to flowering.

At Kabete and Katumani, the results from the combining ability analysis of variance (Tables 4 and 5) showed the importance of specific combinations of parents in breeding strategies aimed at attaining early flowering sunflowers. Consequently the cross Gro 21 x Fedha seems suitable for this purpose at both locations due to its highly significant negative SCA for this trait (Tables 10 and 11). Similarly, crosses 090 x 026, Smena x Shaba and Argentario x Fedha can make suitable early flowering hybrids at Kabete. On the other hand, Smena x Fedha and Gro 21 x 026 are not suitable as far as early flowering is concerned, because of the significant positive SCA effects for days to flowering at Kabete and Katumani. For the same reasons, 090 x Shaba was found unsuitable at Kabete. At Njoro (Table 12) no cross showed significant SCA for days to flowering. This could be attributed to the fact that at Njoro, the analysis of variance for combining ability (Table 6) showed minor importance of specific combinations of parents for days to flowering. Sindagi et al. (1979) also found less importance of specific combinations of parents through the analysis of variance for combining ability, and consequently observed no cross with significant SCA effects for this trait.

Number of days to maturity.

The ratios of GCA to SCA mean squares at Kabete and Katumani (Tables 4 and 5) indicated that hybrid varieties could be the best breeding strategy in obtaining early maturing sunflowers. Therefore, the crosses Argentario x Fedha, Smena x Shaba, 090 x 026 and Gro 21 x Fedha would form suitable early maturing hybrids due to their significant negative SCA effects for this trait at Kabete (Table 10). Similarly, Amiata x 026 and Gro 21 x Fedha could also form promising early flowering hybrids at Katumani (Table 11). Smena x Fedha and 090 x Shaba at Kabete, and Gro 21 x 026 at Katumani would form late maturing hybrids as per SCA results obtained at these two locations (Tables 10 and 11). The SCA effects for this trait at Njoro were non-significant.

Stem diameter.

At all the three locations, no cross showed significant SCA for stem diameter (Tables 10, 11 and 12). This was probably because the analysis of variance for combining ability indicated less importance of specific combinations of parents for this trait. Similar results were obtained by Rao (1980).

Stem height.

At Kabete (Table 10) Smena x Shaba and Smena x Fedha showed significant negative and positive SCA effects respectively for stem height. Consequently Smena x Shaba can result into a dwarf variety, while Smena x Fedha will result into a tall variety of sunflower. This study revealed no significant SCA effects for stem height at Katumani and Njoro. Sindagi et al. (1979) also obtained no cross with significant SCA effects, out of the thirty three crosses studied. This was so probably because their study showed minor need for the exploitation of non-additive gene effects for stem height. This was also true with the present study at all the three locations (Tables 4 , 5 and 6).

Head diameter.

At Kabete and Njoro, the ratios of GCA to SCA mean squares (Tables 4 and 6) indicated that specific combinations of parents may not have to be tested in order to find the best cultivars in improving head size. Consequently, no cross showed significant SCA effects for this trait at these two locations (Tables 10 and 12). On the other hand, GCA and SCA effects were equally important for head diameter at Katumani (Table 6). Likewise, Gro 21 x 026 at Katumani (Table 11) showed significant positive SCA for head diameter, and it can be used to develop hybrids with large head size at this location. Sindagi *et al*. (1979) also observed that of all the thirty three crosses studied, only one had significant SCA effects for head diameter. However, he concluded that three crosses gave high SCA effects for this trait. This conclusion was not all that valid because only one cross showed significant SCA.

Diameter of the sterile head centre.

At all the three locations, no cross showed significant SCA effects for the diameter of the sterile head centre (Tables 10, 11 and 12). This was not surprising since the analysis of variance for combining ability had earlier shown that most emphasis should be put on the exploitation of the additive rather than the non-additive gene effects in the improvement of this trait at the three locations.

Number of empty seeds per head.

At Kabete (Table 10) combination Smena x Fedha had high positive SCA for the number of empty seeds, while at Njoro (Table 12) 090 x 026 showed high positive SCA. The crosses 090 x Fedha and Smena x 026 showed high negative SCA effects for this trait at Njoro. Thus Smena x Fedha and 090 x 026 would give sunflowers with high number of empty seeds at Kabete and Njoro respectively. On the other hand, combinations Smena x 026 and 090 x Fedha are likely to result into sunflowers with low number of empty seeds at Njoro. At Katumani (Table 11) no cross showed significant SCA effects for this trait, despite the high ratio of SCA to GCA mean squares obtained for this trait (Table 5). This may be attributed to the large error variance recorded for this trait, compared to other characters. The results of this study revealed few crosses with significant SCA effects for this trait at Kabete and Njoro, and none at Katumani. However, Sindagi et al. (1979) observed that over fifty percent of the crosses studied had significant SCA effects for the number of filled seeds per head.

Hundred seed weight.

None of the crosses showed significant SCA for 100-seed weight at all the three locations (Tables 10, 11 and 12). This is in line with the results obtained for this trait from the analysis of variance for combining ability which suggested that simple selection of suitable parents were far more effective than testing of specific combinations of parents in the improvement of 100-seed weight. Sindagi *et al*. (1979) recorded three crosses with high but non-significant SCA effects for this trait.

Husk percentage.

The only significant SCA effect for the husk percentage was shown by Argentario x Fedha at Katumani (Table 11). This was a positive value and therefore would result into high husk percentage which would be undesirable for breeding a variety with high kernel percentage and consequently high oil yield.

Seed yield per plant.

