COMBINING ABILITY AND HETEROSIS FOR YIELD AND YIELD COMPONENTS IN PEAS (*Pisum sativum* L.)

BY

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DECLARATION

I declare that this thesis is my original work and has not been submitted for a degree in any other University.

Date. 12.5.92 .... J.N. Njenga. ....

This thesis has been submitted for examination with my approval as a University Supervisor.

Date. June 8, 1992 ... Dr. P.M. Kimani. ....

DEDICATION

To my loving parents Njenga and Wanjiku.

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ABSTRACT

Pea production in Kenya is relatively low mainly due to diseases, pests and use of unimproved cultivars. Pea is an important and cheaper source of protein for majority of the population. This study was designed to determine the relationship between seed yield and its components and the nature of gene action and heterosis for yield, yield components and other plant traits in some of the pea cultivars grown in Kenya.

Seven cultivars of peas (Pisum sativum L.) were crossed in a half-diallel crossing system and the parents together with their F_1 hybrids evaluated for seed yield per hectare, 100-seed weight, seeds per pod, number of pods per plant, pod length, number of primary branches per plant, plant height and days to flowering at Kabete and Kinangop during the long rain season of 1989. The experimental design used was a randomised complete block design with 3 replications at each location. General and specific combining abilities were determined by Griffing's (1956a) Method 2, Model 1.

The genotypes were found to differ significantly ($P = 0.001$) for all characters studied at both locations. Seed yield per hectare was found to be positively correlated with all the other characters studied. However, it was only significantly correlated with seeds per pod, pods per plant, branches per plant and plant height. These yield components can be utilised in the selection for yield improvement.

Yield heterosis of the F_1 based on the midparent value averaged 65% over locations. Among the parental cultivars, Nyaritho was the best combiner for seed yield per plant, pods per plant, branches per plant, plant height and days to flowering while Carouby was the best combiner for 100-seed weight, seeds per pod and pod length. None of the hybrids flowered earlier than the early parent at both locations. Scout was found to impart earliness to its progeny.

Both general and specific combining abilities were responsible for the manifestation of variability for all the traits studied except pod length, seeds/pod and 100-seed weight where specific combining ability was of no importance. However general combining ability was more important than specific combining ability for all the traits. All the characters were found to be strongly influenced by the environment.

1. INTRODUCTION

The garden pea (Pisum sativum L.) is one of the edible legumes or pulse crops. It belongs to the sub-family Papilionaceae. One of the sub-divisions of this family, Viciae, includes the genus Pisum. Within the genus Pisum, two species have been distinguished, P. arvense, the field pea, and P. sativum, the garden pea.
Its exact origin and progenitor is unknown, but is one of the oldest cultivated plants and was grown in the neolithic farming villages of the Near East at least as early as 7000-6000 B.C. (Zohary and Hopf, 1973). Blixt (1970) as quoted by Gritton (1980) states that the Mediterranean is the principal centre of diversity, with secondary centres in Ethiopia and Near East.

While peas are grown in diverse environments, they are best suited to cool, moist climate. Worldwide, peas are an important food crop being consumed both in the green succulent state and as dry edible seeds. The potential role of legumes as a source of proteins to improve human nutrition has long been recognised. Food legumes have on average twice as much proteins as cereals and various species are consumed all over the world.

The consumption of grain legumes ranges from insignificant amounts in Europe and North America to fairly large quantities in Asia, South America and Africa. In several countries in East and Central Africa, food legumes, mainly beans and peas, are a daily component of the diet. It has, for instance, been estimated that the average daily consumption of legumes in East Africa ranges from about 65g in Kenya to nearly 75g in Uganda (Protein Advisory Group Statement, 1983).

In Kenya and other developing countries where the incomes of the majority of the population is relatively low, most of the people depend on plant protein due to the high cost of the animal protein. The food legumes provide most of this protein.

One of the most important legumes in Kenya is the garden pea. Pea seeds are higher in protein content than most cereals and are exceeded by few edible legumes. Furedi (1970) found that pea seeds were composed of about 90% cotyledons, 9% testa and 1% embryo which contained 22, 5 and 31% crude protein respectively. In addition where they are incorporated at relatively high levels in diets, legumes also contribute substantially to the energy, mineral and vitamin requirements of the body. Peas, can be used as a cooked vegetable or in soup. They may be dehydrated, canned or freezed. However, inspite of all this, there is minimal research if any on the crop in Kenya.

Genetic improvement of any crop involves evaluation and hybridization of genotypes and selection of superior types. Recently much interest has developed in producing and growing F_1 hybrids of several normally self- pollinated species where a considerable amount of heterosis has been demonstrated. However, few studies dealing with heterosis, inbreeding depression or quantitative aspects of inheritance in peas are known though Keeble and Pellew (1910) reported heterosis for plant height in peas.

To develop the best F_1 hybrid, there is need to combine those parents which are the best combiners. The worth of a parent in a cross will depend on its ability to produce superior hybrids when crossed with others. The measure of this ability is called the combining ability and forms part of the present investigations.

Knowledge of heterosis and nature of gene action in any material one is working with forms an important criterion in selecting parents in a breeding programme. Little if any has been done to determine combining ability and heterosis in Kenyan peas despite the fact that peas have been grown for a long time for domestic and export markets. Hardly has any objective selection been done to improve peas in Kenya. Thus the objectives of this study were:-

1. To determine whether there is any useful association between yield and other plant traits that could be used as selection criteria.

2. To obtain estimates of specific and general combining abilities for a number of important traits in Kenyan peas and

3. To estimate the amount of heterosis for these traits.

2. LITERATURE REVIEW

2.1 Correlations.

Yield is a complex character determined by several components. In an attempt to facilitate breeding for high yield, it is logical to examine the various components and give more attention to those having the greatest influence on yield (Kambal, 1969). In peas the main yield components are pods per plant, seeds per pod, pod length, 100-seed weight and number of primary branches per plant.

Correlation studies are of interest to a breeder because they indicate the relative ease with which the different characters can be selected together (Kambal, 1969). The knowledge of correlations among variables such as yield, its components and other plant characters is useful for designing a breeding programme for any crop (Dahiya *et al*., 1977). To give the best results, correlation studies should be carried out under different environments such as years and locations (Pandey and Gritton, 1975).

2.1.1 Correlations between seed yield and its Components in peas (*Pisum sativum* L.).

The importance of relationship of yield to its various components in peas was realised quite early and various correlations have been reported by different workers. However some workers have reported conflicting results for the same character. Singh and Singh (1969) observed that grain yield was significantly correlated with branches per plant, seeds per pod, pods per plant and 100-seed weight. Increase in yield seemed to be influenced by branches per plant and pods per plant (Singh and Singh, 1970).

Pandey and Gritton (1975) reported that the genotypic correlation between weight per seed and yield was high. Positive correlations were also found between yield and pods per penduncle, pods per plant, pod length and seed size (Tikka and Assawa, 1977). However the yield was most influenced by seed size.

Rodin and Konovalov (1975) observed the highest positive correlation with seed yield to be shown by the number of fertile nodes per plant followed by number of seeds per pod, number of pods per fertile node and 1000-seed weight.

Plant height and the height of the first fertile node were found to be negatively correlated with seed yield by Ranalli _et al_ (1981). The number of pods per plant and seed size were the most important characters. Number of pods per plant was directly associated with final yield and accounted for about half of the yield variability. Its indirect action through both seeds per pod and seed size was negative. Seeds per pod had a negligible effect on final yield. However Dahiya _et al_ (1977) reported a significant and positive correlation between yield and plant height, number of pods per plant and 100-seed weight.

Malik and Hafeez (1977) showed that seed yield per plant was correlated with the mean number of pods per plant (r = 0.976) and the mean number of seeds per plant (0.982). In an analysis of yield components in plants undergoing varietal trials, Vereshchaka et al (1976) observed that the highest correlation was between seed yield and number of pods per plant (r = 0.5 - 0.87).

Chowdhury et al (1969) also found yield to be positively correlated with the number of pods per plant, number of seeds per pod and 100-seed weight while Sachan and Singh (1973) found significant and positive correlation between seed yield and number of leaves, pods and seeds per plant, pod length and 100-seed weight. Multiple correlation coefficients showed that the greatest contributors to yield are seeds per plant followed by number of pods per plant and 100-seed weight.

In a diallel analysis, Bodian (1976) found weak and nonsignificant correlations between seed yield and pod length, pod breadth, number and weight of seeds per pod in the parental varieties but the correlations rose becoming highly significant in the F_1 and F_2.

Savkin(1986) reported correlations between yield and its components to vary between years and between varieties. He reported that yield was most consistently correlated with the number of seeds per plant and pods per plant.

Studies have also been carried out to establish which of the yield components have the greatest positive direct effect on yield. However even here different workers have reported conflicting results. Wakankar et al (1974) and Singh et al (1985) observed that the number of pods and 100-seed weight had the greatest positive direct effect on yield. They therefore concluded that emphasis should be placed on these two traits during selection. Chandel and Joshi (1976) reported similar results but included seeds per pod among the components.

Singh and Santoshi (1986) reported number of seeds per plant and seed weight to be the most important components while Asfandiyarova (1983) reported stem length and number of pods per plant to be most important. The selection for seed number did not appear to be a suitable approach in breeding for yield. Number of pods per plant and number of primary branches per plant had the highest positive direct effect on yield according to Kalloo and Dhankar (1977). Their indirect contributions towards yield were also found to be high.

2.1.2 Correlations Among Yield Components in Peas.

The yield components could be most effective in breeding for yield if they were positively correlated both phenotypically and physiologically with each other, or at least unrelated. Unfortunately some of the components have been found to be negatively correlated. Negative relationships indicate that selection for improvement in one of the components would result to a concomitant decrease in one or more of the other components.

Narsinghani et al (1978a) and Singh et al (1985) found the yield components to be positively correlated with each other with the exception of 100-seed weight. However, Krarup and Davis (1970) had earlier failed to detect any correlation among yield components in peas but observed significant and positive correlations between the components and yield.

Savkin (1986) found the most stable correlations to be those between height of insertion of the lowest pod and stem length and between pods per plant and number of seeds per plant. Bodian (1976) reported high correlations between pod length, number and weight of seeds per pod in parental varieties in diallel analysis studies. However in the F_1 and F_2 the characters showed slightly lower but highly significant correlations among themselves.

Plant height has been reported to be positively correlated with pods per plant and seeds per plant (Pandey and Gritton, 1975). Strong positive genotypic and phenotypic correlations were obtained between pods per plant and seeds per plant and also between seeds per pod and seeds per plant indicating that selection for either or both of these traits would result in superior yield. Cervato et al (1977) also found height to be positively associated with the yield components. They observed that late maturing genotypes were also the tallest. Contrary to this, Malik and Hafeez (1977) observed that height was not significantly correlated with any of the other yield components.

A negative correlation was found between 1000-seed weight and most of the other yield components (Malik and Hafeez, 1977; Makasheva and Varlakhov, 1978). However Vereshchaka et al (1976) found 1000-seed weight to be negatively correlated with only seed number per pod while Rodin (1971) observed a very small correlation between seed weight per plant and 1000-seed weight and found an inverse correlation between number of seeds per plant and 1000-seed weight.

Wakankar et al (1974) reported pod number pér plant and 100-seed weight to be positively but nonsignificantly correlated with pod length and seed number per pod. The number of seeds per pod and number of pods per node were found to be negatively correlated by Simakov and Balko (1981). Among the yield components they studied, 1000-seed weight, number of seeds per pod and number of pods per fertile node showed the least variation. The highest yielding forms had an optimum combination of seed number per plant and 1000-seed weight. Singh and Singh (1969) observed significant positive correlations between days to flower and days to maturity, between pod length and seeds per pod and between pod length and 1000-seed weight. There were significant negative associations between 1000-seed weight and seeds per pod, between 1000-seed weight and pods per plant and between branches per plant and pod length.

Rodin (1971) reported weak correlations between seed weight per plant and number of seeds per pod. He also reported that seed weight per plant was most closely correlated with number of seeds per plant. Similar results were reported by Makasheva and Varlakhov (1978) with seed weight per plant and seeds per pod.

2.1.3 Correlations Between Yield and Maturity Traits

Knowledge on correlations between yield and maturity is important in an attempt to select for increased yield per unit time. This will indicate if earliness results in sacrifice for yield. Ranalli (1981) showed that the number of days to flowering was significantly correlated with most of the other characters including yield while Chandel and Joshi (1976) reported that the number of days to flowering had a negative direct effect on yield.

A study of 65 lines by Narsinghani _et al_ (1978b) revealed that the number of seeds per plant followed by 100-seed weight, number of days to maturity and height had the most direct effects on yield. The number of days to flowering and number of branches per plant had negative direct effects on yield. Most characters had indirect effect via number of seeds per plant. Singh and Singh (1985) observed that pods per plant, days to flowering and seeds per pod had a direct effect on yield in some crosses while days to maturity, pods per plant and specific leaf weight directly affected yield in other crosses. Another study by Narsinghani et al (1978a) showed that seed yield per plant was positively correlated with number of days to flowering, maturity period, height, number of branches, number of pods per plant and number of seeds per plant.

2.2 Diallel analysis and the concept of combining ability.

The planning of any breeding programme largely depends upon the knowledge of the nature and magnitude of genetic and non-heritable variation of the crop. Of the many methods developed for this purpose, the diallel analysis has been used extensively because it gives information on the genetic make-up of the characters as early as in the F_1 generation.

