GENOTYPE x ENVIRONMENT INTERACTIONS IN PIGEONPEA {Cajanus cajan (L) Millsp} GROWN IN SEVEN ENVIRONMENTS OF KENYA

BY

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF

MASTER OF SCIENCE

IN

AGRICULTURE

{ PLANT BREEDING }

UNIVERSITY OF NAIROBI

FACULTY OF AGRICULTURE

1 9 8 9

DECLARATION

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

Date 31.3.89 J Wamatu

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

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DEDICATION

To my dear parents Mr. & Mrs. JAMES WAMAIU whose life of service and sacrifice has provided great inspiration for this compilation.

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ACKNOWLEDGEMENTS

I am grateful to my supervisors, Dr. P. M. Kimani and Dr. P. O. Ayiecho for their advice and supervision throughout the period of the field work and writing of this thesis. I also thank Dr. P. M.Kimani for availing me the facilities of the pigeonpea Project during the study.

I also acknowledge the technical assistance of Messrs., Laurence Ashiono, Martin Ajunja, Silas Egessa,Joseph Mutuku, Maara Muriithi, Raphael Muiruri, David M.Nyagi and Miss Irene M. Kabuya. I am thankful to the Machakos Farmers' Training Centre Principal, the Director of the National Horticultural Research station Thika, the Director of the Coast Agricultural Research station, Mtwapa and the Director of the Dryland Farming station, Katumani for availing me the use of land on which a part of this work was done. I also wish to thank Mr. Wright M. Sowa of the Coast Agricultural Research station, Mtwapa for his technical assistance.

Mr.C.O.Agwanda, Mr.J.S. Mwema and Miss Veronicah W. Wabeti also gave some useful ideas and help.I must also express my appreciation to the German Academic Exchange Service [DAAD] for sponsoring this study. I owe many thanks to good many people who helped me in one way or another to make this work a success. Miss Jane Njeri is acknowledged for typing my final

draft.

Finally, I extend special thanks to my family and friends for their encouragement and moral support. To all involved I say A S A N T E S A N A !!

ABSTRACT

Ten pigeonpea genotypes [Three improved cultivars, four exotic lines and three local farmers pigeonpea genotypes were grown in a randomized complete block design in three replications at five locations for two seasons to study genotype x environment interactions for grain yield and other plant characters.

The nature of genotype x environment interactions were investigated by means of regression analysis techniques of Eberhart and Russell [1966] and stability analysis method of Wrickle [1962,1966].

Combined analysis of variance showed that genotypes x environment interaction was significant for grain yield, pods per plant, seeds per pod, 100 seed weight,days to 50% flowering, days to 50% maturity, plant height, length of pod bearing region and number of pod bearing branches.

Results showed that a considerable portion of genotype x environment interaction could be attributed to the linear regression for most characters. Pooled deviations from linear regression for most characters were highly significant. There were significant differences for all traits except grain yields among genotypes for their regression on environment index.

High correlation was found between the ranks of genotypes according to mean performance [$\bar{x}_i$], regression coefficient [b_i], deviations from regression [$s^2 d_i$] and Ecovalence [w_i].

The genotypes which were most stable had minimum deviations from regression [$s^2 d_i$] and very small w_i. Genotypes showed varied response to the various environments with respect to the various traits. The genotype 423/60 the highest grain yield per plant but lacked stability for this trait. The local farmers varieties were the most desirable cultivars for most traits, followed by the improved cultivars and then came the exotic lines. The response of the localy adapted cultivars to the environments used in this study showed that they were well buffered and could adjust their genotypic and phenotypic states in response to the changing environmental conditions. It was concluded that further experiments with all the genotypes covering more sites and seasons be planned to tap the great potential in these cultivars.

CHAPTER 1

INTRODUCTION

Pigeonpea [Cajanus cajan (L) Millsp] is a popular crop in a wide range of climatic and soil conditions in the medium and low potential areas of Central, Eastern and Coast Provinces in Kenya. It is mainly grown by small scale farmers and is normally intercropped with maize, sorghum, cotton and other crops for domestic consumption.

Surplus prodution is usually marketed locally but the amounts involved are not known since accurate data is generally lacking. However, the crop ranks second in importance among other pulses after field beans [Phaseolus vulgaris L.] [Onim, 1980]. Other scientists have ranked it fourth after field beans [P. vulgaris L.] groundnuts [Arachis hypogea L.] and cowpea [Vigna unguiculata L.] [Nyabundi., 1980]. Pigeonpea is grown on over 115,000 ha in Kenya [Kimani,1987] In the fourth and fifth development plans the Kenya government has emphasized increased production of drought tolerant crops including pigeonpea in the medium and low potential areas in view of the fact that although crop production in these areas is marginal due to the relatively low rainfall, increasing population pressure on land is forcing more and more people

to move into these areas.

The International Development Research Centre aided Pigeon Project at the Department of Crop Science, University of Nairobi has since 1975 collected pigeonpea germplasm from African [Nigeria] Caribbean [Trinidad] and Asian [especially India] countries as well as from International Centres to constitute a germplasm bank [Kimani, 1987]. This germplasm bank was evaluated under different environments to gain some understanding of their potential and select some suitable genotypes for further breeding work. A Number of improved cultivars have been developed some of which have been released to farmers.

These new cultivars need to be evaluated in the major pigeonpea growing areas to indicate the extent of environmental influences as well as genotype x environment interactions. This is important since farmers require cultivars with a known potential. Efforts should be made to ensure that these new and existing cultivars get to the intended end users who are small scale farmers many of whom cannot afford much animal protein.

Crop scientists consider stability in performance as one of the most desirable properties of a genotype to be released as a variety for wide cultivation. No breeding work

would be considered complete until the improved genotypes are tested over a wide range of environmental conditions involving different locations and different seasons.

A number of statistical methods are used for estimation of phenotypic stability.For this purpose, the multilocational trials over a number of seasons are conducted and data thus obtained subjected to environment-wise (location) analysis of variance followed by pooled analysis of the data. This has been done in Kenya for pigeonpea (Onim, 1981). The cultivars which were used in the study by Onim(1981) have now been improved further. In case the genotype x environment interaction is found significant one of the various approaches known for measuring the stability of genotypes can be used and the genotypes may be ranked accordingly.

The objectives of this study were:

(i) determine the performance of local, exotic and new pigeonpea cultivars under varying environmental conditions in Kenya.

(ii) estimate the adaptability and stability parameters for plant and yield components for these cultivars.

CHAPTER II

REVIEW OF LITERATURE

2.1 THE CONCEPT OF GENOTYPE X ENVIRONMENT INTERACTION

A phenotype is as a result of an interplay of a genotype and the environment. The relative rankings of genotypes often differ in different environments such that a specified genotype does not exhibit the same phenotypic characteristics under all environments. This variation arises from lack of correspondence of genetic and non-genetic effects and causes difficulties in demonstrating the significant superiority of any variety. The failure of a genotype to give the same phenotypic performance when grown under different environments is a reflection of genotype x environment interaction.

In developing crop cultivars, breeding work is often done at one location and testing of the improved cultivar may be done at several other locations (Onim, 1981). A high yielding genotype in a favourable environment does not mean that the same genotype will also be high yielding genotype in an adverse environment (Falconer, 1981). The reason for this is that although it is the same genotype, different

gene combinations are called into play in the two different environments hence making this genotype behave as if it were two different genotypes in the two environments.

The interaction between a genotype and its environment contributes to the total variance observed for a genotype and can be isolated and its significance determined. When all the genotypes included in a trial behave consistently under all the environments the interaction term is absent.

Various methods for the statistical analysis of genotype x environment interaotion have been proposed. Lin et. al. (1986) proposed that the stability parameters in current use are derived from two components of a two-way classification of data and that there are three types of stability concepts which have been discussed from statistical and biological points of view. The concepts of stability according to them are that a genotype is considered stable if the variation of its performance among environments is small or if its response to environments is parallel to the mean response of all genotypes in the trial or if the residual mean square from the regression model on environmental index is small.

Genotype x environment interactions are of major importance in the development and evaluation of plant cultivars.

2.2 ESTIMATION OF GENOTYPE X ENVIRONMENT INTERACTION

Various techniques have been devised to evaluate genotype stability over a range of environments in many crops. A widely used technique is regression analysis proposed by Yates and Cochran (1938) amplified by Finlay and Wilkinson (1963) and refined and adopted by other workers (Eberhart and Russell, 1966; Perkins and Jinks, 1968; Shukla, 1972; Langer et. al., 1979). In this technique genotype x environment interaction is partitioned by calculating a regression of the yields of a given genotype in different environments on the respective means of all genotypes.

Lewis (1954) suggested the use of 'phenotypic stability factor' (SF) which took into consideration the mean values only in the highest and lowest yielding environments. This method has been used only to a limited extent (Prasada and Singh, 1980), Kermali, 1981), since the SF has some very obvious defects as it does not consider intermediate environments thus introducing some bias.

Plaisted and Peterson (1959) described a procedure to characterize the stability of performance of several varieties. A combined analysis of variance at all locations was

computed for each pair of varieties. The mean of the estimated variance components of genotype x environment interaction for all pairs of genotypes that include genotype is the stability measure for that genotype. This procedure is very cumbersome when the analysis involves many genotypes (Verma et. al. (1975). Plaisted (1960) proposed a variance component for the genotype x environment interaction (θ_i) as a stability parameter whereby one genotype is deleted from the entire set of data and the genotype x environment variance from this subset is the stability index for genotype i.

Wrickle (1962, 1966) developed a method to estimate the ecological valence (W_i) or in short ecovalence which is the contribution of each genotype to the genotype x environment interaction sum of squares and is expressed as its percentage. The lower the ecovalence of a variety, the smaller are its fluctuations from the experimental mean under different environments and thus a smaller share of the interaction sum of squares. Accordingly the genotype with the least ecovalence is considered the most stable. This technique has been used to a very limited extent (Fejer, 1967 and 1973, Qualset, 1968) because it does not allow prediction of the performance of genotypes over environments (Verma et. al., 1975).

Comstock and Moll (1963) showed statistically the effect of large genotype x environment interaction in reducing progress from selection. They developed a model for estimating genotype, environment and genotype x environment interaction variance. A multilocation or multi-year test is required for a meaningful and unbiased estimate of the genetic variance which is of major interest.