The negative SCA for Smena x Shaba for seed yield per plant at Kabete (Table 10) is of particular interest. The line Smena showed highly significant positive GCA for this trait at Kabete (Table 7). However, the analysis of variance for combining ability indicated the relative importance of specific combinations of parents in the control of this character at Kabete since the SCA mean squares were significant and the GCA mean squares were non-significant (Table 4). This has been demonstrated by the significant negative SCA for seed yield, shown by Smena x Shaba. This implies that Smena, selected as a female parent, will not always give high yielding offsprings. The crosses Argentario x Shaba and Smena x Fedha could probably result into reasonably high yielding hybrids because their SCA effects, though non-significant, were quite high and very close to being significant. Gro 21 x 026 would form high yielding hybrids at Katumani while Argentario x Shaba would be a low yielding hybrid at Njoro, as per SCA effects shown by these crosses (Tables 11 and 12). At all the three locationss, few crosses were observed to have significant SCA effects. Sindagi *et al*. (1979) also observed that only two crosses had significant SCA effects for seed yield per plant, out of a total of thirty three crosses.

5.4 Correlation coefficients.

The results of this study showed that at Kabete and Katumani (Tables 13 and 14) head diameter was the most important factor in determining seed yield per plant. Many earlier workers also identified head diameter as the most important determinant of seed yield in sunflower (Pathak, 1974; Ayyasamy et al., 1977; Alba and Greco, 1979; Lakshmanaiah, 1980 and Velkov, 1980). On the other hand, results obtained by Shabana (1977) and Giriraj et al. (1980) showed that seed weight had the most important influence on seed yield, while Tyagi (1985) demonstrated that plant height had the greatest positive association with seed yield. At Njoro, number of empty seeds showed significant negative association with seed yield (Table 15) because empty seeds lack kernel and have only husk and very low weight. Ideally this would imply that the number of filled seeds would be positively correlated with seed yield per plant. Asawa et al. (1977) reported that plant height and filling percentage in seeds were the most important characters governing variability in seed yield of sunflower. Lakshmanaiah (1980) also reported significant and positive correlations between seed yield and seed filling in sunflower.

In addition to head diameter, 100-seed weight at Kabete and Katumani (Table 13 and 14) and stem diameter, stem height and number of days to maturity at Kabete, were found to be important in contributing positively to seed yield per plant. Many workers also found these characters to be important in contributing to seed yield in sunflowers (Natali and Jam, 1970; Kovacik and Skaloud, 1972; Pathak, 1974; Shabana, 1977;

Singh *et al.*, 1977; Asawa *et al.*, 1977; Varshney and Singh, 1977; Alba and Greco, 1979; Giriraj *et al*; 1980; Dua, 1979; Lakshmanaiah, 1980 and Tyagi, 1985). Skoric (1974) reported that height was significantly negatively correlated with seed yield per hectare. Such a situation is likely to occur where relatively tall plants are affected by lodging. Also, weak stems with heavy heads can lead to breakage of the stems (as was observed with a few plants in the present study at Kabete), a condition which can significantly reduce seed yield per unit area when it occurs at a high level.

At Kabete and Katumani, number of days to flowering and number of days to maturity were highly significantly positively correlated. This explains why the two traits tended to behave in a very similar manner at each location, with respect to mean squares from combining ability analysis (Tables 4 and 5), GCA effects (Tables 7 and 8) and SCA effects (Tables 10 and 11). At Kabete, head diameter was positively associated with stem diameter, stem height, number of empty seeds and and 100-seed weight. The relations among head diameter, number of empty seeds and 100-seed weight was clearly demonstrated by 090 which had significant negative GCA effects for these three traits at Kabete (Table 7). Similarly, Shaba showed the same trend, but with positive

GCA effects. At Katumani (Table 8) head diameter was positively associated with diameter of the sterile head centre, the number of empty seeds and 100-seed weight. The highly significant positve correlation between head diameter, and number of empty seeds was of particular interest. First of all, it looked so unrealistic to obtain a significant positive correlation between seed yield and the number of empty seeds at this location. However, this can be explained by the association between the number of empty seeds and head diameter, which implies that the bigger the head diameter, the more the number of empty seeds, yet the bigger the head diameter the higher the seed yield. Hence it definately follows that where there is a bigger head diameter, there will be higher seed yield and more number of empty seeds, which results in a positive association between seed yield and number of empty seeds. At Kabete, head diameter and number of empty seeds were also positively correlated. However, the later was not significantly correlated with seed yield as was the case at Katumani. This was because at Kabete, the association between head diameter and number of empty seeds was not as strong as the association between the two traits at Katumani.

5.5 <u>Path coefficients.</u>

The results obtained at Kabete and Katumani (Tables 16 and 18) indicated that head diameter was the most important single factor contributing positively to seed yield per plant. The relationship between head diameter and seed yield per plant at Katumani was evident from a cross Gro 21 x 026, which showed significant SCA effects for these two traits (Table 11). Results by Alba and Greco (1979), Lakshmanaiah (1980), Velkov (1980) and Tyagi (1985) also revealed that head diameter had the maximum positive direct effect on seed yield in sunflower. At Njoro (Table 18) the greatest direct effect on seed yield per plant was shown by number of empty seeds with a negative coefficient. This was so probably because of the limited moisture at the location, which might have had a very negative effect on the filling percentage of the individual heads, hence making number of empty seeds the most important factor affecting seed yield at this location. Under normal circumstances, the number of empty seeds should be inversely proportional to the number of filled seeds. Consequently, the number of filled seeds per plant should show a positive direct effect on seed yield per plant. Varshney and Singh (1977) reported a positive direct effect of seed filling on seed yield. The maximum positive direct effect on seed yield per plant at Njoro was shown by 100 seed weight.

These results are similar to those obtained by Giriraj *et al*. (1980) and Beard and Geng (1982) who found a maximum positive direct effect of seed weight on seed yield in sunflower.

This study showed that the results of the correlation coefficients and path analysis at Kabete and Katumani identified head diameter as the most important trait determining seed yield per plant. Likewise, correlation coefficients of 100-seed weight, head diameter and number of empty seeds at Njoro were in very close agreement with results obtained through path analysis. Other workers also found that conclusions drawn on the basis of correlation coefficients were similar to those drawn on the basis of path analysis (Giriraj *et al*., 1980 and Velkov, 1980). However, studies by Alba and Greco (1979) and Tyagi (1985) revealed that results from correlations were slightly different from those obtained through path analysis.