A set of crosses produced by involving a number of lines or parents in all possible combinations is designated as diallel cross and the analysis of such crosses is known as diallel analysis. Such an analysis provides information on:

(1) Nature and magnitude of genetic parameters.

(2) General and specific combining abilities of parents and their crosses respectively.

A comparison of four diallel crossing methods for determining combining ability showed that any of the incomplete diallel methods can be used for evaluating a population but, if it is necessary to evaluate each parental form individually, then the method involving direct hybrids and parental forms (without reciprocals) is the best (Agarkova et al, 1980).

The concept of combining ability is becoming increasingly important in plant breeding. It is especially useful in connection with testing procedures, in which it is desired to study and compare the performance of lines in hybrid combinations. Ability of a parent to combine well to produce promising segregating generations is an important criterion in selecting parents for a successful hybridization programme. Jenkins and Brunsen (1932) advocated the use of an open pollinated variety as a tester for preliminary evaluation of lines. Sprague (1939) used topcross method to estimate the combining ability of inbreds.

The terms general and specific combining abilities were originally defined by Sprague and Tatum (1942). The term general combining ability (gca) is used to designate the average performance of a line in a number of hybrid combinations. The term specific combining ability (sca) is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved.

When a diallel crossing system is used in genetic studies the additive and non-additive components of the parent genotypic variance are estimated by the use of general and specific combining abilities components respectively. The relationship between these two sets of parameters was proposed and discussed by Matzinger and Kempthorne (1956), Griffing (1956a) and Kempthorne and Curnow (1961). According to them the population phenoytpic variance is partitioned into various genotypic and environmental components.

Thus, $\sigma^2 P = \sigma^2 G + \sigma^2 E$

But $\sigma^2 G = \sigma^2 A + \sigma^2 NA$

Therefore $\sigma^2 P = \sigma^2 A + \sigma^2 NA + \sigma^2 E$

Where

$\sigma^2 P$ = Population phenoytpic variance

$\sigma^2 G$ = Population genotypic variance

$\sigma^2 A$ = Additive gene variance.

$\sigma^2 NA$ = Non-additive gene variance.

$\sigma^2 E$ = Environmental effect variance estimated by error variance.

Non-additive gene variance can further be divided into dominance and epistatic variances. The relationship between the components of phenotypic variances and combining ability variances was defined such that the population genotypic variance can be partitioned in terms of combining ability variances. Their experiments revealed that, genetically, general combining ability is primarily due to the additive gene action and specific combining ability is due to the non-additive (intra-allelic and/or inter-allelic interactions, dominance or epistasis) effects of genes.

Griffing (1956b) proposed the statistical concept of general and specific combining abilities in homozygous as well as heterozygous base populations. Conflicting results have been reported with regard to the roles of general and specific combining abilities in different materials. Jinks (1955) working with maize, cotton and tobacco concluded that in the unselected materials specific combining ability is mainly a measure of dominance and is of greater importance whereas in the case of selected materials specific combining ability was a measure of epistasis.

The variance of components for the interactions involving specific combining ability and locations and years were consistently larger than the corresponding estimates involving general combining ability. This suggests that the variance of specific combining ability includes not only the non-additive deviations due to dominance and epistasis but also considerable portion of the genotype and environmental interaction (Rojas and Sprague, 1952).

Genetic intrerpretation of data from the diallel experiments is only valid if certain assumptions about the parental materials are true. These assumptions as proposed by Hayman (1954), Kempthorne (1956), Kempthorne and Curnow (1961) and Sokol and Baker (1977) are:

(1) normal diploid segregation.

(2) no maternal effects i.e. no difference between reciprocal crosses. This is the assumption for partial diallel cross (Kempthorne and Curnow, 1961). According to this assumption the reciprocal crosses are identical and so there is no need of making crosses both ways.

(3) The parents are homozygous. This is a valid assumptions for the case of self-pollinating crops, and unless the parents are highly inbred it may not hold for cross-pollinated crops.

(4) The genes are independently distributed among parents.

(5) No non-allelic interaction (Hayman, 1954).

(6) No multiple allelism (Hayman, 1954).

Some of the above assumptions can be more easily accepted than others. The assumption of diploid segregation is made because most of the knowledge concerning gene action is with reference to diploid species. However certain polyploids behave as diploids during segregation thus fulfilling this requirement (Sokol and Baker, 1977). As already mentioned, for self-pollinated crops the assumption of homozygous parents is assured. The assumption of genes being independently distributed among parents is required to simplify the composition of estimates so that they can be interpreted genetically (Sokol and Baker, 1977). This assumption will be assured only if parents of the diallel cross constitute a random sample of inbred lines from a population developed by random mating. Assumption of no non-allelic interaction (no epistasis) is biologically unrealistic. Kempthorne (1956) introduced arbitrary epistasis for the diallel analysis. Gilbert (1958) also noted that until experimentally shown otherwise, the absence of epistasis cannot be assumed when dealing with quantitative traits. The assumption of no multiple allelism was also criticised by Kempthorne (1956) who introduced the assumption of arbitrary number of loci and arbitrary alleles.

From the above discussions, there is no doubt about the usefulness of diallel analysis in plant breeding programmes and hence it was used in this study as a tool to investigate the genetics of inheritance of the quantitative traits in the Kenyan peas.

2.3 The Systems of Genetic Control for Yield and its Components in Peas.

2.3.1 Combining Ability for Yield and its Components.

In any crop plant it is essential to know as much as possible about the genetic systems which control the growth of the plant and particularly those which regulate the most obvious components of yield and other traits of economic importance. Information about these quantitative characters can be obtained by analysing sets of diallel crosses which involves crossing selected cultivars in all possible combinations. However conflicting results for the same character have been reported by some workers.

Singh _et al_ (1985) and Singh _et al_ (1986) reported that both additive and non-additive gene effects were significant for plant height, pods per plant, seeds per pod and seed yield per plant. Singh _et al_ (1985) observed significant additive and non-additive gene effects for yield and other yield-related traits but the additive component was more important. Similar observations were made by Saxena _et al_ (1987) but they found non-additive action to predominate for plant height, number of nodes per plant ,and pod breadth.

In a similar study by Singh and Singh (1970) a preponderance of additive gene action coupled with non-additive action was revealed for almost all quantitative traits the relative magnitude of the action varying with the trait. Three or four groups of genes exhibited dominance for pod number per plant and number of primary branches in the F_1 and one or two groups of genes exhibited dominance for plant height and 100-seed weight in the F_1 and F_2.

Krarup and Davis (1970) reported that the yield characters were primarily controlled by an additive genetic system. However, there was some deviation of the F_1 from the mid-parent more likely due to epistasis or linkage than due to dominance. Specific combining ability was important for all components while general combining ability was only important for seeds per pod and average weight.

Kumar and Agrawal (1981) observed that seed yield per plant and height were principally controlled by non-additive gene action while the number of pods per plant, number of seeds per pod and 25-seed weight were predominantly controlled by additive gene action. For each character, the rank of a variety was generally similar to the rank of its general combining ability. A similar correspondence between varietal ranking and the ranking of varietal specific combining abilities occured for all characters except for 25-seed weight and height. Additive effect was found to be comparatively low for yield by Koranne and Singh (1974) and that the non-additive interaction effects had significant role in its control. Non-significant F-values for yield per plant and pods per plant suggested equal distribution of recessive and dominant alleles, whereas for the remaining characters, dorminant alleles were more than the recessive ones.

Both general and specific combining abilities were found to be significant for yield, seeds per plant and 100-seed weight by Singh et al (1985). The best cross involved one parent with good and the other with poor general combining ability. Das and Kumar (1975) reported that though variances due to both general and specific combining abilities were significant, general combining ability variance predominated for all other characters except for seed yield per plant for which specific combining ability variance was higher. Similar results were reported by Dahiya et al (1977) and Singh and Singh (1985).

The significance of both general and specific combining ability variances for most of the important yield components was also observed by Brahmappa and Singh (1977). Singh and Singh (1987) made the same observations but in their studies found that the additive gene action was more important for all traits. Cervato et al (1977) and Csizmadia (1985) reported higher general combining ability variance than specific combining ability variance although both effects were significant. Parents with high general combining ability were generally above average in phenotypic performance, but specific combining ability effects were generally not proportional to the F_1 performance.

Kumar and Das(1975) reported highly significant general and specific combining ability effects for seeds per pod and pod length. Variances due to general combining ability were significantly higher than those due to specific combining ability indicating additive and epistatic intragenic and intergenic relationships and the predominance of additive or non-additive gene effects.

Graphic analysis of yield and its components by Sharma et al (1977) revealed an overdominance effect of alleles determining height, yield and pod number per plant. Similar results for pod number and yield were reported by Gad and El-Sawah (1985) who also observed complete dominance for 100-seed weight and large additive effects for seeds per pod. Zlarmal (1975) reported superdominance for yield and pod number per plant and complete dominance for seeds per pod and 100-seed weight. Asfandiyarova (1979) also reported overdominance for most of the yield traits and observed complementary epistasis for number of sterile nodes and pod number per plant in the F_1. Dominance effects were highly significant for 100- seed weight, seeds per pod, pod length and vine length (Bhullar et al , 1975). The same results were reported by Singh et al (1977) for pod width and seeds per pod, Singh and Singh (1979) for seeds per pod and by Rattan et al (1976) for seeds per pod and pod length who also found that the number of seeds per pod was controlled by more than two genes and pod length by more than twelve genes.

Epistasis, overdominance and additive effects were evident for yield and pod number per plant according to Nandpuri et al (1973). The interaction effects were more important than the additive effects. High yield and heavy bearing were controlled by dominant alleles. Singh et al (1986) also found dominance components to be predominant for number of seeds per plant and seed yield and additive for 100-seed weight. Srivastava et al (1986) observed only partial dominance for yield per plant. Johnson (1957) as quoted by Gritton (1975) studied the inheritance of thirteen quantitative characters in three pea crosses. Parentals, F_1 and F_2 populations were evaluated and results indicated that genes for low yield, small number of peas per pod, low number of pods per plant and low seed weight were partially dominant.

A number of combining ability studies have also been carried out over different environments to study the extent of genotype x environment interaction. Studies by Syreva (1980), Gupta and Lodhi (1985) and Gupta et al (1986) revealed that both general and specific combining abilities were influenced by environment indicating that in order to obtain unbiased estimates of combining ability, experiments should be performed over a wide range of environments.

One phenomenon common in the results of all the above workers is that both additive and non-additive gene effects are important in the determination of yield and its components in peas and that there is very little evidence of transgressive segregation.

2.3.2 Combining Ability for Maturity Characters.

There is constant demand and endeavour to breed earlier cultivars as well as to provide high quality late maturing cultivars of predictable flowering time. Since flowering time is related to the time of pod maturity, genetic investigations into the inheritance of flowering are basic to the production of required cultivars. The first of these investigations to be attempted in peas was by Rowlands (1964) who crossed seven commercial varieties in a diallel in order to investigate the genetic control of flowering both under natural conditions and in controlled environments using F_1 and F_2 material. He indicated that flowering was largely under the control of a polygenic system in which lateness was dominant to earliness and gene effects were additive but no transgressive segregation was found.

Two further sets of diallel crosses in peas were published by Watts et al (1970) and Krarup and Davis (1970). Watts et al (1970) were particularly concerned with the influence of top yellows virus infection upon time of flowering. They found the presence of both general and specific combining abilities in approximately the same proportions while the general combining ability and its variance showed the same relative order to the cultivars.

However, high general combining ability variance for one cultivar was accompanied by a low specific combining ability variance indicating that the date of first flowering was transmitted uniformly to all F_1's except where interaction occured with other cultivars with high specific combining ability. Some cultivars showed high specific combining ability variances, thus illustrating a tendency to interact unpredictably in certain combinations. In a self-fertilising crop such as peas this must be accompanied by transgressive segregation to be of real value for the production of new cultivars. The evidence of slightly increased earliness in some F_2 progenies does offer hope of producing cultivars maturing earlier than those at present available, although a limit can be reached when earliness alone has insufficient economic justification.

Snoad and Arthur (1973) in a study of quantitative characters also showed that the control of flowering in peas is due entirely to a simple, additive genetic system and that dominance and overall dominance (unidirectional dominance, assymetrical gene effect and non-ascribable dominance) are of no importance. They also investigated the genetic control of the node of first flower, mean internode length, number of flowers per node and number of ovules per pod. They reported that these characters were under polygenic control, and that mean internode length was influenced by a major gene. They therefore concluded that, on the basis of the seven parents used in their study, the proper breeding approach is thus the development of pure lines.

Pandey and Gritton (1975) reported significant general and specific combining ability variances for days to bloom. Singh <u>et al</u> (1977) made the same observations but found specific combining ability variances to be higher than general combining ability variances. Studies by Kumar and Das (1975) revealed that days to flowering and maturity were under the control of additive gene action although substantial dominant effect was also found for maturity. Saxena <u>et al</u> (1987) reported the same results for days to maturity while Dabias (1974) and Rattan <u>et al</u> (1976) reported the same for days to flowering although a slight level of dominance was observed. Sharma <u>et al</u> (1977) showed that a partial dominance effect of alleles determined days to flowering.

Singh and Singh (1970) found that one or two groups of genes exhibited dominance for the number of days to flowering in the F_1 and F_2 material. Likewise, Johnson (1957) reported that flowering time was probably determined by one or two major genes plus partially dominant modifiers for late flowering.