A dynamic approach to the interpretation of varietal adaptation was developed by Finlay and Wilkinson (1963). They showed that regression of yields of separate genotypes accounted for a large part of genotype x environment interactions as reported earlier by Yates and Cochran (1938). This led to the realization that the components of a genotype and the environmental interactions were linearly related to environmental effects when these effects were measured on the same scale as the genotypic effects. The observed values are regressed on environmental indices defined as the difference between the marginal mean of the environments and the overall mean. The regression coefficient is then taken as the stability measure. They reported the adaptation of some 277 barley varieties grown in seven seasons at three sites in Australia. They reported that phenotypic stability of the varieties was inversely proportional to the mean yield. From

the analysis, the varieties specifically adapted to good and poor environments and those showing general adaptability could be identified. Varieties from particular geographical regions showed a similarity in type of adaptation which provides a useful basis for plant introduction.

The regression technique of Finlay and Wilkinson (1963) was modified by Eberhart and Russell (1966) by adding another stability parameter namely the deviation from regression (s^2_d). They defined an ideal variety as one which has a high mean yield (u), unit regression coefficient (b) = 1.0) and the least deviation from regression ($s^2_d = 0$). They found that the estimates of squared deviations for many maize hybrids were near zero against large estimates for others thus indicating the utility of this parameter in characterizing varieties for stability.

Although this technique has been extensively used by crop breeders (Borojevic S et. al.,1982; Eberhart et. al. 1969), Galvez,G., 1980, Nguyen et. al., 1980,Pfahler, P.L et. al., 1979, Pollock, J.S., 1975, Russell, R. 1978, Stafford, R.E.1982 and Tai et. al., 1982) to study cultivar due to the advantage of using the independent variable (environmental index), the validity of their method has been questioned (Freeman, 1973, Freeman and Perkins 1971; Shukla,1972).

Based on the principle of structural relationship analysis Tai (1971) presented a method of genotypic stability where a genotype x environment interaction of a particular variety is partitioned into two components i.e. the linear response to environmental effects (α) and a deviation from response (λ). He showed that the phenotypic estimates of stability (Eberhart and Russell, 1966) may be quite different from genotypic estimates when a small number of genotypes is tested over a small number of environments with a limited or uncertain ranges of environmental variation. The approach of Finlay and Wilkinson (1963), Eberhart and Russell (1966) and Tai (1971) is purely statistical and the components of their analyses have been related to parameters in a biometrical genetical model (Verma and Gill, 1975).

Allard and Bradshaw (1964) discussed the significance of the genotype x environment interaction on the basis of the relative magnitude of different variances estimated from multi-location-year testing. They suggested that heterozygous and heterogeneous populations offer the best opportunity to produce varieties which show small genotype x environment interactions. They used the term 'individual buffering' for individuals where the individual members of a population are well buffered such that each member of the popu-

lation is well adapted to a range of environments and 'population buffering' if the variety consists of a number of genotypes and adapted to a somewhat different range of environments. Data are analysed in the above models assuming they represent a random sample of environments though they are normally collected in a non-random way in a series of seasons and locations.

Bucio-Alanis [1966] developed a mathematical model to measure the genotype x environment interaction when only two homozygous parents were grown under a large number of environments. Bucio-Alanis and Hill [1966] extended the above model to include F_1 between the two homozygous parents. This methodology, unless extended to include more than two homozygous lines, lacks general utility because there is need for adequate control lines against which the breeder may evaluate the performance of new lines.

Perkins and Jinks [1968] extended the technique of Bucio - Alanis [1966] and Bucio-Alanis and Hill [1966] to cover many inbred lines and crosses among them. The regression coefficient so abtained [β_i] is similar to that of Finlay and Wilkinston [1963] except that the observed values are adjusted for location effects before regression.

Perkins and Jinks {1968} further extended their model to include F_1's which may not have any systematic relationship. This approach is superior in its predictive values across generations which is not possible with procedures suggested by Finlay and Wilkinson {1963}, Eberhart and Russell {1966} and Perkins and Jinks [1968 a, b].

Shukla [1972 a] suggested a method deriving a stability variance $\{\sigma^2_i\}$ which is based on residuals in a two way classification. In this method variance of a genotype across environments is the stability measure. He proposed that an approximate F-test was provided by the ratio of $\{\sigma^2_i\}$ to the pooled error mean square $\{\sigma^2_e\}$ calculated in the usual manner for combined analysis. This stability variance was evaluated by Eagles and Frey {1977} for selecting oat {Avena sativa L. } cultivars.

Francis and Kannenberg (1978) used the conventional coefficient of variability (CV%) of each genotype as a stability measure when they were studying genotype x environment interactions in 15 single cross maize hybrids from a six inbred diallel of short season maize grown in yield tests over 16 environments for five years. They found that phenotypic response invoked by a change in environment is not the same for all genotypes (Comstock and Moll, 1963). They suggested

that where 'predictable' environmental variations exist (Allard and Bradshaw, 1964) the genotype x environment interaction can be reduced by stratification of environment and allocation of different genotypes to different environments (Horner and Frey, 1957). Obilana and El-Rauby (1980) considered the coefficient of determination (γ_i^2) as a stability parameter. An (γ_i^2) value near 1.0 indicated that the response of that genotype to environmental change was more stable. A stable genotype would thus have a very high (γ^2) value. This method was used by Nguyen et. al. (1980).

Several authors have examined the relationships of various stability parameters (Hanson, 1970; Langer et. al., 1979, Easton and Clements, 1973; Nguyen et. al., 1980; Becker, 1981; Gray, 1982; Kang and Miller, 1984; Lin et. al., 1986). Quaslet (1968) working with wheat reported the absence of any correlation between W_i and both b_i and $s^2 d_i$. Jowett (1972) concluded that W_i is considerably less informative than b_i and $s^2 d_i$ when working with sorghum. Prasad and Singh (1980) concluded that SF was as effective as $s^2 d_i$. They also reported the absence of any similarity between $s^2 d_i$ and W_i and also SF and W_i.

Becker (1981) suggested that the observed correlati-

ons among stability parameters lead to the conclusion that coefficient of regression is equivalent to variance as a measure of stability according to the biological concept of a stable genotype {one with constant yield} and that mean square deviations from regression is equivalent to ecovalence as a measure of stability from the agronomic concept of stability {one which has yield which is predictable from the level of productivity of the environment}. He also suggested that the use of different concepts of stability will lead to different ranking of genotypes for the parameters belonging to the two different concepts which are not correlated with each other.

Among the methods discussed above majority of the crop breeders use regression analysis techniques. This is because, although genetic effects are not generally independent of environmental effects many authors have observed that the relation between the performance of different genotypes in various environments and some measure of these environments is often linear or nearly so. The weaknesses of the statistical theory of regression analyses developed independently by various workers were pointed out by Freeman and Perkins {1971}. They suggested that fundamental statistical assumptions were not usually satisfied and that the choice of

the sums of squares and degrees of freedom from which the regression components were subtracted was not appropriate. Secondly, the use of the mean yield under each environment as the environmental value of the particular set of genotypes as an independent variable which is in fact not independent of the phenotypic variable regressed onto it has been criticized (Verma and Gill, 1975).

2.3 GENOTYPE X ENVIRONMENT INTERACTION IN PIGEONPEA

Many studies have been reported on the genotype x environment interaction in many crops but only a few have been reported in pigeonpea.

Abrams et. al.(1969) reported results on genotype x environment interaction in pigeonpea in Puerto Rico. They evaluated 20 varieties of pigeonpea at two locations for three years. They found that the first and second order interactions for yield, days to flowering and plant height were as large as the variety component of variance. They found that variety x location x year interaction, although statistically significant was of small magnitude and equal to, or smaller than the variety x year interaction. The variety x location interaction was of much smaller magnitude than the variety x year interaction and was statistically non-signif-

icant. Wallis et. al. (1980) reported variety evaluation trials at four environments in South-eastern Queensland in Australia. They reported that the date of occurence of the first frost was an important limiting factor to pigeonpea production in Queensland and therefore the interaction of sowing dates and days to pod set in different varieties are critical factors. They concluded that phenology and vegetative growth is influenced by photoperiod x temperature interaction and thus by sowing date and latitude.

Onim (1981) discussed the importance of genotype x environment interaction studies in cultivar development in pigeonpea and reported that there is some evidence that most pigeonpea cultivars are location specific. He reported that when locally adapted, Machakos and Kitui cultivars were planted in Kisumu in the Lake Victoria basin or at Mombasa in the Kenya Coast they failed to flower. He also reported that medium maturing pigeonpea cultivars at ICRISAT in India take approximately 160 days to mature there but when 60 such cultivars were planted at Kisumu they all matured in 120 days. He found highly significant differences between environments but genotypes x environment interactions for grain yield was not significant.

Kimani (1988) reported that data obtained when a

number of genotypes were evaluated in Kabete, Machakos (ICRAF Field station), National Dryland Farming station (Katumani), Makueni, Kiboko, Kikambala and Thika showed considerable environmental and genotype x environmental influences. He reported further that yield, plant height, duration to maturity, pods per plant and number of primary branches were considerably affected by environment. Seeds per pod and 100 seed weight were affected to a lesser extent. He suggested the need to test genotypes over several locations to quantify the extent of genotype x environment interactions on various traits and identify the relatively stable ones.

CHAPTER 111

MATERIALS AND METHODS

3.1 MATERIALS

Three improved cultivars, four exotic lines and three local farmers' pigeonpea genotypes were used in this study. They differed in maturity duration and other plant characters. These were:

(a) IMPROVED CULTIVARS

These cultivars are mainly selections from the local germplasm collection. They have been selected on basis of wide adaptability, desirable seed and pod characters and high grain yield.

1. NPP 670:

Is an early maturing hybrid variety(4.5-5.5 months) that is high yielding with large cream/white seeds. It is a popular variety with a determinate/semi determinate growth habit. It has good seed yield (1500-2600 kg/ha), earliness and desirable seed characters. It is drought tolerant and can be harvested twice a year. It normally grows to a height of about 1.2 m but this varies with altitude (i.e. at 1800 m a.s.l. it matures early and grows to a height of 0.7 m.