Stem diameter, 100-seed weight, stem height and number of days to maturity showed very close relation with seed yield per plant at Kabete (Table 13). However, their direct effects were quite small. Instead, their importance in contributing to seed yield was shown by their strong indirect effects via head diameter, except the number of days to maturity. All the characters, except number of days to maturity, were highly positively correlated with head diameter. The importance of number of days to maturity in contributing to seed yield per plant was shown by a small indirect effect of the trait via number of days to flowering, with which it was found to be strongly correlated. Tyagi (1985) also found significant positive correlations of plant height and 100-seed weight with seed yield, but observed negative direct effects of these traits on seed yield. However, the traits had strong indirect effects via head diameter, with which they were found to be significantly correlated. Similar results with 1000-seed weight were also obtained by Alba and Greco (1979). At Katumani (Table 14), correlation coefficients showed 100-seed weight to be important in determining seed yield per plant. This was revealed by both the direct and indirect effects via head diameter. The number of empty seeds at this location had a highly significant correlation coefficient with seed yield per plant, but negligible direct effect. Its major contribution was through head diameter. The indirect effects of 100-seed weight and number of empty seeds on seed yield via head diameter were due to the significant correlations between these two traits and head diameter.

The results obtained at Njoro tended to be slightly different from those obtained at Kabete and katumani. This could be attributed to the poor weather conditions during the growing season at Njoro (Appendix 1). The location received relatively little rainfall, compared to the other two locations. This was made worse by the relatively lower temperatures, which made crops grow at a very slow rate, thus being exposed more to the poor weather conditions. The rainfall at Katumani was also relatively low as compared to that at Kabete, but the high temperatures at Katumani allowed plants to grow at a very fast rate so as to escape the harsh weather conditions especially limited moisture. Therefore the crops at Katumani were not as affected as those at Njoro, although Katumani is well known as a dryland area. The unfavourable growing conditions that prevailed at Njoro most certainly had an impact on the performance of a number of genotypes, and that was why some of the results recorded for this location seemed different compared to the results from the other two locations. Laosuwan and Atkins (1977) also encountered similar problems when dealing with estimates of combining ability and heterosis in converted exotic sorghums.

In general, the results of the present study had a lot of similarity with those of earlier workers.

However, in a number of cases, conclusions drawn by earlier workers were slightly or completely different from the results of this study. Fick et al (1974) noted that some variation between results is expected because of differences among the germplasm collections studied. The same explanation could be advanced to account for the differences noted in the present investigation. Environmental effects may account for further differences in results. This is particularly true on considering the fact that the yield traits dealt with in this study were strongly conditioned by genotype-environmental interactions. An example of this was the poor performance of the crops at Njoro compared to the other two locations namely Kabete and Katumani.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the results of this study, the following conclusions can be drawn:

1. At Kabete, number of days to flowering, number of days to maturity and seed yield per plant were mainly under the influence of the non-additive gene effects, since the SCA mean squares were significant, and the GCA mean squares were non-significant. Stem diameter, stem height, diameter of the sterile head centre, head diameter, number of empty seeds, 100-seed weight and husk percentage were primarily governed by the additive gene effects.

2. At Katumani, the significance of the SCA mean squares and the non-significance of the GCA mean squares for days to maturity and days to flowering means that these traits were mainly under the control of the non-additive gene effects. The number of empty seeds was also mainly controlled by non-additive gene effects because the SCA mean squares were much higher than the GCA mean squares. The rest of the traits at this location were mainly influenced by additive

gene effects.

3. The additive gene effects were responsible for the manifestation of variability among the crosses at Njoro with respect to all the traits looked at in this study. This was concluded because for all the characters, the GCA mean squares were higher than the SCA mean squares, and none of the SCA mean squares were significant.

4. The number of days to flowering and number of days to maturity at Kabete and Katumani; seed yield per plant at Kabete; and number of empty seeds at Katumani were primarily under the control of non-additive gene effects. Consequently selection as a means of improving sunflower with respect to the above characters will not be very effective Instead, improvement can easily be achieved by use of suitable crosses or hybrid varieties.

5. With the exception of the traits mentioned above (4), the rest of the characters at the three locations were mainly under the influence of the additive gene effects. Therefore sunflower improvement with respect to the above characters can easily be achieved through simple and/or recurrent selection because there will be quick response

to selection. In this case, testing of many specific combinations of parents will not be necessary in order to find the best cultivar.

6. Hybrid combinations viz: 090 x 026, Argentario x Fedha, Smena x Shaba and Gro 21 x Fedha at Kabete, and Amiata x 026 and Gro 21 x Fedha at Katumani showed good SCA for earliness, as per SCA obtained for days to flowering and days to maturity.

7. Crosses Argentario x Shaba and Smena x Fedha were late maturing but relatively high yielding at Kabete.

8. Although Smena x Shaba appeared fit for Kabete because of its earliness, it was found to be unsuitable with regard to seed yield per plant, due to its significant negative SCA for this trait.

9. Smena was a good general combiner for seed yield per plant at Katumani, stem diameter at Kabete and Njoro, and stem height at Kabete because it showed significant positive GCA effects for these traits at the respective locations.

10. Shaba showed good GCA for head diameter and 100-seed weight at Kabete and husk percentage at Njoro. At Njoro, Gro 21 was a good general combiner for 100-seed weight.

11. Correlation coefficients and path coefficients indicated that the most important determinant of seed yield per plant at Kabete and Katumani was head diameter. At Njoro, 100-seed weight and head diameter had the highest positive direct effects on seed yield per plant. At this location number of empty seeds was found to have a negative direct effect with seed yield, and this was higher than the positive direct effects of 100-seed weight and head diameter.