2.4 Heterosis

Heterosis is the increased or decreased vigour of F_1 over its better parent or midparent value. It is not fixable from generation to generation as the heterozygote advantage is confined to F_1 population only. In cultivated crop plants, this phenomenon has adequately been reported in crops such as maize, sorghum, pearl millet, onion, tomato, wheat, sunflower, peas and many others.

Tyagi et al (1975) demonstrated that crosses involving both good combining parents as well as crosses involving one good and one poor combining parent had high specific combining ability as well as high heterosis.

It is a general observation that genetic diversity plays a major role in the expression of heterosis. Wu (1939), Hayes and Johnson (1939) presented conclusive evidence that genetic diversity plays an important role in expression of heterosis.

Shull (1948) while discussing heterosis observed that physiological vigour of an organism as manifested in rapid growth, height and robustness is positively correlated with the degre of dissimilarities in the gametes by which union the organism was formed.

Ballosteros (1956) studied the effect of genetic diversity on the expression of heterosis in maize. He reported that the crosses between the inbreds of highest genetic diversity in general, gave significantly higher yield than those crosses involving lines from the same parentage or of close origin.

The phenomenon of heterosis and its utility have not yet been fully explored in grain legumes although preliminary information is available. Solomon et al (1957) reported hybrid vigour upto the extent of 24.5% for grain yield of pigeon pea (Cajanus cajan). However in their study the best yielding hybrid could not outyield the best parent. Bond et al (1964) observed significantly higher yield in case of field bean hybrids when compared with open pollinated varieties. Ramanujam et al (1964) in their studies with gram reported significantly greater yield than the best parent in some crosses. Bhatnagar and Singh (1964) recorded heterosis for yield in mungbean where some of the crosses greatly exceeded the better parent. Singh and Jain (1970) also reported hybrid vigour in F_1 generations over better parents for grain yield and its components in mungbean.

In peas (Pisum sativum L.), heterosis and inbreeding depression in the F_2 were observed for plant height, seed yield and its components (Pandey and Gritton, 1975). Similar results were reported by Singh et al (1975) who observed the greatest values of heterosis over the better parent to be those for yield per plant and number of pods per plant. Significant heterosis was also associated with high values of inbreeding depression in the F_2.

Singh and Singh (1970) crossed six pea varieties of indigenous and exotic origin in all possible combinations and found that three crosses involving one cultivar produced significantly higher yields than the better parent. Heterosis was also recorded for number of primary branches per plant, pods per plant, length of the main branch and days to flowering.

Using ten cultivars Venkateswarlu and Singh (1982) evaluated parents, F_1 and F_2 for yield and yield components and reported that all traits except height showed significant heterosis in F_1 and significant inbreeding depression in F_2. Average seed yield in the F_1 exceeded the mean parental value by 47% and the better parent by 22%.

Positive heterosis for number of pods and number of seeds per plant was found in a large number of F_1 hybrids by Arndt (1980). Srivastava and Sachan (1975) reported heterosis over the better parent for all the yield components but was highest for the number of branches per plant and seed yield per plant. However Bhullar et al (1976) observed that heterosis over the better parent existed only for plant height and 100-seed weight with days to flowering, pod length and number of pods per plant showing heterosis only when compared with the mean parental values only.

Kalaidzhieva and Kalinov (1975) observed negative heterosis for pod weight and seeds per plant, the lower weight being dominant, but intermediate inheritance for

1000-seed weight and number of pods per plant. For number and weight of seeds, inheritance was intermediate, though negative heterosis occured if the parents differed markedly in these characters. Among a number of hybrids studied by Vetrova (1977), stable heterosis for pods per plant, number of seeds per pod, number of seeds per plant and for yield per plant was found.

Ram et al (1986) reported that pods per plant, pod length and seeds per pod were the major contributors to heterotic yield increase. Ranking of crosses on the basis of heterosis did not correspond to ranking on the basis of specific combining ability effects such that crosses having high mean values for seed yield and its components did not show high specific combining ability effects. This suggests that selection should be based on heterosis.

Srivastava and Sachan (1975) observed heterosis over midparent and better parent for branches per plant, pods per plant, length of pod, seeds per pod and yield per plant but negative hybrid vigour was observed for plant height. Little or no heterosis for characters other than yield components suggested that these characters have no direct bearing on the seed yield of pea. Therefore when finding out the causes for higher yield in the F_1's, information on characters other than yield components seems to be of little use. Whitehouse et al (1958) suggested that there cannot be any gene system for yield as yield is an end product of the multiplicative interactions between yield components. Most workers have shown that heterosis is present in almost all yield components and the increase in yield in the F_1 hybrids is just the result of increase in yield components.

3. MATERIALS AND METHODS

3.1 Site Description and Weather Conditions.

The first trial (Experiment I) was conducted at the Field station of the Faculty of Agriculture, University of Nairobi located at an altitude of about 1820 m above sea level. The area receives about 1046 mm of rainfall per annum with mean temperatures of 23.4 °C (max.) and 12.6 °C (min.). The soils have been classified as nitosols. These soils are deep, friable clay type resistant to erosion (Siderius, 1978).

A second trial (Experiment II) was carried out at the Farmers' Training Centre (FTC), Njabini in South Kinangop of Nyandarua District where most of the peas are grown in Kenya. The station is located at an altitude of 2530m above sea level. It receives about 1650mm of rainfall per annum with mean temperatures of 20°C (max.) and 4°C (min.). The soils at this site are the Volcanic Andosols which are characterised by a fine texture, high silt content, high amounts of organic matter, high water storage capacity and good physical characteristics.

The weather conditions during the study period are shown in Appendix 1 and 2 for Kabete and Kinangop respectively.

3.2 Planting materials.

Seven cultivars of garden peas (Pisum sativum L.) varying in yield, maturity and morphological characteristics were crossed in diallel system to form 21 F_1 single crosses excluding reciprocals.

Crossing was carried out under glasshouse conditions between December 1988 and February 1989. The glasshouse was thoroughly wetted to keep humidity high throughout the crossing period. High relative humidity reduces the dessication of flowers after emasculation and is conducive to good seed set (Bliss, 1980).

The parental cultivars were:-

3.2.1 Greenfeast.

A wrinkled-seeded, bush type variety with medium height (60 cm). It is extremely popular for fresh markets. Pods are slightly curved and dark-green.

3.2.2 Thanatu is a short early maturing local variety with green round seeds.

3.2.3 Onward is a bush type, wrinkle-seeded variety and a reliable heavy cropper. The pods are large, dark-green, straight and square-ended, borne mostly in pairs and well filled with medium sized, very sweet peas. It is a popular variety for home gardens and markets as well.

3.2.4 Nyaritho

This is a very popular variety in Kenya and especially around Kinangop area because of its high yields. It cooks very well and can be consumed either green or dry. However, it is a very tall variety (180 cm) and readily lodges.

3.2.5 Scout.

This is an early maturing variety of medium height. The pods are dark green and usually short while seeds are green and wrinkled.

3.2.6 Kagoci.

This variety is not very popular because it has a high sugar content and does not cook well when dry. It is of medium height (85 cm) and has light green wrinkled seeds.

3.2.7 Carouby.

A green-seeded, tall variety which requires staking. It is very popular for home and market gardens.

Thanatu, Kagoci and Nyaritho are some of the local varieties that have been grown in Kenya for many years. They were collected from farmers' fields in South Kinangop, Nyandarua District. The farmers do not buy new seed for planting but use a portion of the seed from the previous harvest. The pea is a self-pollinating crop and thus the varieties could be regarded as pure lines. Johnson (1957) observed that selfing increases homozygosity. In his experiments, the progenies of individual plants remained uniform and when compared with the parent, the average weight and size of the progeny was similar to those of parents and the small variation got in seed size or weight was only due to environmental components. Greenfeast, Onward, Scout and Carouby are maintained by the Kenya Seed Company through pure line selection.

3.3 Experimental Design.

The crosses and their parents were grown at the two locations for one season. The design was a randomised complete block design with three replications.

Each of the 28 entries (7 parents and their 21 single crosses excluding reciprocals) was planted in two 5m plots at a spacing of 50cm x 50cm. A 1m array between plots was maintained. Four guard rows were planted surrounding the experimental materials at both sites.

3.4 Planting and Field Management.

Planting at Kabete was done on March 15, 1989 and on March 31, 1989 at Njabini during the long rains. Diammonium phosphate (18%N, 21-23%P) was applied at 200 kg ha^{-1}. Furadan was applied to the planting furrow at a rate of 2g per metre furrow to control seedling pests like cutworms.

After germination the plants were sprayed with Dithane M45 at the rate of 30g in 20 l of water after every two weeks until the pods started drying to protect them from powdery mildew. Whenever it occured, it was effectively controlled by Bayleton at the rate of 30-40g per 20 l of water. Diazinone at the rate of 30 c.c. in 20 l of water was used to control spider mites and aphids whenever they appeared.

The experimental plots at both sites were kept weed free by hand weeding and for easy management purposes all the plants were staked.

3.5 Data Collection.

Data was recorded on five randomly picked plants in each plot and information recorded for the following characters:-

1. Days to flowering
2. Plant height
3. Number of primary branches per plant
4. Pods per plant
5. Pod length
6. Seeds per pod
7. 100-seed weight
8. Seed yield per hectare.

Except for days to flowering, all other data was collected at the dry seed stage.

3.5.1 Days to Flowering.

This was recorded as the number of days from planting to the date when 50% of the plants in a plot had flowered.

3.5.2 Plant Height.

This was recorded as the length from the base of the plant at the soil level to the tip. Height per plant was calculated as the average height of all the selected plants in a plot.

3.5.3 Number of Primary Branches per Plant.

The total number of primary branches from the five plants were counted to calculate the mean number of primary branches per plant.

3.5.4 Pods per Plant.

The total number of pods from five randomly selected plants in a plot was averaged to give the number of pods per plant.

3.5.5 Pod Length.

The length of a pod was measured from tip to tip. The total length of the pods from the random plants was averaged to give the pod length.

3.5.6 Seeds per Pod.

The total number of peas from five randomly selected plants in a plot was divided by the total number of pods to estimate the number of peas per pod.

3.5.7 100-seed Weight.

A random sample of 100 seeds was weighed to determine 100-seed weight.

3.5.8 Seed Yield per Hectare.

Seed from all the selected plants in a plot was weighed and the total weight averaged to give the seed yield per plant. This was then multiplied by the number of plants in one hectare to give seed yield per hectare.

3.6 Statistical and Genetic Analysis.

3.6.1 Analysis of Variance.

Data from all the entries were subjected to analysis of variance to test the significance of genotypic differences (Singh and Chaudhary, 1977). Data from each location was analysed separately to test homogeneity of variance before a combined ANOVA (Gomez and Gomez, 1976) was performed to determine the magnitude of genotype x environment interaction.

3.6.2 Correlations.

Correlation analysis was done as suggested by Panse and Sukhatme (1964). The sum of products was calculated using the formula :-

$$(x-\bar{x})\ (y-\bar{y}) = 1/N \quad x \quad y$$

where

xy = the sum of products of x and y values which are values for any two variables.

x = total of x values.

y = total of y values.

N = number of observations per variable.

The correlation coefficient (r) was then calculated by the formula:

$$r = \frac{(xi-\bar{x})\ (yi - \bar{y})}{(xi - \bar{x})^2 \ \ (yi - \bar{y})^2}$$

T- values were calculated as

$$t = \frac{r}{[(1-r^2)/(n-2)]^{0.5}}$$

Where

r = correlation coefficient

n = number of pairs involved.

3.6.3 Genetic Analysis.

The characters for which there was significant genotypic differences were subjected to genetic analysis to determine their combining ability and heterosis.

3.6.3.1 Combining Ability Analysis

The combining ability analysis was carried out according to Griffing's (1956a) Method 2, Model I (fixed effect) since the experimental material consisted of parents and only one set of F_1's. The mathematical model for combining ability analysis is:-

$$X_{ij} = \mu + g_i + g_j + S_{ij} + \frac{1}{bc}\sum_k \sum_l e_{ijkl}$$

$i,j = 1,\ldots,P.$

$k = 1,\ldots,b.$

$l = 1,\ldots,c.$

Where

p = genotypes

b = blocks

c = individuals for each of the pb plots.

and

μ = the population mean

$g_i(g_j)$ = gca effect for the i^{th} (j^{th}) parents.

s_{ij} = sca effect such that $s_{ij} = s_{ji}$.

e_{ijkl} = environmental effect associated with $ijkl^{th}$ observation.

x_{ij} = the mean of the i x jth genotype over k and l

The sum of squares were calculted as follows:-

$$S_g = \frac{1}{p+2} \sum_i (X_{i.} + x_{ii})^2 - \frac{4}{p} x_{..}$$

$$S_s = \sum_i \sum_j X^2_{ij} - \frac{1}{p+2} \sum_i (x_{i.} + x_{ii})^2 + \frac{2}{(p+1)\ (p+2)} x^2_{..}$$

Where S_g = sum of squares due to gca.

S_s = sum of squares due to sca.

P = number of parents.

xi. = the total of the array of the ith parent.

xii = the mean value of the ith parent.

x.. = the grand total of $\frac{1}{2}$ P (p-1) progenies and p parentals.

x_{ii} = the progeny mean value in the diallel table.