2. 423/60:

This is a variety developed at the National Dryland Farming Station, Katumani. It has a spreading growth habit with cream or brown seeds.

3. THIKA LINE SELECTION

This is a breeding line selected by a pigeonpea project. It is an advanced stage of single plant selection. The line has a spreading growth habit. It was included in this study to determine its adaptability and stability of performance.

(b) EXOTIC CULTIVARS

These were all introductions from the International Crop Research Institute for semi-Arid Tropics (ICRISAT), India. They are variable in plant characters including seed colour, seed weight, specificity of adaptation and plant height. This variability necessitated their inclusion in this study. They have been used in hybridisation programs with Kenyan pigeonpea types to combine the desirable grain appearance and high yielding ability of the latter with earliness and resistance to Fusarium wilt of the former.

(1) ICPL 215: Is an early maturing cultivar developed

at ICRISAT, India. It has a campact growth habit and a dark

green stem. Seed colour may be brown or white.

(2) ICPL 7035: This originated from Indian Bheda coll pedigree. It is indeterminate and has large dark brown seeds with red streaks and is late maturing in ICRISAT.

(3) ICPL 312: This has a semi-spreading growth habit. Seeds are cream/white or brown.

(4) T21: Is a high yielding early maturing variety from ICRISAT, India. It is indeterminate with a spreading growth habit. Seeds are orange with white speckles.

(c) LOCALLY ADAPTED CULTIVARS (FARMERS VARIETIES)

1. MARIAKANI 11 was collected from farmers' field at the Coast Agricultural Research station, Msabaha sub-station. Selection has not been done previously although this variety is very well adapted to the coast region. The seed colour is variable.

2. MUNYENZENI 11: This is a variety collected from farmers' field at the coast by the Coast Agricultural Research station, Msabaha sub-station. No selection has been done on this variety but it is well adapted to the coast region. Seed colour is variable (black, light brown, maroon and white).

3. MARIKEBUNI 7: This is a coastal variety collected from Msabaha. This variety is well adapted to the coastal

region. Seed colour is very variable {light brown, maroon, cream and white}. The seeds are medium sized.

3.2 LOCATIONS

The study was conducted at five locations for two seasons in the 1987 short rains and 1988 long rains. Experiment 1 was planted at Kabete Campus field station, the National Horticultural Research station, Thika and the National Dryland Farming station, Kiboko substation,during the short rains in October, 1987. Experiment 11 was planted at Kabete, Thika, Kiboko, Machakos Farmers' Training centre and Coast Agricultural Research station Mtwapa during the long rains (March/April) 1988.

All locations are in pigeonpea growing areas except Kabete. They varied in soils, moisture availability, temperature fluctuations and are suitable to specific strains of pigeonpea.

Kabete is on Latitude 1° 14' 20" S longitude 36° 45' E and 1820 metres above sea level. In the 1987/88 short rains kabete received 486.1 mm of rainfall (Appendix4).The mean maximum and minimum temperatures in the year of study were 23.33° C and 13.25° C respectively. The mean humidity, radiation and sunshine hours received in the two seasons under study are also shown in Appendix 4. The soils are deep

friable clay type resistant to erosion(Keya and Mukunya, 1979).

The National Horticultural Research Station, Thika is on Latitude 01° 01' S, Longitude 37° 04' E and an altitude of 1600 metres above sea level. The station received a total annual rainfall of 930 mm (Appendix 5) with mean temperatures of 25.72 °C and 14.3°C(max and min respectively). The soils are deep, well drained, dusky-red to dark reddish brown, friable clay with moderate fertility (Jaetzold and Schmidt, 1983).

Machakos Farmers Training Centre field station lies on Latitude 1° 33' S, Longitude 37° 14' E and an altitude of 1596 metres above sea level. The potential evaporation is 32-83 mm. The station received a total rainfall of 611.7 mm (Appendix 6). The mean maximum and minimum temperatures were 25.96° C and 13.0 ° C respectively. The site is located about 70 kilometres South East of Nairobi and 7 kilometres South of Machakos town. The region is a sub-humid to semi-humid zone and is underlain by rocks of the Precambrian basement system, the predominant rocks being gneisses and banded gneisses. The predominant soil type is a well drained dark reddish brown sandy clay derived from basement complex gneisses. The soil is friable, with a well developed blocky

structure and clay skins. The soil pH is between 6.0 - 6.5 with medium nutrient levels and the soil has a medium base saturation of 50-80% with moderate levels of organic matter (top soil organic carbon = 1.0 - 1.5% (ICRAF publication report, March, 1987).

Kiboko is located approximately 160 km from Nairobi on the Nairobi/Mombasa highway. The altitude is approximately 1000 m (3300 ft) above sea level, and lies between latitudes 2° 10' S and 2° 25' S and longitudes 37° 40' E and 37° 55' E. The climate of Kiboko falls under the influence of the intertropical convergence zone (Whyte, 1968), characterized by a bimodal distribution of wet and dry seasons. The months of January and February are the driest months while rains occur in April and May. Meteorological records taken at Makindu Meteorological station since 1928 indicate that rainfall data of the study area over the last 45 or so years conforms to a long-term annual average of approximately 600 mm with an annual mean relative humidity of 62.5 %.However the site received 331 mm of rainfall and had a mean annual relative humidity of 27.62 % in the year of study(Appendix 7) The mean maximum and minimum temperatures taken at Makindu are 28.6°C and 16.5°C respectively with an annual mean temp-

erature of 23° C and annual dew point of 15.7° C. The Potential average annual evaporation is approximately 2000 mm.

The soils are Regosols and are predominantly shallow, well drained, black to very dark greyish brown (Near hills and foot slopes). The area has a slope less than 5% and soils on these slopes are mostly derived on relatively undifferentiated basement system rocks predominantly gneisses. Soil types are ferrosols (deep,dark red brown to dark brown) and Luvisols (red and dark reddish brown from firm sandy clay with a top soil of loamy sand) [Hatch et. al., 1984).

Mtwapa is on latitude 3° 56' S longitude 39° 44'E and altitude 21 metres above sea level. Between November,1987 to October 1988 the station received 953.8 mm rainfall. The mean maximum and minimum temperatures in the same period were 29.9° C and 22.9° C respectively with a mean temperature of 26.4° C. The soils are sandy.

The above five locations belong to the ecological (climatic) zone 111 and IV which fall between the very dry and wet areas - where the annual ratio of precipitation to evapotranspiration (P/Eo) is 53-67 % in zone 111 and 38-52 % in Zone IV (Siderius and Muchena,1977).

3.3 FIELD LAYOUT AND OBSERVATIONS

All the ten genotypes were planted at Kiboko on 21, November 1987, at Kabete on 24, November 1987 and at Thika on 25, November 1987 to comprise experiment I. In experiment 11 all the genotyes were planted at Kabete on 26, March 1988, at Machakos on 28, March 1988 Thika on 29, March 1988 Mtwapa on 1, April 1988 and at Kiboko on 16 April, 1988.

At each location the genotypes were grown in a randomized complete block design with three replications for the particular seasons(s). Spacing was 75 cm between rows and 30 cm within rows. A plot consisted of three rows each, five meters long. Two guard rows were planted with the local farmers variety, Katheka. No fertilizer was applied. The crop was weeded thrice during the growing season and supplemental irrigation was provided in the 1987 short rains.

Plants were sprayed twice at the beginning of each flowering cycle using Rogor L40 and Thiodan at rate of 75 ml/20 litres of water for each insecticide. Those insecticides were sprayed to control the pod fly (Melanogromyza

chalcosoma) and pod borer (Heliothis) and other pod sucking insects prevalent on the crop at that time.

3.4 DATA COLLECTION

Data was recorded on the following traits.

(i) Days to 50 % flowering: This was recorded as the number of days from emergence to the day when 50% of the plants in the whole plot had open flowers.

(ii) Days to 50 % maturity: This was the duration from the date of planting to the day when 50% of the plants in each plot had brown pods.

(iii) Plant height (cm): The average length of 5 randomly selected plants in centimetres from the ground level to the tip of the main stem of each plant.

(iv) Grain Yield per plant (g): This was based on the mean yield of five randomly selected plants per plot.

(v) Pods per plant: This was obtained as the average number of pods per plant from five randomly selected plants.

(vi) 100 seed weight (g): For each entry 100 clean healthy seeds were counted and their weight recorded in grams.

(vii) Length of pod bearing region (cm): For each of the five representative plants per plot, lengths from the first pod to the last pod on each of four branches was measured. The mean of these lengths for the five random plants per plot was recorded as the length of pod bearing region in centimetres.

(viii) Number of pod bearing branches: This was recorded as the number of pod bearing branches for each of five randomly selected plants per plot.

(ix) Seeds per twenty randomly selected pods per plot:

Other characters recorded were pod colour, seed shape, growth habit, main seed colour, seed pattern, pattern of pod streaks and stem colour. Twelve (12) months climatic data were collected within each environment and is given in Appendices 4 - 8.

3.5 STATISTICAL PROCEDURES

3.5.1 THE LINEAR MODEL

Data was analysed according to the following linear model:

$$Y_{ijk} = \mu + g_i + Ej + (gE)_{ij} + e_{ijk}$$

where

Y_{ijk} is the measured value for the K^{th} plot of the i^{th} genotype at the j^{th} environment.

μ is the mean of the genotype means in the study

g_i is the effect of the i^{th} genotype and $\sum g_i = 0$

where $i = 1, 2 \ldots\ldots 10$.

E_j is the effect of j^{th} environment and

$\sum E_j = 0$ and $j = 1, 2, 3\ldots\ldots\ldots 7$.

$(gE)_{ij}$ is the specific interaction effect due to the i^{th} genotype and j^{th} environment and

$$\sum_i (gE)_{ij} = \sum_j (gE)_{ij} = \sum_i \sum_j (gE)_{ij} = 0$$

e_{ijk} is the random error term with mean 0 and variance e^2

3.5.2 ANALYSIS OF VARIANCE

The data for each trial was analysed separately to determine significance of main effects (Appendix 1).