12. Apart from the head diameter, stem diameter, 100-seed weight and plant height were found to contribute positively to seed yield at Kabete. Similarly, 100-seed weight, stem height and seed filling were found to be positively associated with seed yield per plant.

Recommendations:

1. Crosses 090 x 026, Argentario x Fedha, Smena x Shaba and Gro 21 x Fedha are the most promising for further breeding work in the improvement of earliness in the highlands of Kenya. Likewise, Amiata x 026 and Gro 21 x Fedha are recommended for dryland areas of Kenya for the same purpose.

2. More research should be directed at the yielding potential of crosses Argentario x Shaba and Smena x Fedha, in the Kenyan highlands.

3. Smena should be incorporated into breeding programmes that aim at increasing seed yield per plant in the dryland areas of Kenya. In a similar manner it should be used for stem diameter and stem height in highlands of kenya.

4. Shaba appears the most promising in the improvement of sunflower with respect to head diameter and seed weight in the Kenya highlands. This parent is also recommended for breeding programmes that aim at high oil percentage because of its significant negative GCA for husk percentage.

5. Breeding programmes aiming at maximizing seed yield per head in sunflower should put a lot

of emphasis on the size of the head, the bigger the head diameter, the higher the yield. This applies to both the highlands and drylands of Kenya,

6. In addition to head diameter mentioned above, stem diameter, 100-seed weight and plant height should be given due consideration in highlands, while 100-seed weight, height and seed filling must also be put under consideration in the drylands.

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Appendix 1. Mean monthly temperatures and monthly rainfall for the three locations during the growing season.

Location	Altitude (m)	Rainfall and temperature	April	May	June	July	August	September
Kabete	2,123	Rainfall(mm)	278.9	145.0	95.1	18.8	13.4	
		Temp(°C)	19.4	18.4	16.6	16.0	16.5	
Katumani	1,575	Rainfall(mm)	66.7	49.4	71.9	23.3		
		Temp(°C)	21.6	19.9	19.2	17.8		
Njoro	2,185	Rainfall(mm)		132.0	115.5	48.9	99.3	35.0
		Temp(°C)		17.3	16.1	15.4	15.8	17.0

Appendix 2. Means of the performance of the parents for seed yield, its components and maturity traits at Kabete.

Parents	Days to flowering	Days to maturity	Stem diameter (cm)	Stem height (cm)	Head diameter (cm)	Diameter of sterile centre (cm)	No. of empty seeds	100 seed weight (g)	Seed yield per head (g)	Husk percentage
Lines										
Amiata	88.1a *	128.1a	2.33a	157.8a	14.3b	3.00**	62.6b	7.07bc	60.4c	25.9c
Argentario	71.6d	128.2a	2.45a	160.3a	18.3a	2.96	61.0b	6.95bc	95.2a	31.1ab
Gro 21	79.1bc	122.7a	1.37b	118.1b	7.2c	2.50	38.3b	5.09d	15.6d	31.9a
Smena	72.4d	125.2a	2.32a	150.1a	15.4b	3.86	131.8a	7.10bc	66.5bc	28.1bc
090	75.7dc	128.8a	2.11a	138.0ab	15.6b	3.68	73.9b	8.38a	68.6bc	28.6bc
Testers										
026	82.4b	129.1a	2.50a	153.3a	14.8b	2.30	53.1b	6.82bc	87.3ab	24.9c
Shaba	72.2d	121.8a	2.43a	153.8a	15.9ab	2.91	47.4b	7.40b	81.8ab	25.9c
Fedha	72.2d	111.1b	2.16a	158.2a	14.1b	2.66	57.7b	6.24c	55.0 c	26.5c

*Values followed by the same letter within a letter series are not significantly different at the 5% level according to the Duncan's multiple range test.

**Values not followed by a letter are not significantly different according to the F-test.

Appendix 3. Means of the performance of the parents for seed, yield, its components and maturity traits at Katumani.

Parents	Days to flowering	Days to maturity	Stem diameter (cm)	Stem height (cm)	Head diameter (cm)	Diameter of sterile centre (cm)	No. of empty seeds	100-seed weight (g)	Seed yield per head (g)	Husk percentage
Lines										
Amiata	63.5b*	106.8bc	2.58**	112.6	19.3a	4.75	55.5	8.58ab	97.5a	28.8
Argentario	63.9b	104.5bcd	2.45	103.3	15.4b	4.22	51.4	8.63ab	57.4bc	23.9
Gro 21	71.6a	119.8a	2.50	118.3	11.7c	5.00	44.8	7.17c	22.8d	25.4
Smena	61.4b	101.2d	2.15	108.5	14.4bc	3.73	47.5	9.23a	65.0bc	25.9
090	60.0b	108.6b	2.19	105.3	19.6a	4.28	53.1	8.78ab	97.3a	24.9
Testers										
026	60.8b	100.1d	2.03	98.9	14.1bc	3.97	52.3	8.73ab	54.5c	21.0
Shaba	62.9b	101.9cd	2.19	96.9	16.8b	4.45	56.2	8.63ab	82.8ab	25.3
Fedha	64.6b	104.2bcd	2.30	106.7	16.6b	4.08	52.2	8.33b	71.5bc	25.2

*Values followed by the same letter within a letter series are not significantly different at the 5% level according to the Duncan's multiple range test.

**Values not followed by a letter are not significantly different according to the F-test.

Appendix 4. Means of the performance of the parents for seed yield, its components and maturity traits at Njoro.