To get the sum of squares due to error, the sum of squares obtained from the earlier ANOVA were further divided by the number of replications (three in this case).

The gca and sca effects were determined as follows:-

$g_i = \frac{1}{p+2} [(x_{i.} + x_{ii}) - \frac{2}{p} x_{..}]$ giving the gca effect of the ith parent while the sca effect of the ijth cross was estimated by:-

$$s_{ij} = x_{ij} - \frac{1}{p+2}(x_{i.} + x_{ii} + x_{j.} + x_{jj}) + \frac{2}{(p+1)(p+2)} x_{..}$$

where $x_{j.}$ = the total of the array of the j^{th} parent

x_{jj} = the mean value of the j^{th} parent.

The combining ability effects were tested by comparing with a Critical Difference (C.D.) calculated as follows:-

C.D. = S.E x t

where S.E. = Standard error and

t = t-value for the error degree of freedom.

The standard error of the estimates was calculated as the square root of the variance of the estimates. The variance of the estimates were calculated as:-

$$\text{Var}\ (g_i) = \frac{p - 1}{p(p + 2)} \delta^2$$

$$\text{Var}\ (s_{ij}) = \frac{p^2 + p + 2}{(p + 1)(p + 2)} \delta^2 \qquad (i \neq j)$$

Each comparison was a two-tailed test and all calculations followed a worked example by Singh and Chaudhary (1977).

The analysis was based on a model with fixed effects and therefore the relative importance of general and specific combining abilities in determining progeny perfomance was assesed using the combining ability effects as suggested by Baker (1978). The formula used was :-

$$\text{GCA:SCA+GCA ratio} = \frac{2\bar{g}^2}{2\bar{g}^2 + \bar{s}_{ij}^2}$$

where

$$\bar{g}^2 = \Sigma g_i^2$$

$$\bar{s}_{ij}^2 = \frac{\Sigma s_{ij}^2}{2p(p-1)}$$

g_i = gca effects

s_{ij} = sca effects

p = number of parents

3.6.4 Heterosis Estimation.

Heterosis for each of the traits was calculated from the midparent and better parent values and defined as follows:-

$$\text{\% Heterosis (above midparent)} = \frac{\bar{F}_1 - Mp}{Mp} \times 100$$

$$\text{\% Heterosis (above better parent)} = \frac{\bar{F}_1 - Bp}{Bp} \times 100$$

where $\bar{F}_1$ = the hybrid mean.

Mp = the midparent value

Bp = the better parent value.

The significance of heterosis values was tested using comparison of sample means; meaningfully paired observations as described by Steel and Torrie (1980).

4. RESULTS

4.1 Success Rate in Crossing.

A total of 1,105 crosses were made among the seven parents (Appendix 3). Of these, 985 were successful, giving an overall 89.1 percent of successful crosses. Unfortunately there was no available literature from another worker for comparison.

4.2 Variability Among Parents and Hybrids.

The mean performance of the parents and their single cross hybrids for the various characters studied at Kabete and Kinangop are presented in Tables 4.1(a) and 4.1(b) respectively. In general the parents and their single cross hybrids had greater values in all characters studied, they were taller and took more days to flower at Kinangop.

4.2.1 Number of Days to Flowering.

The number of days to flowering differed significantly (P = 0.001) at the two locations. Among the parents, the range at Kabete was from 41 days (Scout) to 55 days (Nyaritho) while among the hybrids the range was from 46 days (Thanatu x Scout) to 56 days (Greenfeast x carouby; Greenfeast x Nyaritho; Scout x Carouby; Nyaritho x Carouby and Kagoci x Carouby). At Kinangop the range was from 50 days (Scout) to 66 days (Nyaritho) for parents and

Table 4.1a: Mean performance of seven parental lines grown at Kabete and Kingangop during the 1989 long rains.

	Days to flowering		Plant height (cm)		Primary branches per plant		Pod length (cm)		Pods per plant		Seeds per pod		100-seed weighting		Seed yield (kg ha^{-1})	
(a) Parents	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG
Greenfeast	49.33	57.33	66.67	76.67	5.11	7.33	7.05	8.10	52.80	54.56	5.30	7.04	17.64	22.33	1571.7	2060.5
Thanatu	46.33	56.67	55.83	70.83	10.00	12.37	5.34	6.51	51.03	54.06	4.73	5.19	18.71	24.96	1786.5	2490.8
Onward	48.83	59.67	84.17	96.17	5.50	8.57	7.11	8.17	39.83	43.72	4.47	7.58	15.85	20.18	1074.0	1546.8
Nyaritho	54.67	66.33	158.33	178.33	11.51	13.47	5.90	7.10	163.07	166.41	4.60	7.65	14.59	20.09	3388.0	4594.3
Scout	40.67	50.00	40.83	52.83	2.02	4.49	5.40	6.93	21.17	24.11	4.87	6.14	19.63	23.02	742.1	1191.6
Kagoci	47.00	53.33	82.50	99.50	4.52	7.73	7.70	9.06	44.17	46.48	6.40	7.30	16.87	24.04	1565.2	2152.9
Carouby	50.33	59.67	110.83	128.83	10.56	12.27	11.20	12.49	53.00	57.29	6.07	6.50	27.96	32.21	2987.7	4652.1
Mean	48.09	57.86	85.59	100.45	7.01	9.46	7.09	8.34	60.72	63.80	5.21	6.77	18.75	23.83	1873.5	2669.9
S.E.($\bar{X}$)	1.37	2.62	3.79	5.79	0.31	0.75	0.81	0.85	2.19	2.43	0.63	0.43	1.79	2.74	294.8	509.3
C.V.(%)	3.49	5.56	5.45	7.06	5.34	9.69	14.03	12.46	4.42	4.66	14.89	7.81	10.55	13.24	19.6	23.4
LSD$_{0.05}$	2.99*	5.71	8.26	12.62	0.68	1.63	1.76	1.85	4.77	5.29	1.39	0.94	3.90	5.97	639.7	1105.2

Where KAB = Kabete;

KNG = Kinangop.

Table 4.1 (b): Mean performance of the 21 single cross hybrids grown at Kabete and Kinangop, Kenya, during the 1989 long rains.

	Days to flowering		Plant height (cm)		Primary branches per plant		Pod length (cm)		Pods per plant		Seeds per pod		100-seed weight		Seed yield (kg ha^{-1})	
Hybrids	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG
x Thanatu	53.67	64.00	82.50	103.50	7.53	10.06	6.84	8.44	63.57	72.61	4.80	6.85	18.65	26.21	2004.4	2872.9
x Onward	55.33	63.33	72.50	84.50	6.21	9.02	7.41	8.95	54.07	61.59	5.10	6.44	16.67	64.92	1688.3	2596.8
x Nyaritho	56.33	64.67	180.00	199.00	9.52	12.36	6.80	8.27	97.48	105.15	6.33	8.08	20.81	26.32	3842.7	5822.4
x Scout	47.00	55.00	65.83	84.83	3.61	5.69	6.65	8.48	49.57	57.57	5.40	6.52	19.35	27.23	1893.1	3060.5
x Kagoci	55.00	63.33	67.50	77.50	7.50	10.25	7.83	9.51	56.56	64.76	5.53	5.57	17.28	22.38	2003.9	3248.3
x Carouby	56.33	61.67	98.33	110.33	11.55	14.02	8.30	10.15	83.33	90.14	5.67	7.90	26.55	31.61	4242.1	6730.4
Thanatu																
x Onward	53.67	60.67	75.00	89.00	8.00	9.92	6.62	8.24	77.32	86.53	4.50	7.44	19.53	27.29	2909.7	4975.3
x Nyaritho	56.67	63.67	183.33	206.33	13.03	15.78	6.58	7.99	115.40	124.52	5.23	7.26	19.15	22.80	3796.3	5756.5
x Scount	46.00	52.33	58.33	73.33	5.50	8.28	5.98	7.68	66.20	75.31	4.47	6.65	19.00	24.83	2081.5	3524.7
x Kagoci	54.67	62.33	65.00	73.00	10.00	12.58	6.36	7.94	61.00	70.53	5.07	7.12	18.24	21.01	2111.9	2597.7
x Carouby	54.67	62.00	98.33	116.33	11.01	13.43	8.31	9.98	54.23	62.02	5.33	8.66	25.88	28.47	3037.7	5059.5
Onward																
x Nyaritho	55.00	63.33	193.33	211.33	12.91	15.34	6.42	8.17	146.20	153.43	4.40	7.93	17.64	19.97	4808.5	5256.5
x Scout	47.33	53.33	75.83	82.83	7.01	9.34	7.40	8.80	49.27	58.07	4.67	6.91	17.17	23.61	1737.3	2237.2
x Kagoci	54.33	64.67	76.67	97.67	9.01	11.03	7.36	8.91	55.23	63.46	5.47	8.64	17.28	20.38	1834.9	3392.9
x Carouby	56.33	64.00	85.00	102.00	12.02	14.09	9.00	10.80	56.00	63.02	5.07	8.23	26.12	31.42	2829.4	3708.3
Nyaritho																
x Scout	50.33	61.00	188.33	207.33	7.52	10.15	6.73	8.43	118.20	127.86	5.20	7.31	19.47	21.67	4619.2	8153.9
x Kagoci	54.00	63.33	178.33	200.33	12.00	14.28	7.05	8.64	138.27	146.62	5.13	7.97	17.01	19.14	4040.7	5779.7
x Carouby	56.33	67.33	201.67	220.67	11.03	13.48	7.92	9.50	104.48	110.48	5.80	8.18	24.13	27.95	4390.0	5995.3
Scout																
x Kagoci	44.67	56.00	69.17	75.17	4.70	7.17	6.72	8.48	57.20	66.94	5.07	7.33	19.84	24.27	2562.3	2939.5
x Carouby	48.33	59.33	100.83	115.83	5.00	7.56	9.52	11.20	57.13	66.28	5.73	7.06	28.67	34.68	3213.5	4061.5
Kagoci																
x Carouby	56.33	65.33	108.33	128.67	12.01	13.94	9.25	10.91	53.00	61.26	4.80	8.26	28.65	32.49	3172.8	5207.5
Mean	53.06	61.46	110.67	126.64	8.88	11.32	7.35	9.02	76.83	85.15	5.18	7.58	20.72	25.36	2999.4	4427.5
S.E($\bar{x}$)	1.38	2.61	6.02	8.37	0.85	0.85	0.54	0.54	5.09	5.44	0.54	0.33	1.78	2.98	399.4	748.5
C.V (%)	3.18	5.18	6.66	8.09	11.70	9.22	8.92	7.26	8.11	7.82	12.80	5.43	11.62	15.33	16.4	20.7
LSD 0.05	2.79	5.27	12.17	16.92	1.72	1.72	1.09	10.9	10.29	10.99	1.09	0.67	3.60	6.02	806.8	1512.0

Where KAB = Kabete;

KNG = Kinangop.

from 52 days (Thanatu x Scout) to 67 days (Nyaritho x Carouby) for the hybrids (Table 4.1(a) and 4.1(b)).

On average the parents flowered 9.8 days and hybrids 8.4 days earlier when planted at Kabete than at Kinangop.

4.2.2 Plant Height.

Plant height differed significantly (P = 0.001) at both locations. Each line and its hybrids was taller at Kinangop compared to Kabete. The average height was 85.6cm and varied from 40.8cm to 158.3cm among the parents compared to a mean of 110.7cm with a range of 58.3cm to 201.7cm among the hybrids at Kabete. At Kinangop, the mean height was 100.5 cm with a range of 52.8cm to 178.3cm among the parents while that of the hybrids was 126.6cm and ranged from 73cm to 200.7cm (Tables 4.1(a) and 4.1(b)). Nyaritho was the tallest parent while Scout was the shortest at both locations. Nyaritho x Carouby was the tallest hybrid at both locations while Thanatu x Scout and Thanatu X Kagoci were the shortest at Kabete and Kinangop respectively.

4.2.3 Number of primary branches per plant.

All the lines and their hybrids had more primary branches when planted at Kinangop than at Kabete. Among the parents, Nyaritho had the highest number of primary branches per plant at both locations with 11.5 and 13.5 primary branches per plant at Kabete and Kinangop respectively. The cross involving Nyaritho and Thanatu performed best at both locations with 13.0 and 15.8 primary branches per plant at Kabete and Kinangop respectively (Tables 4.1(a) and 4.1(b)).

Scout, with only two branches at Kabete and 4.5 at Kinangop had the lowest number of primary branches per plant. The cross involving this line and Greenfeast performed worst at both locations with an average of 5.9 branches over the two locations.

4.2.4 Pod Length.

Pod length differed significantly (P = 0.001) at both locations. The mean pod length was 7.1 cm and varied from 5.3 cm to 11.2 cm among the parents compared to 7.4 cm with a range of 5.9 cm to 9.5 cm among the hybrids at Kabete. At Kinangop the mean pod length was 8.3 cm with a range of 6.5 cm to 12.5 cm among the parents while that of the hybrids was 9.0 cm and ranged from 7.7 cm to 11.2 cm (Tables 4.1(a) and 4.1(b)).

Carouby had the longest and Thanatu the shortest pods at both locations. Hybrids Scout x Carouby and Thanatu x Scout had the longest and shortest pods respectively at both locations.