Bartlettes test was applied to error mean squares to test for homogeneity of variances before a combined analysis. The outline of the combined analysis is given in appendix 2.

The sources of variation, degrees of freedom, expected Mean squares and F tests were as shown in Table 1.

The pooled analysis of variance was done on the basis of plot means where each value is the mean of three observations (i.e. one from each, replication). Thus the pooled error which was used for testing the significance of variance due to genotype x environment interaction needed to be further divided by 3. If the variance due to genotype x environment interaction was found significant further analysis was carried out to estimate stability parameters.

3.5.3 EBERHART AND RUSSELL REGRESSION MODEL

Eberhart and Russell (1966) considered that the regression of each variety on an environmental index and a function of the squared deviations from regression would provide estimates of the desired stability parameters.

These parameters are defined according to the following model.

Table 1: Sources of variation, degrees of freedom expected mean squares and F-tests for combined analysis.

Source of variation	df	MS	Expected mean square (EMS)	Computed F
Environments (E)	(n-1)	EMS	$\sigma_e^2 + gr \frac{\Sigma E_j^2}{n-1}$	EMS/eMS
Reps within environment(R)	n(r-1)	RMS		
Genotype (G)	(g-1)	GMS	$\sigma_e^2 + nr \frac{\Sigma g_i^2}{(g-1)}$	GMS/eMS
G X E	(g-1)(n-1)	GxE MS	$\sigma_e^2 + r \frac{\Sigma\Sigma(gE)^2}{(n-1)(g-1)}$	GxEMS/eMS
Pooled error	(n-r)(g-1)	ems	σ_e^2	
Total	nrg-1			

Where n = total number of environments
g = total number of genotypes
r = replicates.

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

where Y_{ij} = genotype mean of the i^{th} genotype grown at the j^{th} environment.

μ_i = mean of the i genotype over all environments.

β_i = regression coefficient measuring the response of the i^{th} genotype of varying environments.

δ_{ij} = deviation from regression of the i^{th} genotype in the j^{th} environment.

I_j = environmental index obtained as mean of all genotypes at the j^{th} environment minus the grand mean (μ).

Regression analysis was performed as detailed in Appendix 3. In this model the sums of squares due to environment and genotype x environment are partitioned into environments (linear), genotype x environment (linear) and deviations from regressions (the deviations being calculated separately for each genotype).

The first stability parameter is a regression coefficient estimated by

$$b_i = \sum_j Y_{ij} I_j / \sum_j I_j^2$$

The performance of each genotype was predicted by using estimates of the parameters where

$$\hat{Y}_{ij} = \bar{X}_i + b_i I_j \quad \text{where}$$

$\bar{X}$ is an estimate of U_i

The deviations [$\delta_{ij} = Y_{ij} - \hat{Y}_{ij}$] were squared and summed to to provide an estimate of another stability parameter $s^2_{d_i}$

$$s^2_{d_i} = (\sum_j \delta^2_{ij} / n-2) - s^2_e / r$$

where s^2_e / r is the estimate of the pooled error (or the variance of a genotype mean at the j^{th} location and

$$\sum_j \delta_{ij}^2 = [\sum Y_{ij}^2 - Y_i^2/n] - (\sum_j Y_{ij} I_j)^2 / \sum_j I_j$$

A genotype with unit regression coefficient ($b_i = 1.0$) and deviation not significantly different from zero ($s^2_{d_i} = 0$) is said to be stable.

For each genotype these two parameters were obtained. The significance of differences among genotype means i.e. $H_0 = U_1 = U_2 = \cdots = U_n$ was tested by the appropriate 'F' test defined as $F = MS1 / MS_3$

To test that genotypes do not differ with respect

to their regression on the environmental index i.e.

$$H_0 = b_1 = b_2 = \text{---------} = b_n$$

$$F = MS_2 / MS_3$$

Individual deviation from linear regression for each genotype was tested by F test of their individual MS/ error averaged over replicates as follows:

$$F = \left[\left(\sum_j \delta_{ij}^2 \right) / n-1 \right] / \text{Pooled error}$$

3.5.4 WRICKLE'S STABILITY PARAMETER

Wrickle (1962) developed a stability parameter which he termed the "ecological valence" or in short, ecovalence (w_i). He partitioned genotype x environment sums of squares using the formular.

$$W_i = \sum_j \left[Y_{ij} - (Y_{i.}/n) - (Y_{.j}/g) + Y../gn \right]^2$$

Where Y_{ij} is the mean performance of the i^{th} G(genotype) in the j^{th} E (Environment). The lower the ecovalence of a genotype the smaller are its fluctuations from the experimental mean under different environments and thus a smaller

share in the interaction sum of squares. Accordingly the genotype with the least ecovalence is considered to be more stable while those with a high ecovalence have poor stability.

The W_i values were obtained and expressed as a percentage of G x E sums of squares.

3.5.5 RANK CORRELATIONS

The Spearman's rank correlation uses the relative positions or rankings of values to measure the relationship between the rankings of individuals by two methods.

Denoted by R it is defined as:

$$R = 1 - \frac{6\sum D^2}{n(n^2 - 1)}$$

Where D is the difference between corresponding ranks for the two variables and n is the number of pairs of values. It is also possible to use the rank correlation coefficient on data where unwiedly figures would make the calculation of ordinary correlation coefficient very tedious. Use of rank correlation does not produce an accurate result as the true correlation coefficient but gives a rough indication as to the strength of the relationship between the variables.

The rank correlation was obtained for all combinations of mean performance ($\bar{X}$), Wrickles' stability value

(W_i), linear regression coefficient (b_i) and deviation from linear regression ($s^2_{d_i}$). The R values were tested for significance at 0.05 and 0.01 levels for (n-2) degrees of freedom from coefficient of correlation table.

CHAPTER IV

RESULTS

4.1 MEAN PERFORMANCE OF GENOTYPES

4.1.1 Grain yield (kg/ha)

The mean grain yields (kg/ha) for each genotype in all the environments are shown in Table 2. 423/60 had the highest overall mean across locations and seasons. For this genotype the highest yields were recorded at Mtwapa in the 1988 long rains. It was followed by cultivar Thika Line Sel which was also the second highest yielding at Kabete in the 1987 short rains and Mtwapa and Thika in the 1988 long rains. At Kabete the best two lines were T21 and Thika Line selection. At Kiboko in the 1987 short rains the best lines were ICPL 215 and Mariakani II. At Thika in the 1987 short rains the best two lines were Mariakani II Marikebuni 7.

At Mtwapa the best two lines were 423/60 and Thika Line Selection.Cultivar T21 and Mariakani II gave the highest grain yield at Machakos in the 1988 long rains.

In the 1988 long rains at Kiboko the best two cultivars were Mariakani II and 423/60 while at Thika in the same season 423/60 and Thika Line Selection were the best two cu-

Genotypes	1987 short rains			1988 long rains				Mean
	Kabete	Kiboko	Thika	Mtwapa	Machakos	Kiboko	Thika	
426/60	680(6)+	3100(4)	290(6)	7200(1)	1320(3)	710(2)	760(1)	2010(1)
T21	1070(1)	2730(6)	190(8)	3650(4)	1640(1)	370(8)	180(3)	1400(5)
NPP 670	1030(3)	2350(7)	270(7)	870(10)	1010(6)	500(5)	110(7)	880(9)
MUNYENZENI II	640(7)	2780(5)	600(3)	3600(5)	910(7)	520(4)	100(8)	1310(6)
MARIAKANI II	910(5)	3350(2)	1000(1)	4250(3)	1450(2)	1100(1)	150(6)	1740(3)
MARIKEBUNI 7	920(4)	3270(3)	710(2)	3440(6)	1160(4)	480(7)	170(5)	1450(4)
THIKA LINE SEL.	1040(2)	2230(8)	530(4)	6340(2)	1130(5)	490(6)	490(2)	1750(2)
ICPL 312	130(10)	980(10)	70(10)	1900(8)	260(9)	60(10)	-	570(10)
ICPL 215	390(9)	3780(1)	300(5)	1610(9)	230(10)	310(9)	170(4)	970(7)
ICPL 7035	570(8)	1725(9)	100(9)	3110(7)	510(8)	690(3)	-	1120(8)
Mean	740	2630	410	3600	960	520	270	1320
CV%	46.60	45.0	49.50	43.10	29.10	34.70	46.50	42.1
LSD (P=0.05)	13.27	45.67	7.77	59.81	10.79	6.97	3.81	21.16

( )+ Ranks are given in parenthesis

ltivars. Cultivar Mariakani II had the highest yield in the 1987 short rains followed by Marikebuni 7 while ICPL 312 had the lowest yields over all the three locations. In the 1988 long rains the cultivars 423/60 and Thika Line Selection were the highest yielding. The best performance for all the genotypes was recorded in Mtwapa in the 1988 long rains and at Kiboko in the 1987 short rains. The poorest performance was at Thika in the 1988 long rains and in the 1987 short rains. The range for grain yield was 1440 kg/ha for the two seasons.

4.1.2 Pods per plant

The mean number of pods per plant for each genotype in all the environments are shown in Table 3. On average Thika Line Selection had the largest number of pods per plant at Mtwapa, Kiboko and Thika in the 1988 long rains and was best overall performer.

Cultivar 423/60 was the second overall and was second in Mtwapa in the 1988 long rains. The cultivar with the lowest number of pods at almost all environments was NPP 670 The ten genotypes had more pods at Mtwapa and Machakos in the 1988 long rains and their performance was poorest at Kabete and Thika in the 1987 short rains.The range for pods plant in the two seasons was 66.

locations) in Kenya during 1987 short rains and 1988 long rains.