Parents	Days to flowering	Days to maturity	Stem diameter (cm)	Stem height (cm)	Head diameter (cm)	Diameter of sterile centre (cm)	No. of empty seeds	100-seed weight (g)	Seed yield per head (g)	Husk per-percentage
Lines										
Amiata	80.5ab*	116.0**	3.20a	133.7ab	17.6a	3.13	29.6a	8.60a	25.0	20.4
Argentario	77.7bc	115.7	2.80a	141.3a	16.9a	1.90	7.0bc	4.67cd	37.8	35.9
Gro 21	75.7c	117.0	1.27b	106.3c	6.4b	2.10	5.6bc	3.80d	13.0	30.0
Smena	76.0c	115.0	2.50a	129.0ab	14.0a	2.00	14.2bc	6.80abc	50.0	25.0
090	82.6a	117.1	3.00a	133.6ab	16.8a	0.48	4.0c	8.00ab	40.0	34.9
Testers										
026	75.7c	114.7	2.90a	115.4bc	17.4a	1.30	11.5bc	5.2bcd	45.9	23.1
Shaba	79.7ab	117.0	3.27a	137.7ab	16.3a	1.50	16.2b	7.57ab	48.8	28.2
Fedha	78.3bc	119.0	3.00a	129.9ab	16.1a	1.93	7.7bc	7.87ab	36.2	25.6

*Values followed by the same letter within a letter series are not significantly different at the 5% level according to the Duncan's multiple range test.

** Values not followed by a letter are not significantly different according to the F-test.

Data on number of empty seeds transformed; $x = (x + 1)^{\frac{1}{2}}$

Appendix 5. Means of the performance of the crosses for seed yield, its components and maturity traits at Kabete.

Character	Lines.	Testers				
		0.26	Shaba	Fedha	Total	Mean
Days to flowering	Amiata	72.9cde*	66.8f	76.2bcd	215.9	70.0k
	Argentario	77.3bc	73.1bcde	74.1bcde	224.5	74.8j
	Gro 21	78.8b	70.8b	70.9ef	220.0	73.3jk
	Smena	77.8bc	70.4ef	86.1a	234.3	78.1i
	090	63.3f	72.2de	73.9bcde	213.4	71.1
	Total	374.1	353.4	380.6	1108.1	
	Mean	74.8p	70.7p	76.1p		73.9
Days to maturity	Amiata	123.3bcde	111.8f	125.7bcd	360.8	120.3j
	Argentario	128.6b	123.1bcde	115.0def	366.7	122.2j
	Gro 21	126.7bc	121.6bcdef	115.8def	364.1	121.4j
	Smena	128.4b	116.2cdef	138.4a	383.0	127.7i
	090	113.3ef	120.8bcdef	119.0bcdef	353.1	117.7j
	Total	620.3	593.5	613.8	1827.6	
	Mean	124.1m	118.7n	122.8mn		121.8
Stem diameter	Amiata	2.27b	2.50ab	2.55ab	7.32	2.44ef
	Argentario	2.40b	2.44b	2.23b	7.14	2.38f
	Gro 21	2.44b	2.67ab	2.30b	7.41	2.47ef
	Smena	2.63ab	2.52ab	2.98a	8.13	2.71e
	090	2.37b	2.54ab	2.58ab	7.49	2.5ef
	Total	12.11	12.67	12.64	37.49	
	Mean	2.42i	2.53i	2.53i		2.50
Stem height	Amiata	163.0bcd	176.0abc	171.7bcd	510.7	170.2gh
	Argentario	163.9bcd	177.1ab	168.2bcd	509.2	169.7gh
	Gro 21	149.4d	167.6bcd	152.3cd	469.6	156.4i
	Smena	177.5ab	169.7bcd	195.4a	542.6	180.1g
	090	163.7bcd	167.7bcd	160.9bcd	492.3	164.1hi
	Total	817.5	858.1	848.5	2524.1	
	Mean	163.5L	171.6L	169.7L		168.3

Appendix 5 (Contd..)

Character	Lines	Testers				
		026	Shaba	Fedha	Total	Mean
Head diameter (cm)	Amiata	16.3ab	16.9ab	16.9ab	50.1	16.7e
	Argentario	15.5ab	16.5ab	15.1ab	47.1	15.7e
	Gro 21	15.3ab	17.2ab	15.0b	47.5	15.8e
	Smena	15.7ab	17.5ab	18.0a	51.2	17.1e
	090	15.6ab	16.7ab	15.3ab	47.6	15.8e
	Total	78.4	84.8	80.3	243.6	
	Mean	15.7i	17.0h	16.1hi		16.24
Diameter of the sterile centre (cm)	Amiata	2.02**	2.44	3.05	7.51	2.50
	Argentario	2.68	3.85	3.64	10.17	3.39
	Gro 21	2.36	2.65	2.76	7.77	2.59
	Smena	4.29	1.74	3.38	9.41	3.14
	090	1.74	2.79	2.79	7.32	2.44
	Total	13.09	13.47	15.62	42.18	
	Mean	2.62	2.69	3.12		2.81
Number of empty	Amiata	66.7bcd	119.7a	88.2abcd	274.6	91.5g
	Argentario	54.8cd	96.8abc	54.1cd	205.7	68.6gh
	Gro 21	62.3 bcd	97.2abc	43.4d	202.9	67.6gh
	Smena	60.3cd	83.6abcd	113.3ab	257.2	85.7g
	090	60.6cd	50.9cd	55.9cd	167.4	55.8h
	Total	304.7	448.2	354.9	1107.8	
	Mean	60.9L	89.6k	71.0kL		73.9
100-seed weight (g)	Amiata	7.38abc	7.51abc	7.42abc	22.31	7.44f
	Argentario	6.77c	7.69abc	7.21bc	21.67	7.22fg
	Gro 21	7.03bc	8.25a	7.09bc	22.37	7.46f
	Smena	7.14bc	7.87ab	7.63abc	22.64	7.55f
	090	6.79c	6.97bc	6.98bc	20.74	6.91g
	Total	35.11	38.29	36.33	109.74	
	Mean	7.02k	7.66j	7.27k		7.3

Appendix 5 (Contd..)