4.2.5 Number of Pods per Plant.

There were significant differences (P = 0.001) in the number of pods per plant at both locations. The mean number of pods per plant was 60.7 and ranged from 21.2 to

163.1 for the parents compared to 76.8 with a range of 49.3 to 146.2 among the hybrids at Kabete. At Kinangop, the mean was 63.8 with a range of 24.1 to 166.4 among parents while the mean of the hybrids was 85.2 and ranged from 57.6 to 153.4 (Tables 4.1(a)and 4.1(b)).

Nyaritho had the highest number of pods per plant and Scout the lowest at both locations. The hybrid Onward x Nyaritho had the highest number at both locations while Onward x Scout and Greenfeast x Scout had the lowest number at Kabete and Kinagop respectively.

4.2.6 Seeds per Pod.

There were highly significant differences ($P = 0.001$) in the number of peas per pod among the genotypes at both locations. The mean number of peas per pod was 5.2 and varied from 4.5 to 6.4 among the parents compared to 5.2 with a range of 4.4 to 6.3 among the hybrids at Kabete. At Kinangop the mean was 6.8 with a range of 5.2 to 7.7 among parents while that of the hybrids was 7.6 and ranged from 6.5 to 8.7 peas per pod (Tables 4.1(a) and 4.1(b)).

At Kabete, Kagoci had the highest number of peas per pod and Onward the lowest. The cross Greenfeast x Nyaritho performed best while Onward x Nyaritho performed worst. At Kinangop Nyaritho and Thanatu had the highest and lowest number of peas per pod respectively. Thanatu x Carouby was the best hybrid while Greenfeast x Scout had the lowest number of peas per pod.

4.2.7 100-seed Weight.

There were highly significant differences (P = 0.001) in the 100-seed weight at both locations. The mean 100-seed weight among the parents at Kabete was 18.8g ranging from 14.6g to 28.0g compared to 20.7g among the hybrids and ranging from 16.7g to 28.7g. At Kinangop the parental mean was 23.8g and varied from 20.1g to 32.2g and the hybrid mean was 25.4g varying from 18.5g to 34.7g (Tables 4.1(a) and 4.1(b)).

Carouby and Nyaritho had the highest and lowest 100-seed weights respectively at both locations. The crosses Kagoci x Carouby and Scout x Carouby had the heaviest seeds at Kabete and Kinangop respectively. The hybrid Greenfeast x Onward had the lowest 100-seed weight at both locations.

4.2.8 Seed Yield.

Seed yield differed significantly (P = 0.001) among genotypes at both locations. The mean yield per hectare at Kabete was 1873.5Kg and ranged from 742.1Kg to 3388 Kg among the parents compared to 2999.4 Kg with a range of 1737.3 Kg to 4808.5 Kg among the hybrids. The parental mean yield per hectare at Kinangop was 2669.9 Kg and varied from 1191.7 Kg to 4652.1 Kg while the hybrid mean was 4427.5 Kg varying from 2237.2 to 8153.9 Kg (Tables 4.1(a) and 4.1(b).

The best yielding parents were Nyaritho and Carouby at Kabete and Kinangop respectively while Scout was the lowest yielding parent at both locations. Hybrids Onward x Nyaritho and Nyaritho x Scout were the best yielding hybrids at Kabete and Kinangop respectively. The cross Onward x Scout was the lowest yielding hybrid at both locations.

4.3 Correlations.

Table 4.2 shows the correlations between yield and its components at Kabete and Kinangop.

4.3.1 Correlations between Yield and its Components.

Seed yield at Kabete was positively and significantly (P = 0.01) correlated with pods per plant (r = 0.80), branches per plant (0.69), plant height (0.86) and days to flowering (r = 0.58). It was positively but non-significantly correlated with 100-seed weight (r = 0.36), seeds per pod (r = 0.16) and pod length (r = 0.20).

At Kinangop, seed yield was positively and significantly (P = 0.01) correlated with peas per pod (r = 0.49), pods per plant (r = 0.71), branches per plant (r = 0.63) and days to flowering (r = 0.55). However it was positively and non-significantly (P = 0.05) correlated with 100-seed weight and pod length.

Table 4.2: Phenotypic correlations among yield and yield components at Kabete and Kinangop.

	100-seed weight		Seeds per pod		Pods per plant		Pod length		Branches/plant		Plant height		Days to flowering	
	KAB^{+}	KNG^{+}	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG
Seed yield	0.36	0.25	0.16	0.49**	0.80**	0.71**	0.20	0.28	0.69**	0.63**	0.86**	0.76**	0.58**	0.55**
100 seed wt.			0.34	0.17	-0.20	-0.28	0.75**	0.71**	0.30	0.08	0.07	-0.04	0.21	0.01
Seeds per pod					-0.11	0.35	0.49**	0.42*	-0.02	0.46*	0.19	0.41*	0.14	0.58**
Pods per plant							-0.22	-0.19	0.61**	0.62**	0.85**	0.81**	0.50**	0.55**
Pod length									0.22	0.21	0.05	0.04	0.28	0.24
Branches per plant											0.61**	0.60**	0.79**	0.76**
Plant height													0.52**	0.52**

$^{+}$ KAB = KABETE; KNG = KINANGOP

* - Significant at 5%

** - Significant at 1%

4.3.2 Correlations among Yield Components.

The correlations between 100-seed weight and pod length was positive and significant (P = 0.01) with r = 0.75 at Kabete and r = 0.71 at Kinangop. Correlations between 100-seed weight and pods per plant was negative and non-significant (P = 0.05) at both sites (Table 4.2). 100-seed weight showed low, positive and non-significant (P = 0.05) correlations with seeds per pod, branches per plant and days to flowering. It was also positively and non-significantly correlated with plant height (r = 0.07) at Kabete while at Kinangop the correlation was negative and non-significant (r = -0.04).

Seeds per pod was positively and significantly (P = 0.01) correlated with pod length (r = 0.49) at Kabete. It was also positively but non-significantly correlated with plant height and days to flowering while correlations with pods per plant and branches per plant were low, negative and non-significant. At Kinangop,seeds per pod was positively and significantly (P = 0.05) correlated with pod length (r = 0.42), branches per plant (r = 0.46) and plant height(r = 0.41). It was also positively and significantly (P = 0.01) correlated with days to flowering while correlation with pods per plant was positive but non-significant.

Correlations between pods per plant and branches per plant, plant height and days to flowering at both sites were high, positive and significant (P = 0.01) with correlation coefficient ranging from 0.50-0.85. However it was negatively and non-significantly correlated with pod length at both sites.

Pod length showed low, positive and non-significant (P = 0.05) correlations with branches per plant, plant height and days to flowering at both sites while branches per plant had high, positive and significant (P = 0.01) correlations with plant height and days to flowering with correlation coefficients ranging from 0.60 - 0.79. Correlation between plant height and days to flowering was positive and significant (P = 0.01) and was the same at both sites (r = 0.52).

4.4 Combining Ability.

The results of the analysis of variance over locations are shown in Table 4.3. Estimates of GCA and SCA effects are presented in Tables 4.4 and 4.5 respectively.

4.4.1 Number of Days to Flowering

Both GCA and SCA mean squares for the number of days to 50% flowering were highly significant. The differences between the two locations, GCA x location and SCA x location interactions were also highly significant. The GCA:SCA + GCA ratio was 0.89 indicating that GCA mean squares were larger in magnitude and more important for this trait (Table 4.3).

Among the parents only Scout showed highly significant negative GCA effects. Nyaritho and Carouby showed highly significant positive GCA effects (Table 4.4).

Kagoci x Carouby showed highly significant positive SCA effects. Three crosses at Kabete and eight at Kinangop showed negative SCA effects but none of these were significant (Table 4.5.)

4.4.2 Plant Height.

GCA and SCA mean squares for plant height were highly significant (P = 0.01) and the GCA:SCA + GCA ratio was very close to one (0.93). There were also highly significant differences between the two locations. The GCA x location and SCA x location mean squares were highly significant and larger in magnitude than those of GCA and SCA respectively (Table 4.3). Nyaritho and Carouby had highly significant positive GCA effects and were the best general combiners for plant height. All the other parents showed highly significant negative GCA effects (Table 4.4). The best specific combiner was Nyaritho x Scout ($S_{ij} = 40.02$) at Kinangop). Three crosses at both locations showed highly significant negative SCA effects (Table 4.5).

4.4.3 Number of Primary Branches per Plant.

Both GCA and SCA mean squares for the number of primary branches per plant were highly significant. The GCA:SCA + GCA ratio was 0.89. This again shows the relative importance of GCA in the determination of this trait. There were highly significant differences between the two locations and GCA x location and SCA x location interactions were also highly significant (Table 4.3).

Among the parents, Thanatu, Nyaritho and Carouby showed highly significant (P = 0.01) positive GCA effects for this trait while Greenfeast and Scout showed highly significant (P = 0.01) negative GCA effects (Table 4.4). Significant positive SCA effects were shown by 9 and 8 crosses at Kabete and Kinangop respectively. The highest SCA effects were shown by Greenfeast x Carouby at both locations (S_{ij} = 2.54 at Kabete and S_{ij} = 2.78 at Kinangop) (Table 4.5).

4.4.4 Pod Length.

The GCA mean squares for pod length were highly significant but the SCA mean squares were very low and insignificant. Pod length showed the highest GCA:SCA + GCA ratio which was 0.95. This indicates that SCA was of very little importance in the determination of this character. The two locations showed highly significant differences and so was the GCA x location and SCA x location interactions (Table 4.3).

Table 4.3: Mean squares for general and specific combining ability for various traits of seven pea lines and their F_1 hybrids grown at two locations in Kenya in 1989.

Source	d.f.	Days to flowering	Plant height (cm)	Branches per plant	Pod length (cm)	Pods per plant	Seeds per pod	100-seed weight (g)	Seeds yield (Kg per ha)
Locations (L)	1	3206.28**	10150.62**	252.11**	102.21**	2063.66**	201.44**	947.63**	42365.30**
Reps/L	4	4.72	63.45	3.69	0.12	71.86*	0.39	14.10	456.65
GCA	6	121.17**	16673.84**	65.84**	13.99**	9465.42**	1.41**	120.73**	6306.88**
SCA	21	14.40**	1293.22**	5.71**	0.47	484.32**	0.32	8.51	1315.17**
GCA x L	6	25976.88**	103673.04**	752.26**	533.23**	48169.80**	314.26**	4161.05**	55629.40**
SCA x L	21	6358.00**	25533.28**	195.41**	126.91**	11957.40**	70.11**	1004.05**	12206.41**
Pooled Error	54	4.30	45.44	0.62	0.37	21.95	0.22	5.71	191.43
GCA:SCA ratio		0.89	0.93	0.89	0.95	0.93	0.69	0.89	0.77

*, ** = Significant at 0.05 and 0.01 probability levels respectively.

Table 4.4: Estimates of general combining ability (GCA) effects of the seven pea lines grown at two locations in Kenya in 1989.

	Days to flowering		Plant height (cm)		Branches per plant		Pod length (cm)		Pods per plant		Seeds per pod		100-seed weight (g)		Seed yield (Kg per ha.)	
Parents	KAB[+]	KNG[+]	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG
Greenfeast	0.86**	0.24	-15.03**	-16.42**	-1.25**	-1.20**	-0.06	0.09	-8.03**	-8.62**	0.21	-0.17*	-0.80*	-0.32	-8.12**	-9.59**
Thanatu	-0.28	-0.24	17.90**	-17.51**	0.86**	0.88**	-0.81**	-0.84**	-4.74**	-4.32**	-0.28*	-0.52**	-0.44	0.08	-5.74**	-5.93**
Onward	0.45	0.47	-9.84**	-11.25**	-0.13	-0.11	0.01	-0.07	-7.19**	-7.22**	-0.37**	0.19*	-1.74**	-2.03**	-10.52**	-18.46**
Nyaritho	2.60**	3.50**	67.38**	71.19**	2.40**	2.44**	-0.58**	0.62**	51.50**	51.37**	-0.01	0.34**	-1.60	-2.39**	29.28**	39.02**
Scout	-5.29**	-5.28**	-21.69**	-23.97**	-3.33**	-3.30**	-0.52**	-0.43**	-15.84**	-15.36**	-0.14	-0.46**	-0.12	0.28	-11.08**	-15.40**
Kagoci	0.05	-0.31	-11.69**	-12.16**	-0.34*	-0.24	0.16	0.19	-8.09**	-7.80**	0.26*	0.28**	-1.09*	-1.31*	-8.01**	-12.31**
Carouby	1.60**	1.61**	8.77**	10.08**	1.80**	1.58**	1.81**	1.86**	-7.62**	-7.86**	0.34**	0.34**	5.79**	5.69	14.22**	22.67**

[+] KAB = Kabete; KNG = Kinangop

*, ** = Significantly different from the standard value of 0.05 and 0.01 probability levels respectively.

Table 4.5: Estimates of specific combining ability (SCA) effects for 21 F_1 pea hybrids grown at two locations in Kenya in 1989.