Genotypes	1987 short rains			1988 long rains				Mean
	Kabete	Kiboko	Thika	Mtwapa	Machakos	Kiboko	Thika	
423/60	9(7)+	38(7)	7(9)	351(2)	59(5)	51(3)	50(2)	81(2)
T21	23(1)	57(3)	9(7)	236(3)	149(1)	44(4)	27(3)	78(3)
NPP 670	11(5)	22(9)	10(6)	53(10)	33(7)	29(8)	11(8)	24(10)
MUNYENZENI II	10(6)	30(8)	11(5)	161(6)	52(6)	37(6)	14(7)	45(6)
MARIAKANI II	12(4)	48(4)	13(2)	170(5)	77(2)	54(2)	16(6)	56(5)
MARIKEBUNI 7	13(3)	57(2)	16(1)	202(4)	68(4)	41(5)	19(5)	59(4)
THIKA LINE SELECTION	19(2)	39(6)	13(3)	356(1)	72(3)	74(1)	58(1)	90(1)
ICPL 312	5(10)	15(10)	7(10)	101(9)	18(10)	11(10)	-	26(9)
ICPL 215	8(9)	48(5)	12(4)	110(8)	27(8)	27(9)	22(4)	36(8)
ICPL 7035	9(8)	95(1)	9(8)	118(7)	19(9)	34(7)	-	41(7)
Mean	12	45	11	186	57	40	22	53
CV %	47	28	37	45	28	28	37	36
LSD (P=0.05)	43	22	11	144	28	19	14	40

+Ranks are given in parenthesis

4.1.3 Seeds per pod

The mean number of seeds per pod for each genotype at all the environments are shown in Table 4. There was little variation in the trait across environments. The cultivar Mariakani II had the highest number of seeds per pod at Mtwapa, Machakos and Kiboko in the 1988 long rains and at Kabete, Kiboko and Thika in the 1987 short rains. It was followed by Munyenzeni II which had 5 seeds per pod on average. The cultivar ICPL 312 had the lowest number of seeds per pod.

The best expression of this trait was at Mtwapa and Machakos in the 1988 long rains followed by Kabete in the 1987 short rains. At Thika, in the 1988 long rains the genotypes had the lowest seeds per pod. The range for this trait was 2.

4.1.4. Seed weight

The mean 100-seed weight for each genotype in all the environments are shown in Table 5. The Cultivar NPP 670 had the largest seeds (g). This genotype had the largest 100-seed weight at Mtwapa and Thika in the 1988 long rains, Kabete and Thika in the 1987 short rains. It was followed by ICPL 7035 which had the highest 100 seed weight at Machakos and Kiboko in the 1988 long rains and Kiboko in the 1987

Table 4: Seeds per pod for 10 pigeonpea genotypes grown in seven environments (five locations) in Kenya during 1987 short rains and 1988 long rains.

Genotypes	1987 Short rains				1988 Long rains			
	Kabete	Kiboko	Thika	Mtwapa	Machakos	Kiboko	Thika	Mean
423/60	5(2)+	5(5)	4(5)	5(4)	5(4)	5(4)	4(3)	5(4)
T 21	4(9)	4(10)	3(9)	4(7)	4(9)	4(7)	4(7)	4(9)
NPP 670	4(6)	4(7)	4(7)	4(6)	4(8)	4(6)	3(8)	4(6)
MUNYENZENI II	5(2)	5(4)	5(2)	6(3)	6(2)	5(2)	5(1)	5(2)
MARIAKANI II	6(1)	5(1)	5(1)	6(1)	6(1)	6(1)	4(3)	5(1)
MARIKEBUNI 7	5(4)	5(3)	5(4)	6(2)	6(2)	5(3)	5(1)	5(3)
THIKA LINE SEL.	4(8)	4(9)	4(6)	4(8)	4(6)	4(5)	4(5)	4(5)
ICPL 312	3(10)	5(6)	5(3)	4(8)	5(5)	1(10)	—	3(10)
ICPL 215	4(7)	4(8)	4(8)	4(8)	3(10)	4(7)	4(6)	4(7)
ICPL 7035	5(5)	5(2)	3(10)	5(4)	4(6)	3(9)	—	4(8)
Mean	5	4	4	5	5	4	3	4
CV %	11.7	6.3	7.7	9.8	8.7	14	5.8	9.1
LSD(P=0.05)	0.41	0.49	0.57	0.82	0.68	0.98	0.32	0.61

+Ranks are given in parenthesis.

Table 5: A 100-seed weight (g) for 10 pigeonpea genotypes grown in seven environments (five locations) in Kenya during short rains (1987) and long rains (1988)

Genotypes	1987 short rains			1988 long rains				
	Kabete	Kiboko	Thika	Mtwapa	Machakos	Kiboko	Thika	Mean
23/60	12.63(4)+	12.065(3)	12.865(5)	13.6(4)	13.621(3)	11.25(3)	12.756(3)	12.684(4)
' 21	9.63(10)	8.997(10)	9.211(10)	10.2(10)	10.03(10)	7.39(10)	10.273(8)	9.39(10)
NPP 670	17.57(1)	19.25(2)	24.70(1)	22.1(1)	19.13(2)	14.25(2)	20.703(1)	19.672(1)
MUNYENZENI II	11.7(5)	11.481(5)	10.845(9)	12.41(5)	13.2(7)	10.35(4)	10.47(7)	11.494(5)
MARIAKANI II	11.2(7)	11.3(6)	11.015(7)	11.62(9)	13.4(4)	9.94(6)	11.579(5)	11.436(6)
MARIKEBUNI 7	11.0(8)	10.514(8)	10.175(6)	11.9(6)	13.27(5)	10.3(5)	10.989(6)	11.164(7)
THIKA LINE SEL.	10.5(9)	10.905(7)	11.01(8)	11.83(7)	12.38(8)	8.597(8)	12.448(4)	11.096(8)
ICPL 312	12.97(3)	10.444(9)	17.191(3)	11.67(8)	12.12(9)	8.48(9)	—	10.411(9)
ICPL 215	11.60(6)	11.753(4)	15.479(4)	13.68(3)	13.23(6)	9.9(7)	13.474(2)	12.731(3)
ICPL 7035	17(2)	21.69(1)	22.485(2)	21.9(2)	21.21(1)	16.3(1)	—	17.226(2)
Mean	12.58	12.84	14.498	14.091	14.16	10.68	10.27	12.73
CV %	17.1	5.4	11.6	6.8	13.9	13.2	11.3	11.33
LSD (P=0.05)	3.7	1.2	3.0	1.7	3.4	2.4	2.0	2.49

+Ranks are given in parenthesis

short rains. Cultivars T21 and ICPL 312 had the smallest seeds. On average the ten genotypes had the largest seeds at Mtwapa, Machakos (in the 1988 long rains), Kiboko and Thika (in the 1987 short rains). Seed size varied with location and seasons with a range of 10.282.

4.1.5 Days to 50% Flowering

The mean number of days taken for each genotype to reach 50% flowering are shown in Table 6.

Cultivars ICPL 312 was the first to reach 50% flowering at all the environments except at Thika where it flowered later than T21. On average ICPL 312 took the shortest duration to flower followed by T21 while NPP 670 was the last to flower.

Duration to flowering also varied with the location and season. The genotypes generally flowered earliest at Kiboko in the 1988 long rains and at Kabete in the 1987 short rains.

4.1.6 Days to 50% maturity

The mean number of days taken to reach 50% maturity for each of the genotypes in all environments are shown in Table 7. Cultivar ICPL 312 was the earliest to reach 50% pod maturity followed by T21. The cultivars, Mariakani II and NPP

locations) in Kenya in 1987 (short rains) and 1988 (long rains).

Genotypes	1987 short rains			1988 long rains				
	Kabete	Kiboko	Thika	Mtwapa	Machakos	Kiboko	Thika	Mean
423/60	122(10)+	111(5)	125(7)	112(8)	103(4)	88(3)	111(3)	110(7)
T21	87(2)	98(2)	89(2)	79(2)	105(5)	79(2)	108(1)	92(2)
NPP 670	105(6)	135(10)	143(10)	125(10)	109(9)	103(10)	131(10)	122(10)
MUNYENZENI II	107(7)	123(8)	130(9)	99(4)	111(10)	97(7)	114(4)	111(8)
MARIAKANI II	114(9)	115(6)	122(6)	100(5)	108(8)	99(9)	124(9)	112(9)
MARIKEBUNI 7	107(7)	110(4)	129(8)	99(3)	107(7)	97(8)	119(6)	110(6)
THIKA LINE SEL.	94(4)	117(7)	93(3)	100(5)	105(5)	96(6)	115(5)	103(4)
ICPL 312	76(1)	95(1)	87(1)	64(1)	87(1)	70(1)	111(2)	84(1)
ICPL 215	92(3)	110(3)	95(4)	103(7)	92(2)	94(4)	121(8)	101(3)
ICPL 7035	99(5)	130(9)	106(5)	114(9)	96(3)	95(5)	120(7)	108(5)
Mean	100	114	112	100	102	92	117	105
CV %	10.99	6.3	8.46	2.11	4.2	3.2	9.34	6.37
LSD (P = 0.05)	18.9	12.3	16.2	3.6	7.4	5.1	18.8	11.8

+Ranks are given in parenthesis.

670 were the latest genotypes to reach 50 % pod maturity.

On average the genotypes matured later at Thika and Kiboko in the 1987 short rains than at other locations. Cultivar NPP 670 was the first to mature at Machakos in the 1988 long rains although it was the latest when all locations were considered.

4.1.7 Plant height

Plant height varied with genotypes, location and season. The mean plant heights (cm) at maturity for all the genotypes across the environments are shown in Table 8. Overall among all genotypes, ICPL 312 was the shortest followed by ICPL 215, NPP 670 and ICPL 7035. Cultivar 423/60 had the tallest plants on average. Plants were generally taller at Mtwapa in the 1988 long rains and Kiboko in the 1987 short rains compared to Thika in the 1988 long rains where plants were the shortest.

4.1.8 Length of pod bearing region

The mean lengths (cm) of pod bearing regions at maturity for each genotype in the environments are shown in Table 9. Cultivar ICPL 312 had the shortest pod bearing length followed by ICPL 215, NPP 670 and ICPL 7035.

locations in Kenya during 1987 (short rains) and 1988 (long rains).