Character	Lines	Testers				
		026	Shaba	Fedha	Total	Mean
Seed yield per head (g)	Amiata	60.1c	65.1bc	77.2abc	202.4	67.5g
	Argentario	63.0bc	84.4ab	60.7c	208.1	69.4g
	Gro 21	65.1bc	76.8abc	55.9c	197.8	65.9g
	Smena	84.5ab	74.1abc	94.6a	253.2	84.4f
	090	57.9c	68.6bc	65.2bc	191.7	63.9g
	Total	330.6	369.0	353.6	1053.2	
	Mean	66.1j	73.8j	70.7j		70.2
Husk per-centage	Amiata	25.6abc	27.4abc	26.3abc	79.3	26.4fg
	Argentario	28.8a	26.8abc	28.5ab	84.1	28.0f
	Gro 21	26.7abc	26.6abc	25.2bc	78.5	26.2g
	Smena	26.8abc	26.6abc	25.4abc	78.8	26.3g
	090	24.9c	25.9abc	27.1abc	77.9	26.0g
	Total	132.8	133.3	132.5	398.6	
	Mean	26.6j	26.7j	26.5j		26.6

*Values followed by the same letter within a letter series are not significantly different at the 5% level according to the Duncan's multiple range test.

**Values not followed by a letter are not significantly different according to the F-test.

Appendix 6. Means of the performance of the crosses for seed yield, its components and maturity traits at Katumani.

Character	Lines	Testers				
		026	Shaba	Fedha	Total	Mean
Days to flowering	Amiata	60.3c*	61.2c	61.9c	183.4	61.1g
	Argentario	63.4c	62.4c	64.7bc	190.5	63.5f
	Gro 21	69.7a	63.8c	60.2c	193.7	64.6f
	Smena	62.9c	62.3c	68.5ab	193.7	64.6f
	090	60.3c	59.8c	62.1c	182.2	60.7g
	Total	316.6	309.5	317.4	943.5	
	Mean	63.3 i	61.9 i	63.5 i		62.9
Days to maturity	Amiata	99.1c	103.3abc	104.4abc	306.8	102.3f
	Argentario	101.6abc	102.2abc	101.7abc	305.5	101.8f
	Gro 21	106.8a	102.6abc	100.7bc	310.1	103.4f
	Smena	103.2abc	99.5c	105.7ab	308.4	102.8f
	090	100.3bc	99.5c	100.3bc	300.1	100.0f
	Total	511.0	507.1	512.8	1530.9	
	Mean	102.2i	101.4 i	102.6i		102.1
Stem diameter (cm)	Amiata	2.35**	2.19	2.33	6.87	2.29
	Argentario	2.67	2.12	2.18	6.97	2.32
	Gro 21	2.44	2.15	2.47	7.06	2.38
	Smena	2.44	2.28	2.31	7.03	2.34
	090	2.32	2.00	2.35	6.87	2.29
	Total	12.22	10.94	11.64	34.8	
	Mean	2.44	2.19	2.33		2.32
Stem height (cm)	Amiata	96.6	93.3	108.0	297.9	99.3
	Argentario	112.0	102.3	105.0	319.3	106.4
	Gro 21	111.6	87.8	107.4	306.8	102.3
	Smena	109.6	102.5	112.0	324.1	108.0
	090	93.2	103.3	109.2	305.7	101.9
	Total	523.0	489.2	541.6	1553.8	
	Mean	104.6	97.8	108.3		103.6

Appendix 6 (Contd..)

Character	Lines	Testers				
		026	Shaba	Fedha	Total	Mean
Head diameter (cm)	Amiata	15.8bc	16.6abc	16.9abc	49.3	16.4f
	Argentario	16.6abc	16.9abc	15.8bc	49.3	16.4f
	Gro 21	19.1a	15.8bc	16.6abc	51.5	17.2f
	Smena	17.6abc	16.8abc	18.2ab	52.6	17.5f
	090	15.2c	16.4abc	17.2abc	48.8	16.3f
	Total	84.3	82.5	84.7	251.5	
	Mean	16.9i	16.5i	16.9i		16.8
Diameter of the sterile centre(cm)	Amiata	4.12	4.43	3.92	12.47	4.16
	Argentario	4.42	4.25	4.26	12.93	4.31
	Gro 21	4.61	3.68	3.92	12.21	4.07
	Smena	4.79	4.10	4.33	13.22	4.41
	090	4.27	4.12	4.40	12.79	4.26
	Total	22.21	20.58	20.83	63.62	
	Mean	4.44	4.12	4.17		4.24
Number of empty	Amiata	50.1	53.4	47.9	151.4	50.5
	Argentario	51.4	54.1	50.3	155.8	51.9
	Gro 21	55.2	45.8	48.8	149.8	49.9
	Smena	52.5	51.5	51.0	155.0	51.7
	090	50.2	50.5	53.3	154.0	51.3
	Total	259.4	255.3	251.3	766.0	
	Mean	51.9	51.1	50.3		51.1
100 seed weight (g)	Amiata	8.67	8.75	8.47	25.89	8.63
	Argentario	8.70	8.80	8.57	26.07	8.69
	Gro 21	8.94	8.70	8.66	26.30	8.77
	Smena	8.63	8.87	9.07	26.57	8.86
	090	8.83	9.07	8.37	26.27	8.76
	Total	43.77	44.19	43.14	131.1	
	Mean	8.75	8.83	8.63		8.74

Appendix 6 (Contd...)