	Days to flowering		Plant height (cm)		Branches per plant		Pod length (cm)		Pods per plant		Seeds per pod		100-seed weight		Seed yield (Kg per ha.)	
Hybrids	KAB[†]	KNG[†]	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG
Greenfeast																
x Thanatu	1.27	3.43*	11.02**	17.33**	-0.51	-0.48	0.39	0.51	1.27	5.73	-0.32	0.16	-0.34	1.47	-3.96	-12.36
x Onward	2.19*	2.06	-7.04	-7.92	-0.82	-0.53	0.18	0.26	-5.78*	-2.39	0.07	0.96**	-1.01	-4.09*	-7.06	-6.74
x Nyaritho	1.04	0.37	23.24**	24.13**	-0.06	0.32	0.16	0.13	-21.06**	-17.42**	0.94*	0.54*	2.99**	4.05*	7.00	16.43
x Scout	-0.40	-0.53	-1.85	5.13	-0.22	-0.67	-0.10	0.15	-1.64	1.74	0.14	-0.22	0.04	2.29	-1.40	1.80
x Kagoci	2.27*	2.84	-10.19**	-14.02**	0.67	0.83	0.42	0.56	-2.39	1.56	-0.13	0.09	-1.06	-0.97	-1.71	3.41
x Carouby	2.05*	-0.75	0.18	-3.43	2.54**	2.78**	-0.73*	-0.47	23.90**	26.80**	-0.07	0.36	1.34	1.26	32.01**	55.48**
Thanatu																
x Onward	1.68	-0.12	-1.67	-2.33	-1.14*	-1.71**	0.12	0.29	14.18**	18.25**	-0.03	0.39	1.49	4.26*	21.06**	49.07**
x Nyaritho	2.53**	-0.15	29.44**	32.56**	1.33*	1.66**	0.60	0.60	-6.43*	-2.35	0.44	0.06	0.96	0.13	3.45	11.12
x Scout	-0.25	-2.72	-6.48	-5.28	-0.44	-0.16	-0.06	0.10	11.71**	15.18**	-0.30	0.25	-0.67	-0.51	4.92	9.75
x Kagoci	3.09**	2.32	-9.81**	-17.43**	1.08*	1.08*	-0.33	-0.26	-1.24	3.03	-0.10	-0.02	-0.46	-2.74	-1.39	-16.51
x Carouby	1.53	0.06	3.06	3.67	-0.07	0.11	0.01	0.11	-8.48**	-5.62	0.09	1.46**	0.30	-2.28	-0.48	10.05
Onward																
x Nyaritho	0.12	-1.20	31.39**	31.10**	2.22**	2.21**	-0.31	0.01	26.82**	29.46**	-0.40	0.02	0.76	-0.59	33.53**	11.14
x Scout	0.34	-2.42	2.96	-2.04	2.05**	1.89**	0.63	0.45	-2.78	0.84	-0.01	-0.20	-1.20	0.38	-2.91	-9.92
x Kagoci	2.01*	3.96*	-6.20*	0.99	1.06*	0.52	-0.14	-0.06	-4.56	-1.14	0.39	0.79**	-0.12	-1.26	-3.54	15.89
x Carouby	2.45**	1.36	-18.33**	-16.92**	1.92**	1.76**	-0.10	0.16	-4.27	-1.72	-0.08	0.32	1.85	2.78	-0.91	-11.21
Nyaritho																
x Scout	1.19	2.21	38.24**	40.02**	0.02	0.21	0.51	0.63	7.47*	12.03**	0.16	0.06	0.96	-1.20	29.37**	80.52**
x Kagoci	-0.47	-0.42	18.24**	21.20**	1.53**	1.28*	0.13	0.22	19.80**	23.43**	-0.31	-0.02	-0.53	-1.87	11.83*	18.08
x Carouby	0.30	1.65	21.12**	19.31**	-1.61**	-1.34*	-0.62	-0.58	-14.75**	-12.48**	0.29	0.13	-0.28	-0.33	-1.67	-11.52
Scout																
x Kagoci	0.09	1.03	-1.85	-8.79	-0.04	-0.15	-0.22	-0.13	6.06*	10.49**	-0.24	0.14	0.82	0.32	15.21*	1.50
x Carouby	0.19	2.43	9.35*	9.63	-1.88**	-1.58**	0.92*	0.92*	5.51	9.69**	0.34	0.60*	0.77	3.73*	9.26	-5.44
Kagoci x Carouby	2.86*	3.47*	6.85	10.65*	2.13**	1.74**	-0.06	0.01	-6.36*	-2.70	0.99*	0.27	3.72**	3.13	5.17	20.13

[†] KAB = Kabete; KNG - Kinangop

*, ** = Significantly different from the standard value at 0.05 and 0.01 probability levels respectively.

Highly significant positive GCA effects were shown by Carouby at both locations while Thanatu, Nyaritho and Scout showed highly significant negative GCA effects. Thus Carouby was the best general combiner for pod length (Table 4.4). The cross Scout x Carouby showed significant positive SCA effects (S_{ij} = 0.92 at both sites) while at Kabete Greenfeast x Carouby showed significant negative SCA effect (S_{ij} = -0.73). All the other crosses at both sites showed insignificant SCA effects (Table 4.5).

4.4.5 Number of Pods per Plant.

Both SCA and SCA mean squares were highly significant but GCA mean squares were larger in magnitude than SCA mean squares. The GCA:SCA + GCA ratio was 0.93. Locational differences were again highly significant for this trait. The GCA x location and SCA x location interaction mean squares were also highly significant (Table 4.3).

Nyaritho showed highly significant positve GCA effects for pods per plant at both locations. All the other six parents showed highly significant negative GCA effects (Table 4.4). The highest positive SCA effects were shown by hybrid Onward x Nyaritho (S_{ij} = 26.82 at Kabete and S_{ij} = 29.46 at Kinangop). Six crosses at Kabete and only two at Kinangop showed significant negative SCA effects (Table 4.5).

4.4.6 Number of Seeds per Pod.

The GCA mean squares for the number of peas per pod were highly significant (P = 0.01) while the SCA mean squares were low and not significant. The GCA:SCA + GCA ratio was 0.69 showing the relative importance of GCA in the determination of this character. The two locations showed highly significant differences. GCA x location and SCA x location interactions were also highly significant (Table 4.3).

Carouby was the best general combiner with the magnitude of GCA effects being the same at both locations (0.34). Onward at Kabete and Greenfeast, Thanatu and Scout at Kinangop showed significant negative GCA effects (Table 4.4). Greenfeast x Nyaritho and Kagoci x Carouby showed significant positive SCA effects at Kabete while highly significant positive SCA effects were shown by Greenfeast x Onward, Thanatu x Carouby and Onward x Kagoci at Kinangop. Some crosses showed negative SCA effects at both locations but these were low and not significant (Table 4.5).

4.4.7 100-seed Weight.

The GCA mean squares for seed weight were highly significant while the SCA mean squares were not significant. The GCA:SCA + GCA ratio was quite high (0.89) and this again indicates the relative importance of GCA for the expression of seed weight. Locational effects were also highly significant. GCA x location and SCA x location interactions were significant (P = 0.01) (Table 4.3).

The best general combiner for this trait was Carouby at both locations while poorest combiners were Onward at Kabete and Nyaritho at Kinangop (Table 4.4). Only two crosses at Kabete showed significant positive SCA effects. These were Greenfeast x Nyaritho (S_{ij} = 2.99) and Kagoci x Carouby (S_{ij} = 3.72). At Kinangop three crosses showed significant positive SCA effects. These were Greenfeast x Nyaritho (S_{ij} = 4.05); Thanatu x Onward (S_{ij} = 4.26) and Scout x Carouby (S_{ij} = 3.73) (Table 4.5).

4.4.8 Seed Yield .

Both GCA and SCA mean squares for seed yield were highly significant (P = 0.01). The GCA:SCA +GCA ratio was close to one (0.77) showing the relative importance of GCA in the determination of yield. The locational effects were highly significant (P = 0.01). GCA x location and SCA x location interactions were also highly significant for this trait (Table 4.3).

The large and positive GCA effects (Table 4.4) for Nyaritho and Carouby at both locations indicate that these two parents were the best combiners for this trait. Scout was the worst combiner having the largest negative GCA effect (-11.08). However this line combined very well with Nyaritho to give the best SCA effect for seed yield per plant at Kinangop (S_{ij} = 80.52). Of the 21 crosses, eleven and seven crosses at Kabete and Kinangop respectively showed negative SCA effects but none of them was significant (Table 4.5). Other crosses that showed large, positive and significant SCA effects were Greenfeast x Carouby and Thanatu x Onward at both locations and Onward x Nyaritho at Kabete.

4.5 Heterosis.

Heterosis varied in magnitude at the two locations. Some crosses had positive heterosis at one location and negative heterosis in the other location. This indicates the influence of environmental conditions in the expression of heterosis. Heterosis above the midparent and high parent values for all the characters studied are presented in Tables 4.6 and 4.7 respectively.

4.5.1 Number of Days to Flowering.

All the hybrids at Kabete took longer to reach 50% flowering than their midparents and thus expressed positive heterosis. Heterosis values based on the midparent for all the crosses in this location were significant ($P = 0.01$). At Kinangop, two hybrids, Thanatu x Scout and Onward x Scout flowered earlier than their midparents (Table 4.6). Seven and nine hybrids at Kabete and Kinangop respectively flowered earlier than their late flowering parents (Table 4.7). Regardless of location, none of the hybrids flowered earlier than their early parents. Crosses involving the late flowering cultivars i.e. Nyaritho and Carouby also tended to have higher positive heterosis values indicating that the two parents imparted lateness to their progeny.

4.5.2 Plant Height.

Significant heterosis over the midparent was observed in eight crosses at Kabete and nine at Kinangop. The highest value of heterosis was expressed by hybrid Nyaritho x Scout at Kabete (89.1%) and Kinangop (79.4%) (Table 4.6). Eight hybrids at Kabete and nine at Kinangop were taller than their tallest parents (Table 4.7). The highest values were expressed by Nyaritho x Carouby (27.4%) at Kabete and Greenfeast x Thanatu (35%) at Kinangop.

4.5.3 Number of Primary Branches per Plant.

Heterosis above the midparent for this trait was observed in 17 of the 21 crosses (Table 4.6) and above the high parent in 13 of the 21 crosses (Table 4.7). Highest value of heterosis above the high parent was shown by Onward x Kagoci (63.6%) at Kabete.

Table 4.6: Percent F_1 heterosis above midparent for various plant traits of 21 pea crosses grown at two locations in Kenya in 1989.

	Days to flowering		Plant height (cm)		Branches per plant		Pod length (cm)		Pods per plant		Seeds per pod		100-seed weight (g)		Seed yield (Kg ha^{-1})	
Cross	KAB[+]	KNG[+]	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG
Greenfeast																
x Thanatu	12.2**	10.3**	34.6**	40.3**	-0.1	2.1	10.5**	15.5**	22.4**	33.7**	-4.3	12.0**	2.6	10.9**	19.4*	26.2*
x Onward	13.3**	8.3**	-3.9	-2.2	17.0*	13.5*	5.0*	10.0**	16.7*	25.3**	4.4	-11.9**	-0.5	-12.8**	27.7*	44.0**
x Nyaritho	8.3**	4.6**	60.0**	56.1**	14.5*	18.9**	5.4*	8.8**	-9.7*	-4.8	27.9**	10.0**	20.1**	24.1**	55.0**	75.0**
x Scout	4.4**	2.5*	22.5	19.7*	0.1	-3.7	6.5**	12.8**	34.0**	46.4**	6.2*	-1.1	3.8	20.1**	63.7**	88.2**
x Kagoci	14.2**	14.5**	-9.5	-12.0	56.3**	36.1**	6.1**	10.8**	16.7*	28.2**	-5.5*	5.6*	0.1	-3.5	27.8*	54.3**
x Carouby	13.0**	5.4**	10.8	7.4	47.4**	43.1**	-8.8**	-1.41	57.5**	61.2**	-0.26	16.7**	16.5**	15.9**	86.1**	100.5**
Thanatu x Onward	13.4**	2.5*	7.1	6.6	3.2	-5.3	6.5**	12.3**	70.2**	77.0**	-2.2	16.5**	13.0**	20.9**	103.4**	146.4**
x Nyaritho	12.2**	1.9	71.2**	65.6**	20.9**	22.1**	16.1**	17.4**	7.8*	13.0*	14.3**	13.1**	15.0**	1.2	46.7**	62.5**
x Scout	5.9**	-3.7**	20.7	18.6	-8.3	-1.8	10.3**	14.3**	83.4**	92.7**	-6.9*	17.4**	-0.9	3.5	77.3**	91.4**
x Kagoci	17.2**	11.3**	-6.0	-14.3	37.9**	25.2**	-3.1	2.0	26.2**	40.3**	-8.9**	14.0**	2.5	-14.2**	26.0*	11.9
x Carouby	13.1**	4.8**	18.0	16.5	7.3	9.0	0.6	5.1**	4.3	11.4*	-1.3	48.2**	10.9**	-0.4	27.3*	41.7**
Onward x Nyaritho	6.8**	0.5	59.5**	54.0**	51.8**	39.2**	-1.5	7.0**	44.1**	46.0**	-3.0	4.1	15.9**	-0.8	115.5**	71.2**
x Scout	6.4**	-2.7	21.3	11.2	86.7**	43.1**	18.4**	16.6**	61.5**	71.2**	0.0	0.7	-3.2	9.3**	91.3**	63.4**
x Kagoci	14.0**	14.5**	-7.8	-0.2	80.0**	35.3**	-1.4	3.4*	31.5**	40.7**	0.6	16.1**	5.6*	-7.8*	39.0**	83.4**
x Carouby	14.2**	7.3**	-12.8	- 9.3	50.0**	35.2**	-1.6	4.6**	20.7**	24.8**	-3.8	16.9**	19.2**	20.0**	39.3**	19.7*
Nyaritho x Scout	5.6**	4.9**	89.1**	79.4**	11.1	13.0**	18.6**	20.2**	28.3**	34.2**	9.8**	6.0*	13.8**	0.5	123.7**	181.7**
x Kagoci	6.2**	5.9**	48.1**	44.2**	50.0**	34.7**	2.9	6.9**	33.4**	37.7**	-6.7*	6.6**	8.1**	-12.0**	63.2**	71.3**
x Carouby	7.3**	6.9**	49.9**	43.7**	0.0	4.7	-7.6**	-3.0*	-3.6	-1.2	8.7**	15.6**	13.4**	6.9*	37.7**	29.7**
Scout x Kagoci	6.5**	8.4**	12.2	-1.3	44.6**	17.4**	2.3	6.1*	75.1**	89.7**	-10.0**	9.1**	8.7**	3.1	122.2**	75.8**
x Carouby	6.2**	8.2**	33.0**	27.5**	-20.0*	-9.8*	14.5**	15.4**	54.1**	62.9**	4.8*	24.4**	12.1**	25.6**	72.3**	39.0**
Kagoci x Carouby	15.8**	15.6**	12.1	12.7	60.0**	39.4**	-2.7	1.3	9.1	18.1**	-23.0**	19.7**	27.8**	15.5**	39.3**	53.1**

[+] KAB = Kabete; KNG = Kinangop

*, ** = Significance of differences between F_1 and midparent means at 0.05 and 0.01 probability levels respectively.