Genotypes	1987 short rains			1988 long rains				
	Kabete	Kiboko	Thika	Mtwapa	Machakos	Kiboko	Thika	Mean
423/60	158(8)+	155(5)	185(7)	164(9)	119(7)	145(4)	134(1)	151(7)
T21	119(2)	128(2)	131(1)	128(2)	116(6)	138(2)	147(4)	130(2)
NPP 670	140(5)	187(10)	202(10)	160(7)	110(1)	152(8)	168(10)	160(10)
MUNYENZENI II	149(6)	164(6)	195(9)	135(3)	110(1)	150(9)	148(5)	150(6)
MARIAKANI II	179(10)	173(7)	191(8)	135(3)	110(1)	144(3)	165(7)	157(9)
MARIKEBUNI 7	157(7)	146(4)	176(6)	135(3)	112(4)	150(7)	159(7)	148(5)
THIKA LINE SEL.	123(4)	184(9)	143(4)	149(6)	112(4)	146(5)	158(8)	145(4)
ICPL 312	112(1)	127(1)	138(2)	110(1)	129(8)	137(1)	149(6)	126(1)
ICPL 215	119(3)	137(3)	142(3)	137(5)	142(9)	145(4)	142(2)	138(3)
ICPL 7035	159(9)	180(8)	161(5)	162(8)	142(9)	146(6)	144(3)	158(8)
Mean	142	158	166	141	120	145	152	146
CV %	10.9	10.6	8.3	1.5	0.74	0.47	10.4	6.13
LSD (P = 0.05)	26.4	28.8	23.6	3.7	1.5	11.7	27.0	17.7

+Ranks are given in parenthesis

(five locations) in Kenya during 1987 (short rains) and 1988 (long rains).

Genotypes	1987 short rains				1988 long rains			
	Kabete	Kiboko	Thika	Mtwapa	Machakos	Kiboko	Thika	Mean
423/60	88(9)+	136(7)	103(10)	256(10)	97(8)	90(7)	80(9)	121(10)
T21	88(8)	118(4)	77(3)	180(4)	107(10)	72(3)	54(4)	100(5)
NPP 670	73(4)	116(3)	81(5)	144(3)	69(4)	77(5)	59(8)	88(3)
MUNYENZENI II	83(7)	127(6)	81(4)	224(9)	86(5)	72(4)	54(5)	104(6)
MARIAKANI II	80(5)	144(8)	93(9)	223(8)	93(7)	93(8)	54(6)	111(8)
MARIKEBUNI 7	82(6)	124(5)	85(7)	213(6)	90(6)	89(6)	56(7)	106(7)
THIKA LINE SEL.	92(10)	141(9)	90(8)	213(7)	99(9)	110(10)	83(10)	118(9)
ICPL 312	40(1)	58(1)	49(1)	96(1)	36(1)	38(1)	-	45(1)
ICPL 215	52(2)	96(2)	65(2)	113(2)	43(2)	59(2)	47(3)	68(2)
ICPL 7035	67(3)	165(10)	82(6)	191(5)	58(3)	99(9)	-	95(4)
Mean	75	123	81	185	78	80	61	97
CV %	9.0	10.6	13.4	10.7	9.38	9.97	18	11.6
LSD (P = 0.05)	11.5	22.3	18.4	34.0	12.5	13.7	15	18.2

+Ranks are given as parenthesis

Table 9: Mean lenth (cm) of pod bearing region of 10 pigeonpea genotypes grown in seven environments (five locations) in Kenya during 1987 (short rains) and 1988(long rains).

Genotypes	1987 short rains			1988 long rains				
	Kabete	Kiboko	Thika	Mtwapa	Machakos	Kiboko	Thika	Mean
423/60	26(9)+	42(8)	24(10)	63(9)	22(7)	28(6)	20(9)	32(8)
T21	31(10)	47(9)	22(9)	72(10)	35(10)	30(7)	12(6)	36(10)
NPP 670	18(7)	22(2)	15(3)	26(3)	14(3)	11(2)	13(7)	17(3)
MUNYENZENI II	17(6)	40(7)	19(5)	48(8)	19(5)	21(4)	9(4)	25(6)
MARIAKANI II	14(5)	32(5)	20(7)	38(5)	20(6)	24(5)	10(5)	23(4)
MARIKEBUNI 7	14(4)	32(4)	19(6)	43(6)	22(8)	30(8)	15(8)	27(7)
THIKA LINE SEL.	25(8)	49(10)	21(8)	47(7)	25(9)	40(10)	21(10)	32(9)
ICPL 312	7(1)	14(1)	9(1)	14(1)	12(2)	8(1)	-	11(1)
ICPL 215	13(3)	22(3)	14(2)	19(2)	10(1)	12(3)	9(3)	14(2)
ICPL 7035	9(2)	38(6)	18(4)	29(4)	15(4)	33(9)	-	24(5)
Mean	18	34	18	40	19	24	14	24
CV %	47	25	22	36	17	14	24	26.4
LSD (P = 0.05)	14	14.5	6.9	24	5.5	5.6	4.4	10.7

( )+ Ranks are given in parenthesis.

Cultivar T21 had the longest pod bearing length followed by Thika Line Selection and 423/60. The coast farmers' genotypes, Munyenzeni II, Mariakani II and Marikebuni 7 had medium pod bearing lengths. Pod bearing length was generally greater at Mtwapa and Kiboko in the 1988 long rains compared to other locations. In some genotypes, for example NPP 670, pods were borne clustered.

4.1.9 Number of pod bearing branches

The mean number of pod bearing branches at maturity for each genotype in all the environments are shown in Table 10 cultivar ICPL 312 had the lowest number of pod bearing branches followed by NPP 670 and 423/60. The cultivars, Marikebuni 7 and Mariakani II had the highest number of pod bearing branches.

On average the genotypes had more pod bearing branches at Kiboko in the 1987 short rains followed by Mtwapa in the 1988 long rains and Kiboko in the 1988 long rains.

4.2 GENOTYPE X ENVIRONMENT EFFECTS

The results of the combined analysis of variance including all environments are summarised in Table II.

The G x E interactions were highly significant for all traits considered. The effects of both the environment

Table 10: Number of pod bearing branches per 10 plants in [illegible] environments (five locations) in Kenya during the 1987 (short rains) and 1988 (long rains)

Genotypes	1987 short rains			1988 long rains				
	Kabete	Kiboko	Thika	Mtwapa	Machakos	Kiboko	Thika	Mean
423/60	6(3)	11(1)	4(3)	11(5)	4(4)	10(4)	6(8)	7(3)
T21	7(5)	15(7)	5(6)	12(6)	8(10)	8(2)	7(10)	9(6)
NPP 670	9(9)	14(5)	4(5)	5(1)	5(6)	11(9)	3(3)	7(2)
MUNYENZENI II	7(5)	12(2)	9(9)	19(8)	6(8)	10(5)	5(6)	10(7)
MARIAKANI II	7(4)	14(6)	8(8)	25(9)	7(9)	15(10)	4(4)	11(9)
MARIKEBUNI 7	9(10)	24(9)	11(10)	30(10)	6(7)	10(6)	4(5)	13(10)
THIKA LINE SEL.	8(8)	13(4)	6(7)	10(3)	5(5)	11(8)	7(9)	9(5)
ICPL 312	5(1)	13(3)	2(1)	14(7)	2(1)	7(1)	-	7(1)
ICPL 215	8(7)	18(8)	5(4)	10(4)	4(2)	9(3)	5(7)	8(4)
ICPL 7035	6(2)	37(10)	4(2)	9(2)	4(3)	11(7)	-	12(8)
Mean	7	17	6	14	5	10	5	9.0
CV %	20	30	27.2	19.6	19.0	30.2	28.4	25
LSD (P= 0.05)	2.5	8.7	2.7	5	1.6	4.7	1.9	4

( )+ Ranks are given in parenthesis

and genotypes were highly significant for all the traits.

4.3 REGRESSION ANALYSIS

ENVIRONMENTAL INDICES

The values of the environmental indices obtained as the deviation from general mean from the mean of a specific environment averaged over all the genotypes are shown in Table 12.

4.3.1 EBERHART AND RUSSELL (1966) REGRESSION MODEL.

The mean squares from the regression based on Eberhart and Russell (1966) model are shown in Table 13. For all the characters there were significant differences among the genotypes. The G x E (linear) for all the traits was highly significant showing that the genotypes differed significantly for their regression on environmental index.

This also implied that the relationship between genotype performance and the environmental values was not linear for all traits.

The mean squares for pooled deviations from regressions were highly significant for most characters indicating that the major components for the differences in regressions were due to the deviations from the linear function except for grain yield, number of pods per plant and mean length of pod bearing region which were not significant.

ource of ariation	df	Grain yield/ plant X 10^3	Number of pods/ plant X 10^3	Number of seeds/ pod	100-seed weight	Days to 50% flowering	Days to 50% maturity X 10^3	Mean plant height X 10^3	Length of pod bearing region X 10^3	Number of pod bearing branches
nvironments E)	6	8.47**	37.17**	2.71**	29.2**	868.08**	2.17**	20.35**	1.03**	255.01**
eps within nvironment	14	0.13	0.14	0.11	0.86	25.01	0.11	0.05	0.01	2.12
enotype ;)	9	0.78**	3.96**	4.03**	72.6**	814.47**	0.86**	3.86**	0.51**	30.29**
x E	54	1.38**	1.56**	0.63**	9.33**	77.64**	0.25**	0.34**	0.04**	17.95**
ooled rror	126	0.12	0.85	0.06	0.77	19.71	0.05	0.04	0.02	2.30

** Significant at P = 0.01

environments (five locations) in Kenya in 1987 (short rains) and 1988 (long rains).