Character	Lines	Testers				
		026	Shaba	Fedha	Total	Mean
Seed yield per head (g)	Amiata	59.5b	70.3ab	79.0ab	201.8	67.3e
	Argentina	67.9ab	73.8ab	60.0b	201.7	67.2e
	Gro 21	83.3ab	55.3b	68.6ab	207.2	69.1e
	Smena	79.9ab	69.7ab	88.9a	238.5	79.5e
	090	59.0b	74.7ab	68.8ab	202.5	67.5e
	Total	349.6	343.8	358.3	1051.7	
	Mean	69.9h	68.8h	71.7h		70.1
Husk percentage	Amiata	24.3	25.9	23.7	73.9	24.6
	Argentario	24.1	24.9	27.7	76.7	25.6
	Gro 21	24.2	26.0	24.4	74.6	24.9
	Smena	24.0	23.5	23.7	71.2	23.7
	090	23.7	25.6	24.7	74.0	24.7
	Total	120.3	125.9	124.2	370.4	
	Mean	24.1	25.2	24.8		24.7

* Values followed by the same letter within a letter series are not significantly different at the 5% level according to the Duncan's multiple range test.

** Values not followed by a letter are not significantly different according to the F-test.

Appendix 7. Means of the performance of the crosses for seed yield, its components and maturity traits at Njoro.

Character	Lines	Testers				
		026	Shaba	Fedha	Total	Mean
Days to flowering	Amiata	77.3b*	78.3ab	78.7ab	234.3	78.1e
	Argentario	78.0ab	78.3ab	80.3ab	236.6	78.9e
	Gro 21	78.7ab	79.0ab	79.3ab	237.0	79.0e
	Smena	81.0ab	79.7ab	80.3ab	241.0	80.3e
	090	78.7ab	77.7b	81.7a	238.1	79.3e
	Total	393.7	393.0	400.3	1187.0	
	Mean	78.7h	78.6h	80.1h		79.1
Days to maturity	Amiata	114.7**	114.0	116.7	345.4	115.1
	Argentario	114.3	116.7	114.3	345.3	115.1
	Gro 21	115.0	117.7	114.7	347.4	115.8
	Smena	115.0	114.7	121.3	351.0	117.0
	090	114.7	116.3	117.7	348.7	116.2
	Total	573.7	579.4	584.7	1737.8	
	Mean	114.7	115.9	116.9		115.9
Stem diameter (cm)	Amiata	2.58ab	2.65ab	2.67ab	7.90	2.63 ef
	Argentario	2.17b	2.93ab	2.62ab	7.72	2.57f
	Gro 21	2.57ab	3.22a	2.50ab	8.29	2.76ef
	Smena	3.00ab	2.87ab	3.30a	9.17	3.06e
	090	2.67ab	2.93ab	2.63ab	8.23	2.74ef
	Total	12.99	14.60	13.72	41.31	
	Mean	2.60i	2.92i	2.74i		2.75
Stem height (cm)	Amiata	145.7a	148.5a	147.0a	441.2	147.1e
	Argentario	150.3a	145.0a	143.3a	438.6	146.2e
	Gro 21	142.3a	119.3b	137.7ab	399.3	133.1f
	Smena	151.7a	135.7ab	156.9a	444.3	148.1e
	090	149.3a	138.1ab	147.7a	435.1	145.0ef
	Total	739	686.6	732.6	2158.5	
	Mean	147.9i	137.3j	146.5ij		143.9

Appendix 7 (Contd..)

Character	Lines	Testers				
		026	Shaba	Fedha	Total	Mean
Head diameter (cm)	Amiata	17.0a	15.1a	14.1a	46.2	15.4d
	Argentario	14.9a	16.5a	15.9a	47.3	15.8d
	Gro 21	14.1a	15.9a	14.4a	44.4	14.8d
	Smena	16.0a	15.9a	15.9a	47.8	15.9d
	090	13.7a	15.4a	14.7a	43.8	14.6d
	Total	75.7	78.8	75.00	229.5	
	Mean	15.1g	15.8g	15.0g		15.3
Diameter of the sterile (cm)	Amiata	2.00	1.30	1.83	5.13	1.71
	Argentario	4.00	2.47	1.80	8.27	2.76
	Gro 21	3.57	2.03	1.50	7.1	2.37
	Smena	1.67	1.63	2.27	5.57	1.86
	090	2.67	2.98	1.77	7.42	2.47
	Total	13.91	10.41	9.17	33.49	
	Mean	2.78	2.08	1.83		2.23
Number of empty seeds	Amiata	7.6cb	8.2cb	7.1cb	22.9	7.6g
	Argentario	7.7cb	6.8cb	13.0cb	27.5	9.2g
	Gro 21	8.3cb	12.1cb	17.2b	37.6	12.5fg
	Smena	4.0c	11.4cb	15.5cb	30.9	10.3g
	090	30.8a	10.1cb	13.2cb	54.1	18.0f
	Total	58.4	48.6	66.0	173	
	Mean	11.7j	9.7j	13.2j		11.5
100 seed weight (g)	Amiata	4.83ab	5.73ab	4.43b	14.99	5.00f
	Argentario	6.07ab	5.63ab	6.13ab	17.83	5.94ef
	Gro 21	7.07ab	7.33ab	7.63a	22.03	7.34e
	Smena	5.80ab	5.80ab	4.80ab	16.40	5.47f
	090	4.30b	6.17ab	5.30ab	15.77	5.26f
	Total	28.07	30.66	28.29	87.02	
	Mean	5.61i	6.13i	5.66i		5.80

Appendix 7 (Contd..)

Character	Lines	Testers				
		026	Shaba	Fedha	Total	Mean
Seed yield per head (g)	Amiata	33.5	53.6	35.7	122.8	40.9
	Argentario	44.8	32.8	54.2	131.8	43.9
	Gro 21	35.9	50.5	40.6	127.0	42.3
	Smena	31.4	68.4	33.9	133.7	44.6
	090	19.0	30.6	30.9	80.5	26.8
	Total	164.6	235.9	195.3	595.8	
	Mean	32.9	47.2	39.1		39.7
Husk percentage	Amiata	36.7	24.0	45.1	105.8	35.3
	Argentario	30.3	24.5	27.1	81.9	27.3
	Gro 21	23.6	28.3	30.5	82.4	27.5
	Smena	25.1	25.3	40.7	91.1	30.4
	090	28.6	27.0	36.6	92.2	30.7
	Total	144.3	129.1	180.0	453.4	
	Mean	28.9	25.8	36.0		30.2

* Values followed by the same letter within a letter series are not significantly different at the 5% level according to the Duncan's multiple range test.