Table 4.7: Percent F_1 heterosis above better parent for various plant traits of 21 pea crosses grown at two locations in Kenya in 1989.

	Days of flowering		Plant height (cm)		Branches per plant		Pod length (cm)		Pods per plant		Seeds per pod		100-seed weight (g)		Seed yield (Kg. ha^{-1})	
Cross	KAB†	KNG†	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG	KAB	KNG
Greenfeast																
x Thanatu	8.8**	9.1**	23.7**	35.0**	-25.0**	-18.7**	-2.9	4.2	20.4	33.1**	-9.4*	-2.7	-0.3	5.0*	12.2*	15.3*
x Onward	12.2**	6.1**	-13.9**	-12.1*	12.7	5.3	4.2	9.5*	2.4	12.9	-3.8	-15.0**	-5.5**	-17.0**	7.5	26.0**
x Nyaritho	3.0*	-2.5	13.7**	11.6*	-17.4**	-8.2*	-2.9	2.1	-40.2**	-36.8**	19.4**	5.6*	18.0**	17.9**	13.4**	26.7**
x Scout	-4.7**	-4.1*	-1.3	10.6	-29.4**	-22.4**	-5.7	4.7	-6.1	5.5	1.9	-7.4**	-1.4	18.3**	20.5**	48.5**
x Kagoci	11.5**	10.5**	-18.2**	22.1**	47.1**	32.6**	1.3	5.0	7.1	18.7	-13.6**	3.7	-2.0	-6.9*	27.5**	50.9**
x Carouby	11.9**	3.4*	-11.3**	-14.4**	9.5	14.3**	-25.9**	-18.7**	57.2**	57.3**	-6.6	12.2**	-5.0**	-1.9	42.0**	44.7**
Thanatu x Onward	11.0**	1.7	-10.9*	-7.5	-20.0**	-19.8**	-7.0	0.9	51.5**	60.1**	-4.9	-1.8	4.4*	9.3**	62.9**	99.7**
x Nyaritho	3.7*	-4.0**	15.8**	15.7**	13.0*	17.1*	10.2*	12.5**	-29.2*	-25.2*	12.7**	-5.1*	2.4	-8.7**	12.1*	25.3**
x Scout	-0.7	-10.8**	4.5	3.5	-45.0**	-33.1**	9.3*	10.8*	29.7*	39.3**	-8.2	8.3**	-3.2	-0.5	25.5**	41.5**
x Kagoci	16.3**	6.2**	-21.2**	26.6**	0.0	1.7	-18.2**	-12.4**	19.5	30.5*	-20.8**	-2.5	-2.5	-15.8**	18.2**	4.3
x Carouby	8.6**	3.9*	-11.3**	-9.7	4.8	8.6*	-25.9**	-20.1**	2.3	8.3	-12.2**	33.2**	-7.4**	-11.6**	1.7	8.8
Onward x Nyaritho	0.6	-4.5**	22.1**	18.1**	12.2	13.9**	-9.9*	0.0	-10.3	-7.8	-4.3	3.7	11.3**	-1.0	41.9**	14.4*
x Scout	-2.1	-10.6**	-9.9	-13.9*	27.3**	9.0*	4.2	7.7*	23.7	32.8**	-4.1	-8.8**	-12.5**	2.6	61.8**	44.6**
x Kagoci	12.4**	8.4**	-8.9	-1.8	63.6**	28.7**	-5.2	-1.7	25.0	36.5**	-14.5**	14.0**	2.4	-15.2**	17.2**	57.6**
x Carouby	11.9**	7.3**	-23.3**	-20.8**	14.3*	14.8**	-19.6**	-13.5**	5.7	10.0	-16.5**	8.6**	-6.6**	-2.5	-5.3	20.3*
Nyaritho x Scout	-7.9**	-8.0**	18.9**	16.3**	-34.8**	-24.6**	13.6**	18.7**	-27.5*	-23.2*	6.8	4.4	-0.8	-5.9*	36.3**	77.5**
x Kagoci	-1.2	-4.5**	12.6**	12.3*	4.3	6.0	9.1*	-4.6	-15.2	-11.9	19.8**	4.2	0.8	-19.3**	19.3**	25.8**
x Carouby	3.0*	1.5	27.4**	23.7**	4.3	0.1	-29.5**	-23.9**	-36.1**	-33.6**	-4.4	6.9**	-13.7**	-13.2**	29.6**	28.9**
Scout x Kagoci	-0.7	5.0**	-16.2**	-24.5**	4.4	-7.2	-13.0**	-6.4*	29.5*	44.0**	-20.8**	0.4	1.1	1.0	63.7**	36.5**
x Carouby	-4.0*	-0.6	-9.0	-10.1	-52.4**	-38.4**	-15.2**	-10.3*	7.8	15.7	-5.6	20.9**	-4.6**	7.7**	7.6	-12.7*
Kagoci x Carouby	11.9**	9.5**	-2.3	-0.1	14.3*	13.6**	-17.9**	-12.7**	0.0	6.9	-25.0**	13.2**	2.5	0.9	6.2	11.9*

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† KAB = Kabete; KNG = Kinangop

*, ** = Significance of differeces between F_1 and better parent means at 0.05 and 0.01 probability levels respectively.

4.5.4 Pod Length.

Heterosis for this character was generally low at both locations with more crosses showing negative heterosis at Kabete than at Kinangop. However, significant positive and negative heterosis above the midparent and high parent were observed in a number of crosses at both sites (Tables 4.6 and 4.7).

4.5.5 Number of Pods per Plant.

Table 4.6 shows that 18 crosses at Kabete and 19 at Kinangop exceeded the midparent means for pods per plant. Two crosses involving Nyaritho i.e. Greenfeast x Nyaritho and Nyaritho x Carouby expressed negative heterosis at both locations. However these values were low and insignificant. Thirteen and fifteen crosses at Kabete and Kinangop respectively exceeded their high parent means for this character. Useful heterosis above the high parent ranged from 29.5 - 60.1% (Table 4.7).

4.5.6. Seeds per Pod.

The highest magnitude of F_1 heterosis for peas per pod above the midparent was shown by hybrid Greenfeast x Nyaritho (27.9%) at Kabete and Thanatu x Carouby (48.2%) at Kinangop. The expression of heterosis was not consistent at the two locations. Twelve of the 21 crosses had fewer peas per pod than their midparents thus showing negative heterosis at Kabete while this was shown by only two crosses at Kinangop (Table 4.6). Useful heterosis above the high parent was recorded in 9 of the 21 crosses at Kinangop and in only two crosses in Kabete (Table 4.7).

4.5.7 100-seed Weight.

Significant heterosis above the midparent mean was observed at both locations in 14 of the 21 crosses. Eight crosses in Kabete and six in Kinangop had heavier seeds than their better parents while two in Kabete and seven in Kinangop had lighter seeds than their midparent means (Tables 4.6 and 4.7). Heterosis values for this character were generally low at both locations. Crosses involving Carouby as one of the parents had relatively high heterosis values.

4.5.8 Seed Yield .

All the hybrids differed significantly in seed yield from the midparent mean. The hybrid Nyaritho x Scout showed the highest heterosis values above the midparent with 123.7% and 181.9% at Kabete and Kinangop respectively (Table 4.6). Only one hybrid at Kabete and two at Kinangop showed negative heterosis above the high parent. All the other hybrids yielded better than their higher yielding parents (Table 4.7). Highest heterosis above the high parent was observed in Thanatu x Onward (99.7%). Heterosis variation in magnitude was again evident for seed yield as for other traits above.

5. DISCUSSIONS

The seven parents selected were chosen for their differences in the traits studied. Hence inferences of this investigation strictly apply to only these specific lines. However these lines do represent a reasonable sample of the lines available for breeding work and so some extrapolation of the findings is considered appropriate.

5.1 Success Rate in Crossing.

The high percentage (89.1%) of successful pollinations achieved in this study could partly be explained by the characteristics of the pea pollen. The pea produces large quantities of very sticky, deep yellow pollen. Thus more amounts of pollen remain in contact with the stigma of the female flower after pollination. This allows for fertilisation of more ovules resulting in a high number of hybrid seeds per pod. The high percentage could also be due to the fact that environmental conditions necessary for successful pollination (Bliss, 1980) were strictly provided during the crossing period.

Most pollinations were made on the first flush of flowers in all the cultivars which also could explain this high percentage. Crosses made on late flowers resulted in abscission of very young pods. Therefore, if all the first buds in peas (*Pisum sativum* L.) are used for crossing, there are high chances of getting successful pollinations with the desirable number of seeds per pod.

Bliss (1980) reported that the fewer the number of pollinations made per plant, the higher the success rate. In this study, the number of pollinations made per plant never exceeded six and this could also explain the high success rate.

5.2 Mean Performance.

The performance of the hybrids was significantly greater than that of the parents at both locations for all the traits studied (Table 4.1). This could be explained by the presence of hybrid vigour in the hybrids. The ranking of both the hybrids and parents in terms of performance was not consistent in the two locations for some characters. This shows that the expression of these characters is to some extent influenced by the environment.

The performance by both parents and hybrids in all the traits studies was higher at Kinangop than at Kabete. The pea is a temperate crop and thus needs a relatively cool environment. This kind of environment was provided at Kinangop (Appendix 2) during the growing season thus explaining the better performance of the Kinangop crop.

5.3 Correlations.

When one character is selected for, other characters may be affected either positively or negatively.

The results showed that there were highly significant positive correlations between yield and peas per pod (r = 0.49) and pods per plant (r = 0.80) (Table 4.1). Similar results were reported by Singh and Singh (1970), Rodin and Konovalov (1975), Malik and Hafeez (1977) and Vereshchaka (1976). Therefore peas per pod and pods per plant are of critical importance in yield determination. Yield is a product of these components and therefore improvement of the product or its components generally results in the improvement of others as well.

Correlations between yield and morphological characters were largely positive and highly significant. The observed relationships between yield and plant height (r = 0.86) and primary branches per plant (r = 0.69) was in agreement with the observations of Singh and Singh (1970) and Dahiya (1977). These findings indicated that larger garden pea plants with many branches have a higher yield potential than smaller ones. This view may, however, be valid only when yield per plant is considered. The contrary may be true when seed yield per unit area of land is considered since the bigger plants would definitely require greater spacing.

The low and insignificant correlations observed between yield and pod length and between yield and 100- seed weight seem to indicate that these characters did not critically affect yield.

5.4 Combining Ability.

All the traits studied showed highly significant GCA mean squares. The SCA mean squares were also significant for all the traits except for pod length, peas per pod and 100-seed weight. In this study, the GCA:SCA mean squares ratio for all the traits were far much greater than one. This is an indication that the magnitude of GCA mean squares were larger than SCA mean squares for all the traits studied. This indicated that although SCA mean squares were significant, a large part of the total genetic variability associated with the traits was a result of GCA mean squares. The magnitude of GCA and SCA mean squares is an indication of the relative importance of additive or non-additive gene effects in the inheritance of a trait. If the SCA mean square is not significant, one would accept the hypothesis that the performance of a single-cross progeny can be adequately predicted on the basis of GCA. The best performing progeny may be produced by crossing the two parents having the highest GCA's. If both GCA and SCA mean squares are significant, the relative sizes of the mean squares can be used to assess the relative importance of general and specific combining abilities (Baker, 1978). Thus, in this study, superiority of additive gene effects was shown by all the traits studied. These results were in agreement with the findings of Pandey and Gritton (1975), Cervato et al (1977) and Singh et al (1985),all of them working with garden peas. However, the results contradicted the findings of Koranne and Singh (1974), Singh and Singh (1979), Kumar and Agrawal (1981), Singh et al (1985) and Singh et al (1986). These workers found SCA mean squares to be larger in magnitude than those of GCA for yield, yield components and other morphological traits.