Environment	Grain yield per plant	Number of pods per plant	Number of seeds per pod	100-seed weight	Days to 50% flowering	Days to 50% maturity	Mean plant height	Length of pod bearing region	Number of pod bearing branches
. Mtwapa 1988 long rains	51.71	132.46	0.62	1.36	-5.81	-4.93	89.7	16.6	5.39
. Machakos 1988 long rains	-7.52	4.15	0.25	1.43	3.13	-26.14	-17.88	-2.96	-4.03
. Kiboko 1988 long rains	-17.40	-12.99	-0.22	-2.05	-13.51	-1.16	-15.71	0.36	0.98
. Thika 1988 long rains	-24.35	-31.49	-1.09	-2.46	11.99	5.23	-46.91	-12.40	-5.18
. Kabete 1987 short rains	-12.50	-41.26	0.26	-0.15	-5.10	-4.84	-20.91	-5.79	-1.83
. Kiboko 1987 short rains	30.04	-8.39	0.20	0.11	9.00	11.73	26.89	10.53	8.06
. Thika 1987 short rains	-19.99	-42.48	-0.02	1.77	6.57	20.12	-15.11	-5.35	-3.39

urce of variation	df	Grain yield/ plant X 10^3	Number of pods/ plant X 10^3	Number of seeds/ pod	100-seed weight	Days to 50% floweri-ng	Days to 50% maturi-ty X 10^3	Mean plant height X 10^3	Mean length of pod bea-ring regi-on X 10^3	Number of pod bea-ring bra-nches
	9	0.79**	3.96**	4.03**	72.62**	814.47**	0.86**	3.86**	0.51**	30.29*
+ (GxE)	60	1.12	5.12	0.86	11.32	156.68	0.44	2.34	0.14	41.65
(linear)	1	50.84**	223.0**	16.25**	175.29**	5208.49**	13.03**	122.13**	6.18**	1530.07**
x E (linear)	9	0.61*	7.39**	2.47**	26.54**	167.78**	0.57**	1.17**	0.14**	40.23**
oled deviation	50	0.22	0.35	0.26**	5.30**	53.646**	0.17**	0.16**	0.02	12.14**
3/60	5	0.35*	0.56	0.08	0.45	134.38**	0.25**	0.25**	0.03	1.47
1	5	1.03**	1.03*	0.05	1.07	146.837**	0.10	0.18**	0.05*	1.96
P 670	5	0.27*	0.04	0.03	8.5**	101.33**	0.05	0.03	0.01	8.32**
NYENZENI II	5	0.008	0.02	0.08	0.67	58.20*	0.07	0.09	0.005	7.20*
RIAKANI II	5	0.03	0.13	0.08	0.97	27.62	0.25**	0.005	0.003	20.13**
RIKEBUNI 7	5	0.04	0.03	0.08	1.20	52.32*	0.12*	0.04	0.02	20.40**
IKA LINE SEL.	5	0.39**	0.62	0.05	1.88*	68.63**	0.35**	0.08	0.03	1.35
PL 312	5	0.01	0.04	1.67**	9.99**	70.71**	0.21**	0.11*	0.009	3.83
PL 215	5	0.05	0.08	0.22**	2.50**	74.30**	0.09	0.10	0.007	4.68
PL 7035	5	0.04	0.94*	0.24**	25.80**	96.01**	0.15*	0.73**	0.07**	52.02**
an error	126	0.12	0.37	0.06	0.77	19.71	0.04	0.04	0.02	2.30

* = Significant at 0.05
** = Significant at 0.01

Tests of deviation from linear regression for each genotype with respect to grain yield showed significant differences for T21 and Thika Line Selection (at P = 0.01). Cultivars 423/60 and NPP 670 showed significant differences at P = 0.05. Cultivars T21 and ICPL 7035 showed significant differences for pods per plant at P = 0.05

Deviations for seeds per pod were not significant for all genotypes except for the exotic genotypes (ICPL 312, ICPL 7035 and ICPL 215) which were significant at P = 0.01.

Significant differences were detected for 100 seed weight for T21, ICPL 312, ICPL 215 and ICPL 7035 (all at P = 0.01) and for Thika line selection at P= 0.05. Only Mariakani II showed a non significant difference for days to 50 % flowering while Marikebuni 7 and Munyenzeni II were significant at P=0.05 and other genotypes were significat at P=0.01.

Significant deviations were found for days to 50% maturity for 423/60, Mariakani II, Thika Line Selection and ICPL 312 (P= 0.01) as well as for ICPL 7035 and Marikebuni 7 (P = 0.05). For plant height the individual deviations from linear regression were significant for 423/60, T21 and ICPL 7035 (at P = 0.01) while for ICPL 312 significant differences occurred at P = 0.05.

Only cultivars T21 (at P = 0.05) and ICPL 7035 (at p = 0.01) showed significant deviations for length of pod bearing region. For number of pod bearing branches NPP 670, Mariakani II, Marikebuni 7 and ICPL 7035 showed significant differences (P = 0.01) and Munyenzeni II significant difference at P = 0.05.

4.3.2 Stability and adaptability parameters

The values of mean ($\bar{X}_i$), regression coefficient (b_i) and deviations from regression ($s^2_{d_i}$) are shown in Tables 14-22. The genotypes with b_i approximating unity have average adaptability while those above and below unity are adapted specifically to the favourable and unfavourable environments specifically. The genotypes with the lowest $s^2_{d_i}$ are most stable.

Grain yield (kg/ha)

The genotypes which had yields above the mean were 423/60, Thika Line Selection, T21, Mariakani II and Marikebuni 7. These four genotypes represented each of the three different groups of genotypes included in this study.

Cultivar 423/60 had a B_i value showing maximum deviation from unity indicating that it was specifically adapted to favourable environments. The b_i values for Thika Line Selection and Mariakani II showed substantial deviation from unity indicating that these genotypes were also adapted to favourable environments (Table 14).

Cultivar Marikebuni 7 was widely adapted to all environments. Although Munyenzeni II and ICPL 7035 were well adapted, their yields were low.

The $s^2_{d_i}$ values showed that 423/60, T21 and Mariakani II had poor stability. Cultivars Thika Line Selection, ICPL 215 and Marikebuni 7 were the most stable.

The results showed that ICPL 215 was specifically adapted to unfavourable environments and was among the most stable cultivars for grain yield although its grain yields were relatively low. Cultivar NPP 670 showed specific adaptation to favourable environments and was ranked eighth in stability and had low yields.

Based on the above parameters Thika Line Selection, Marikebuni 7 and Mariakani II were the most desirable genotypes combining good yield, wide adaptation and good stability

Table 14: Mean and stability parameters estimates from linear regression model for ... for ten pigeonpea genotypes grown at seven environments (five locations) in Kenya during 1987 (short rains) and 1988 (long rains)

Genotype (G)	Mean grain yield (kg/ha) x 10³ (x)	Regression Coefficient		Deviation from regression (S^2di) (x 10^3)
		Phyenotypic (b_i)	Genotypic (B_i)	
423/ED	2.01(1)	1.814(10)	0.814	0.227(9)
T21	1.40(5)	0.293(8)	−0.707	0.906(10)
NPP 670	0.88(9)	0.243(9)	−0.757	0.155(8)
MUNYENZENI II	1.31(6)	1.020(3)	0.020	−0.110(7)
MARIAKANI II	1.74(3)	1.131(4)	0.131	−0.086(5)
MARIKEBUNI 7	1.45(4)	1.017(1)	0.017	−0.075(3)
THIKA LINE SELEC.	1.75(2)	1.514(7)	0.514	−0.067(1)
ICPL 312	0.57(10)	0.535(6)	−0.465	−0.109(6)
ICPL 215	0.97(8)	0.772(5)	−0.228	−0.071(2)
ICPL 7035	1.12(7)	0.830(1)	−0.170	−0.081(4)
Mean	1.32	0.917	−0.083	0.0689

* Ranks are given in parenthesis

for grain yield.

Pods per plant

The entries which had number of pods above the average number included Thika Line Selection , 423/60, T21, Marikebuni 7 and Mariakani II. The cultivars Thika Line Selection and 423/60 were adapted specifically to the favourable environments while T21, Marikebuni 7 and Mariakani II were widely adapted.

Cultivars Munyenzeni II and ICPL 7035 were well adapted but their mean number of pods were low. For stability based on $s^2_{d_i}$ values, T21, Thika Line Selection and 423/60 had good stability. Cultivars Mariakani II and Marikebuni 7 had poor stability. On the basis of B_i and $s^2_{d_i}$ it was found that in general T21 was the most desirable genotype for pods per plant as it was well adapted and had good stability (Table 15). Cultivars Thika Line Selection and 423/60 had good yields (high number of pods/plant) as well as good stability but were adapted to favourable environments.

Table 15: Mean and stability parameters estimates from linear regression model for pods per plant for ten pigeonpea genotypes grown at seven environments (five locations) in Kenya during 1987 (short rains) and 1988 (long rains).

Genotype (G)	Mean number of pods per plant ($\bar{x}$)	Regression coefficient		Deviation from regression(s^2 di) ($\times 10^3$)
		Phenotypic(b_i)	Genotypic B_i)	
423/60	81(2)+	1.947(10)	0.947	0.289(4)
T21	78(3)	1.286(4)	0.286	0.179(2)
NPP 670	24(9)	0.239(8)	-0.761	0.811(8)
MUNYENZENI II	45(6)	0.871(3)	-0.129	0.828(10)
MARIAKANI II	56(5)	0.906(2)	-0.094	0.723(5)
MARIKEBUNI 7	59(4)	1.084(1)	0.084	0.821(9)
THIKA LINE SELEC.	90(1)	1.928(9)	0.928	0.236(3)
ICPL 312	22(10)	0.566(6)	-0.434	0.808(7)
ICPL 215	36(8)	0.558(7)	-0.442	0.767(6)
ICPL 7035	41(7)	0.615(5)	-0.385	0.093(1)
Mean	53	1.000	0.000	0.556

+Ranks are given in parenthesis

Seeds/pod

Deviation of b_i from unity was minimum for Mariakani II, NPP 670, 423/60 and Marikebuni 7, suggesting that the genotypes had wide adaptability.

Cultivars ICPL 312 and ICPL 7035 were adapted to favourable environments. Number of seeds/pod for T21, Thika Line Selection, Mariakani II, Munyenzeni II and 423/60 showed very good stability compared to others while ICPL 7035 and ICPL 312 had very poor stability.

The cultivars 423/60, Munyenzeni II, Mariakani II and Marikebuni 7 had seeds/pod above average.