** Values not followed by a letter are not significantly different according to the F-test.

Data on number of empty seeds transformed; $x = (x + 1)^{\frac{1}{2}}$.

Appendix 8 (Contd..)

Character	Source	d.f.	S.S.	M.S.	F
Number of empty seeds	Treatments	22	42672.8	1939.7	2.6**
	Blocks	2	1336.0	668.0	0.9
	Error	44	32698.0	743.1	
	Total	68	76706.8		
100-seed weight	Treatments	22	29.032	1.32	5.6**
	Blocks	2	0.028	0.014	0.1
	Error	44	10.428	0.237	
	Total	68	39.489		
Seed yield per head	Treatments	22	18364.6	834.75	5.9**
	Blocks	2	698.96	349.48	2.5
	Error	44	6218.6	141.33	
	Total	68	25282.2		
Husk percentage	Treatments	22	224.16	10.19	3.2**
	Blocks	2	1.3015	0.6507	0.2
	Error	44	139.3	3.166	
	Total	68	364.78		

*, ** Significnat at 5% and 1% level of probability respectively.

Appendix 9. Analysis of variance for the randomized complete block design for seed yield, its components and maturity traits at Katumani.

Character	Source	d.f.	S.S.	M.S.	F
Number of days to flowering	Treatments	22	605.0	27.5	4.5**
	Blocks	2	2.356	1.178	0.2
	Error	44	266.7	6.061	
	Total	68	874.032		
Number of days to maturity	Treatments	22	1288.60	58.571	7.1**
	Blocks	2	43.69	21.845	2.7
	Error	44	362.62	8.241	
	Total	68	1694.88		
Stem diameter	Treatments	22	1.6731	0.0760	1.7
	Blocks	2	0.0784	0.0392	0.9
	Error	44	1.9709	0.0448	
	Total	68	3.7224		
Stem height	Treatments	22	3616.1	164.37	1.2
	Blocks	2	657.61	328.8	2.4
	Error	44	6081.6	138.22	
	Total	68	10355.3		
Head diameter	Treatments	22	201.30	9.150	4.2**
	Blocks	2	10.125	5.063	2.3
	Error	44	95.114	2.162	
	Total	68	306.535		
Diameter of the sterile centre	Treatments	22	7.0179	0.319	1.0
	Blocks	2	1.2016	0.6008	1.8
	Error	44	14.772	0.3357	
	Total	68	22.9913		

Appendix 9 (Contd..)

Character	Source	d.f.	S.S.	M.S.	F
Number of empty seeds	Treatments	22	566.23	25.738	0.6
	Blocks	2	95.163	47.582	1.1
	Error	44	1842.5	41.874	
	Total	68	2503.86		
100 seed weight	Treatments	22	9.6997	0.4409	2.3**
	Blocks	2	4.2567	2.1284	11.1**
	Error	44	8.4276	0.1915	
	Total	68	22.384		
Seed yield per head	Treatments	22	16618.0	755.37	3.9**
	Blocks	2	1941.1	970.53	5.0
	Error	44	8601	195.48	
	Total	68	27160.1		
Husk percentage	Treatments	22	156.89	7.1313	1.75
	Blocks	2	19.897	9.9487	2.5
	Error	44	178.34	4.0532	
	Total	68	355.128		

*, ** Significant at 5% and 1% level of probability respectively.

Appendix 10. Analysis of variance for the randomized complete block design for seed yield, its components and maturity traits at Njoro.

Character	Source	d.f.	S.S.	M.S.	F
Number of days to flowering	Treatments	22	214.38	9.7445	2.7**
	Blocks	2	4.9829	2.4914	0.7
	Error	44	158.96	3.6127	
	Total	68	378.319		
Number of days to maturity	Treatments	22	206.35	9.3797	1.2
	Blocks	2	44.071	22.035	2.9
	Error	44	331.29	7.5293	
	Total	68	581.712		
Stem diameter	Treatments	22	12.196	0.5544	2.9**
	Blocks	2	0.0525	0.0262	0.1
	Error	44	8.3342	0.1894	
	Total	68	20.5825		
Stem height	Treatments	22	9957.5	452.61	2.8**
	Blocks	2	372.2	186.1	1.2
	Error	44	7079.4	160.89	
	Total	68	17409.0		
Head diameter	Treatments	22	329.08	14.958	3.8**
	Blocks	2	8.0891	4.0445	1.0
	Error	44	173.23	3.9371	
	Total	68	510.405		
Diameter of the sterile centre	Treatments	22	40.108	1.8231	1.4
	Blocks	2	6.6302	3.3151	2.5
	Error	44	58.065	1.3197	
	Total	68	104.803		

Appendix 10 (Contd...)

Character	Source	d.f.	S.S.	M.S.	F
Number of empty	Treatments	22	3171.823	144.174	3.6**
	Blocks	2	30.865	15.433	0.4
	Error	44	1749.167	39.754	
	Total	68	4951.855		Njoro
100-seed weight	Treatments	22	117.15	5.325	2.1*
	Blocks	2	14.436	7.218	2.9
	Error	44	110.19	2.504	
	Total	68	241.773		
Seed yield per head	Treatments	22	9987.6	453.98	1.3
	Blocks	2	812.69	406.35	1.2
	Error	44	14923.0	339.15	
	Total	68	25723.0		
Husk percentage	Treatments	22	2686.2	122.1	1.2
	Blocks	2	267.7	133.8	1.4
	Error	44	4189.0	95.2	
	Total	68	7142.9		

*, ** Significant at 5% and 1% level of probability respectively.