On the basis of the average F_1 data and the variance estimates for GCA, an additive system was shown to be very important in determining the number of days to flowering. Not all of the variation was attributable to additivity, however, as specific effects were also significant. The results were similar to those reported by Rowlands (1964), Watts et al (1970) and Gritton (1975) who concluded that flowering was primarily under the control of a simple additive or polygenic system, but with considerable importance of SCA. Inspite of the significant SCA effects, from a practical plant breeding standpoint, the days to flowering of an F_1 was very close to the average of the two parents.

The variety Scout showed highly significant negative GCA estimates for yield and all the yield components including the number of days to flowering. Therefore this cultivar have a low chance of being selected for a breeding programme for yield. But its hybrid combination with Nyaritho had the highest positive SCA estimates for yield and plant height at both locations suggesting that the two cultivars contribute favourable additive effects for these traits to their progeny. This suggest that a poor general combiner for some trait can be quite useful in specific hybrid combination for that same trait with a good general combiner. Therefore, caution should be exercised during selection based on GCA of parental varieties. Scout was the only parent with highly significant negative GCA estimates for days to flowering suggesting that its crosses have a chance of producing earlier flowering progenies. In fact its hybrid combinations with three of the parents, Greenfeast, Thanatu and onward showed negative SCA estimates although they were not significant (Table 4.5). The actual durations to flowering of these hybrids were all shorter than those of the late flowering cultivars. Both GCA and SCA were highly important in the determination of plant height. Thus not only the height of the parents involved in a cross were important in determining the height of the offspring, but also the SCA of each of the parents involved. The increased height can therefore produce more fruiting nodes which can contribute to increased yields.

Nyaritho and Carouby showed highly significant positive GCA estimates for seed yield and in the most important yield components such as pods per plant, primary branches per plant and plant height. These two varieties should therefore contribute positive additive effects for these traits to their progeny. The same varieties showed highly significant positive GCA estimates for the number of days to flowering indicating that although their crosses would be the best in yield, they would also have the greatest possibility of producing late maturing hybrids. This was clearly the case in this study.

The results indicated that the genetic variation for yield and yield components in the pea varieties used in this study was mainly due to additive gene action which is fixable and hence easily exploitable through selection of superior segregants in the early generations and/or by single plant selection.

The value of predictions based on early generation performance and the exploitation of additive gene effects was discussed in barley by Smith and Lambert (1968) and in soyabeans by Leffel and Hanson (1961). They observed that predictions involving a character largely controlled by an additive gene system would be expected to be more reliable than predictions involving characters controlled by non-additive systems. In this study, additive genes were found to be more important for yield and yield components and thus it would appear that predictions for yield based on yield components could be reliable. The estimation of cross yields could therefore be made using early generation bulks and parental yields.

The observed highly significant GCA x location and SCA x location interactions for all the characters studied were in agreement with the findings of Gupta and Lodhi (1985) and Gupta (1986). Therefore the extent to which the GCA and SCA effects were expressed depended on the growing conditions. Such variations could be a result of locational effects such as temperatures, moisture regimes and soil conditions. This indicates that in order to get unbiased estimates of combining ability, experiments should be performed over a wide range of environments.

The large magnitude of GCA x location and SCA x location mean squares as compared to GCA and SCA mean squares respectively suggests that the interaction effects were of relatively major importance for all the traits studied. The presence of highly significant SCA x location interactions could also be interpreted as a problem in hybrid pea production even if there was an easier way of producing hybrid seeds because, though the hybrids may be economically feasible, these interactions may suggest a narrow adaptation of the F_1 hybrids.

The significance of both GCA and SCA mean squares for some traits in the present study suggested that both additive and non-additive gene effects were responsible for the manifestation of variability for these traits. In such a situation, an improvement could be made by selecting superior segregants in early generations followed by more intensive selection in advanced generations.

5.5 Heterosis.

The existence of significant positive heterosis in yield and yield components is encouraging as it indicates that gene combinations do exist which can result in enhanced yield performance in pea cultivars in Kenya. The superiority of some F_1 hybrids for yield and yield components suggest that if an economical method of producing F_1 seed could be found, the commercial production of hybrid peas should be advantageous. Unfortunately pea flowers are cleistogamous and dehiscence and pollination often occur well before flowers open. No cytoplasmic or genetic male sterility has ever been recognised and induced male sterility by chemical means are still to be made.

In a self pollinating species where the cultivars grown are pure lines, any consideration of F_1 hybrids would depend on their superiority over the best pure lines. In this study, F_1's were consistently higher yielding than the best parents in the crosses. A striking heterotic effect for yield was noted for almost all the crosses in this study. Heterosis of F_1s based on the midparent comparison averaged 65% across locations. This compares well with the 56% obtained by Krarup and Davis (1970) and 55% reported by Gritton (1975).

This study did not show a substantial decrease in the number of days to flowering of the F_1s as was indicated by the positive heterosis values for this trait. However, the variety Scout showed a highly significant negative GCA variance for this trait and thus tended to impart earliness to its progeny. Indeed two of its hybrids at Kinangop, Thanatu x Scout and Onward x Scout, flowered earlier than their midparents and thus showed negative heterosis. Thanatu also had negative GCA variance estimates for days to flowering although they were insignificant. This indicates that these two cultivars could be favourable parents for use in breeding programmes where variety earliness is the major objective. Nyaritho and Carouby cannot be used in such a programme since they would tend to impart lateness to their progeny due to their highly significant positive GCA variance estimates for days to flowering.

There was generally higher heterosis values at Kinangop than at Kabete. This could be explained by the weather conditions at both sites during the growing season and especially the temperatures (Appendix 1 and 2). Although the total rainfall at Kabete was more, the temperatures were fairly high (17.9°C at Kabete and 13.1°C at Kinangop on average). The pea being a temperate legume requires low temperatures and Kinangop due to its high altitude just provided this. The temperature variation between the two locations could also explain why it took a longer time (5 months) for the crop to mature at Kinangop than at Kabete (3.5 months). The specific plots where the crops were grown at both sites could also have brought this difference. At Kabete the plot had been extensively cultivated in previous seasons and thus the soil might have been exhausted and its structure altered affecting such properties as water holding capacity. At Kinangop the crop was grown on a virgin land that had been under pasture for the previous seven years.

Heterosis variation in both magnitude and sign in relation to location indicated genotype x environment interaction. This indicates that tests of potential parents for the expression of heterosis should be conducted over a number of locations. As suggested by Walton (1971), genetic diversity alone will not guarantee the expression of heterosis if environmental conditions are not suitable.

6. CONCLUSIONS

A number of conclusions may be made from this study:-

1. Yield was positively correlated with 100-seed weight, peas per pod, pods per plant , branches per plant and plant height.

2. Among the yield components which showed high positive and significant correlations with seed yield, pods/plant and branches per plant would be the best traits to be used for indirect selection for increased seed yield. This is due to their high positive phenotypic correlations with yield. The ease with which these traits can be measured is also an added advantage.

3. Both additive and non-additive gene effects were important sources of variability in all traits studied except pod length,seeds per pod and 100-seed weight in which non-additive effects were of no importance. It was also clear that although non-additive gene effects were important for these traits, the predominance of additive genetic effects was obvious for all of them.

4. Among the parental cultivars, Nyaritho appeared to be the most promising for use in breeding for yield and yield components since it had large GCA estimates for these traits.

Scout could be used in programmes to reduce duration of flowering and maturity in pea cultivars in Kenya.

5. The expression of GCA and SCA effects was highly influenced by the environment. Therefore to get unbiased results experiments should be performed over a wide range of environments.

6. The performance of parents per se could be used to predict the performance of their progenies. The top yielders among the hybrids had at least one of the parents with high seed yield per plant. This shows that the parents to enter into the hybrid programme should be high yielding.

7. Nyaritho x Scout was the best combination for yield, Kagoci x Carouby for seed weight, Thanatu x Scout for pods per plant and Onward x Scout for branches per plant.

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Appendix I: Weather conditions during the study period at the Field Station, Kabete (March - June, 1989)

Month	Temperatures (^{o}C)			Rainfall	Rainy
	Max.	Min.	Mean	mm	days
March	24.9	13.7	19.3	93.1	10
April	22.0	13.8	17.9	210.5	14
May	22.0	13.6	17.8	497.0	17
June	20.8	12.3	16.5	27.5	2
Mean	22.4	13.4	17.9	828.1*	43*

*Totals

Source: Weather station, Field Station, Faculty of Agriculture, University of Nairobi.

Appendix 2: Weather conditions during the study period at FTC, Njabini, South Kinangop (April - August, 1989).

Month	Temperature (^oC)			Rainfall	Rainy
	Max.	Min.	Mean	(mm)	days
April	19.5	9.5	14.5	189.5	19
May	16.9	6.3	11.6	146.2	15
June	17.0	8.0	12.5	87.9	6
July	18.5	6.5	12.5	77.2	10
August	20	8.5	14.3	54.7	9
Mean	18.4	7.8	13.1	555.5*	59*

*Totals

Source: Weather station, FTC Njabini, South Kinangop.

Appendix 3: Results of pollinations for a 7 x 7 half diallel system

in pea (Dec. - Feb. 1989).

Gross		No. of pollinations	No. of pods harvested	% of succesful pollinations
GreenfeastxThanatu		42	38	90.5
	x Onward	48	44	91.7
	x Nyaritho	47	43	91.5
	x Scout	46	44	95.7
	x Kagoci	47	45	95.7
	x Carouby	46	43	93.5
Thanatu	x Onward	48	34	70.8
	x Nyaritho	57	49	86
	x Scout	48	39	81.3
	x Kagoci	56	50	89.3
	x Carouby	54	43	79.6
Onward	x Nyaritho	50	48	96
	x Scout	59	53	89.8
	x Kagoci	59	56	94.9
	x Carouby	54	52	96.3
Nyaritho	x Scout	63	57	90.5
	x Kagoci	60	52	86.7
	x Carouby	53	43	81.1
Scout	x Kagoci	62	56	90.3
	x Carouby	52	46	88.5
Kagoci	x Carouby	54	50	92.6
Totals		1105	985	89.1

Appendix 4: Mean squares from a combined ANOVA for parents

Source	d.f.	Days to flowering	Plant height (cm)	Branches/ plant	Pod length (cm)	Pods/ plant	Peas/ pod	100-seed weight (g)	Seed yield (kg/ha)
Location	1	1000.59**	2317.70**	62.63**	16.46**	101.15**	25.75**	271.42**	6658381.9**
Reps. within location	4	5.6	3.02	0.86	0.10	34.56	0.21	8.07	166754.47
Variety	6	128.41**	9873.70**	71.57**	24.62**	13003.46**	2.18**	106.38**	8375921.72**
Variety x Location	6	7.15	20.23	0.45	0.06	1.14	1.92**	2.56	323201.01
Pooled Error	24	5.58	35.90	0.48	1.02	8.06	0.43	8.02	259729.82
S.E ($\bar{X}$)		1.92	4.89	0.56	0.82	2.31	0.56	2.30	416.12
C.V (%)		4.45	6.44	8.40	13.09	4.56	10.95	13.30	22.43
$LSD_{0.05}$		3.97	10.07	1.16	1.69	4.77	1.10	4.73	858.87

Appendix 5: Mean squares from a combined ANOVA for parents and crosses

Source	d.f.	Days to flowering	Plant Height (cm)	Branches/ plant	Pod length (cm)	Pods/ plant	Peas/ pod	100-seed weight (g)	Seed yield (kg/ha)
Location	1	3212.59**	10340.00**	252.1**	103.32**	2102.71**	200.69**	948.34**	68396152.5**
Reps.within Location	4	4.72	63.25	3.69	0.10	62.92	0.39	14.10	730632.95
Variety	27	111.89**	15471**	57.09	10.37	744.24**	1.68**	35.12**	11655384.3**
Variety x Location	27	4.56	33.62	0.19	0.07	8.02	1.13**	5.24	888811.4**
Pooled Error	108	6.44	68.15	0.74	0.55	33.25	0.33	8.56	459390.3
S.E (X)		2.07	6.74	0.70	0.60	4.70	0.46	2.38	553.40
C.V (%)		4.51	7.35	8.93	9.20	7.55	9.14	12.94	20.23
$LSD_{0.05}$		4.10	13.34	1.39	1.19	9.32	0.93	4.47	1097.94

Appendix 6: Mean square from a combined ANOVA for crosses

Sources	d.f.	Days to flowering	Plant height (cm)	Branches/ plant	Pod length (cm)	Pods/ plant	Peas/ Pod	100-seed weight (g)	Seed yield (kg/ha)
Location	1	2322.86**	8032.03**	189.45**	88.25**	2180.75	180.31	678.46**	64960619.2**
Reps.within Location	4	2.92	91.2	3.38	0.15	45.39	0.28	8.19	611524.495
Variety	20	82.95**	16888.72**	50.18**	6.26**	5593.01**	1.38**	102.42**	9966158.9**
Variety x Location	20	3.56	33.84	0.14	0.02	1.51	0.68**	6.22	941792.7*
Pooled Error	80	6.51	79.69	0.82	0.43	41.62	0.29	9.04	539875.7
S.E (X)		2.08	7.20	0.73	0.53	5.26	0.43	2.45	599.93
C.V (%)		4.45	7.52	8.97	8.01	7.96	8.44	13.37	19.80
$\text{LSD}_{0.05}$		4.14	14.50	1.47	1.06	10.48	0.87	4.48	1195.66