Based on these observation Mariakani II and 423/60 were the most desirable genotypes as they combined good adaptability, good stability and a high number of seeds/pod (Table 16)

100 Seed Weight

Cultivars NPP 670 and ICPL 215 had minimum deviation from unity indicating that they are well adapted. The genotype NPP 670 had poor stability for this trait. On basis of deviations from regression ($s^2_{d_i}$) ICPL 215 was the most stable genotype and also the most desirable genotype for this

Table 16: Mean and stability parameters estimates from linear regression model for seeds per pod for ten pigeonpea genotypes grown at seven environments (five locations) in Kenya during the 1987 (short rains) and 1988 (long rains)

Genotypes (G)	Seeds per pod ($\bar{x}$)	Regression coefficient		Deviation from regression (s^2di)
		Phenotypic (b_i)	Genotypic (β_i)	
423/60	5(4)+	0.505(3)	-0.495	0.020(5)
T21	4(9)	0.239(7)	-0.761	0.005(1)
NPP 670	4(6)	0.612 (2)	-0.388	0.030(7)
MUNYENZENI II	5(2)	0.487(5)	-0.513	0.020(4)
MARIAKANI II	5(1)	0.881 (1)	-0.119	0.017(3)
MARIKEBUNI 7	5(3)	0.534 (4)	-0.466	0.023(6)
THIKA LINE SELEC.	4(5)	0.184(8)	-0.816	0.008(2)
ICPL 312	3(10)	2.956 (9)	1.956	1.612(10)
ICPL 215	4(7)	0.219(6)	-0.781	0.159(8)
ICPL 7035	4(8)	3.286 (10)	2.286	0.182(9)
Mean	4	0.9903	0.009	0.208

** Significant at P = 0.01
* Significant at P = 0.05
+ Ranks are given in parenthesis.

trait as it combined high seed weight, good adaptation and good stability. The results indicated that although ICPL 312 and ICPL 7035 were adapted to favourable environments they were unstable for this trait (Table 17).

Days to 50% flowering

Table 18 shows that the cultivars T21 and ICPL 312 were well adapted to favourable environments and were early flowering. Cultivars Thika Line Selection and ICPL 215 were more adapted to unfavourable environments. Although Marikebuni 7 and Munyenzeni II were well adapted they were not as early as cultivars ICPL 312 and T21.

On the basis of $S^2_{d_i}$ values Mariakani II was the most stable genotype followed by Marikebuni 7 and Munyenzeni II. The cultivar NPP 670 had poor stability while T21 had the poorest stability. Based on the adaptability and stability parameters the early flowering genotypes ICPL 312 and T 21 were adapted to the more favourable hotter environments although rather unstable. Cultivars Marikebuni 7, Mariakani II and Munyenzeni II had good stability and wide adaptation.

Days to 50% maturity

The deviation of b_i values from unity showed that it was minimum for 423/60, Thika Line Selection, Marikebuni 7,

flowering for the pigeonpea genotypes grown in seven environments (5 locations) in Kenya during 1987 short rains and 1988 long rains.

Genotype (G)	Mean days to 50% flowering	Regression coefficient		Deviation from regression (s^2d_i)
		Phenotypic (b_i)	Genotypic B_i	
423/60	110(7)+	0.701(6)	-0.299	114.670(9)
T21	92(2)	1.736(10)	0.736	166.545(10)
NPP 670	122(10)	1.426(8)	0.426	81.624(8)
MUNYENZENI II	111(8)	1.053(2)	0.053	38.491(3)
MARIAKANI II	112(9)	0.925(4)	-0.075	7.911(1)
MARIKEBUNI 7	110(6)	0.957(1)	-0.043	32.613(2)
THIKA LINE SELEC.	103(4)	0.671(7)	-0.329	48.801(4)
ICPL 312	84(1)	1.489(9)	0.489	50.917(5)
ICPL 215	101(3)	0.840(5)	-0.160	54.596(6)
ICPL 7035	108(5)	1.056(3)	0.056	76.303(7)
Mean	105	1.0854	0.0854	67.247

+Ranks are given in parenthesis

Mariakani II and Munyenzeni II had good stability and wide adaptation.

Days to 50% maturity

Deviation of b_i values from unity showed that it was minimum for 423/60, Thika Line Selection, Marikebuni 7 and ICPL 7035 (Table 19) showing that these genotypes had wide adaptation.

Cultivars ICPL 215 and NPP 670 were more adapted to favourable environments. The days to 50% pod maturity for NPP 670, Munyenzeni II, ICPL 215 and T21 showed very good stability as compared to others, while Thika Line Selection, Mariakani II and 423/60 had poor stability.

Cultivars ICPL 312 and T21 were well adapted to unfavourable environments and were early maturing.

Plant height

Table 20 shows that Thika Line Selection, T21, Marikebuni 7 and Mariakani II showed minimum deviation of b_i from unity. This suggested that these genotypes had wide adaptability.

Cultivars 423/60, ICPL 215 and ICPL 312 were adapted to favourable environments. In case of

Table 19 Mean and stability parameters estimates from linear regression model for days to 50% maturity for ten pigeonpea genotypes grown in seven environments (5 locations) in Kenya during 1987 short rains and 1988 long rains.

Genotype (G)	Mean days to 50% maturity ($\bar{x}$)	Regression coefficient		Deviations from regression (s^2di)
		Phenotypic (bi)	Genotypic (βi)	
423/60	151(7)+	1.061(1)	0.061	201.078(8)
T 21	130(2)	0.387(5)	-0.615	50.4638(4)
NPP 670	160(10)	2.015 (10)	1.015	4.766(1)
MUNYENZENI II	150(6)	1.674 (8)	0.674	30.714(2)
MARIAKANI II	157(9)	1.661 (6)	0.661	205.375(9)
MARIKEBUNI 7	148(5)	1.199(3)	0.199	70.388(5)
THIKA LINE SELEC.	145(4)	1.105(2)	0.105	303.194(10)
ICPL 312	129(1)	0.329(7)	-0.671	160.3316(7)
ICPL 215	138(3)	0.062(9)	-0.938	43.1228(3)
ICPL 7035	156(8)	0.506(4)	-0.494	103.038(6)
Mean	146	0.999	0.0001	117.247

+ Ranks are given in parenthesis.

Table 20 Mean and stability parameters estimates from linear regression model for plant height for ten pigeonpea genotypes grown in seven environments (5 locations) in Kenya during 1987 short rains and 1988 long rains.

Genotype (G)	Mean plant height	Regression coefficient		Deviations from regression (s^2di)
		Phenotypic (bi)	Genotypic (ßi)	
423/60	121(10)+	1.34 (9)	0.34	203.895(9)
T 21	100(5)	0.881 (2)	-0.119	138.150(8)
NPP 670	88(3)		-0.336	10.714(3)
MUNYENZENI II	104 (6)	1.258 (5)	0.258	49.186(6)
MARIAKANI II	111(8)	1.242 (4)	0.242	38.117(4)
MARIKEBUNI 7	106(7)	1.127 (3)	0.127	1.924(1)
THIKA LINE SELEC.	118(9)	1.000 (1)	0.000	40.856(5)
ICPL 312	45(1)	0.601 (8)	-0.399	2.438(2)
ICPL 215	68(2)	0.555 (10)	-0.445	55.171(7)
ICPL 7035	95(4)	1.0007	0.339	687.963(10)
Mean	96	0.96687	0.0007	122.841

+Ranks are given in parenthesis

deviations from regression ($s^2_{d_i}$) Marikebuni 7, ICPL 312 and NPP 670 were the most stable for this trait. Although ICPL 312 had good stability and was adapted specifically to the favourable environments it had the shortest plants.

The genotypes 423/60 and ICPL 7035 had very poor stability and were adapted to favourable environments and varied greatly in their heights.

Length of pod bearing region

Table 21 shows that cultivars marikebuni 7, Mariakani II, Thika Line Selection and ICPL 7035 were well adapted. Of these Marikebuni 7 and Thika Line Selection were the most stable for this trait.

The genotypes ICPL 312, ICPL 215 and NPP 670 had the shortest lengths of pod bearing regions. The poorest stability for this trait was recorded for ICPL 7035 and T21.

Number of pod bearing branches

Table 22 shows that ICPL 312, ICPL 215 and Mariakani II had minimum deviation of b_i indicating that they were widely adapted. Cultivars ICPL 7035 and Marikebuni 7 were adapted to the favourable environments. The $s^2_{d_i}$ values sug-

Table 21: Mean and stability parameters estimates from linear regression model for length of pod bearing region for ten pigeonpeapea genotypes grown in seven environments (5 locations) in Kenya during the 1987 (short rains) and 1988 (long rains).

Genotype (G)	Mean length of pod bearing region (cm)	Regression coefficient		Deviations from regression (s^2di)
		Phenotypic (b_i)	Genotypic (β_i)	
423/60	32(8)+	1.441 (6)	0.441	13.288(6)
T21	36(10)	1.814 (10)	0.814	31.909(9)
NPP 670	17(3)	0.415(8)	0.585	6.071(2)
MUNYENZENI II	25(6)	1.345 (5)	0.345	13.244 (7)
MARIAKANI II	23(5)	0.949 (2)	0.051	14.691(8)
MARIKEBUNI 7	25(7)	0.989 (1)	0.011	2.040(1)
THIKA LINE SELEC.	32(9)	1.111 (3)	0.111	7.411(3)
ICPL 312	9.0(1)	0.392 (9)	0.608	9.165(4)
ICPL 215	14(2)	0.423 (7)	0.577	10.796(5)
ICPL 7035	20(4)	1.119 (4)	0.119	51.943(10)
Mean	23	0.9998	-0.0002	16.0558

( )+ Ranks are given in parenthesis.

Table 22: Mean and stability parameters estimates from linear regression model for number of pod bearing branches for ten genotypes grown in seven environments (5 locations) in Kenya during 1987 (short rains) and 1988 (long rains).

Genotype (G)	Mean number of pod bearing branches	Regression coefficient		Deviation from regression (s^2di)
		Phenotypic (b_i)	Genotypic (β_i)	
423/60	7(3)+	0.532 (7)	-0.468	0.832(2)
T 21	9(6)	0.632 (5)	-0.368	0.334(1)
NPP 670	7(2)	0.610 (6)	-0.390	6.025(7)
MUNYENZENI II	10(7)	0.846 (4)	-0.154	4.898(6)
MARIAKANI II	11(9)	1.124 (3)	0.124	17.832(8)
MARIKEBUNI 7	13(10)	1.694 (9)	0.694	18.104(9)
THIKA LINE SEL.	9(5)	0.521 (8)	-0.479	0.947(3)
ICPL 312	6(1)	1.073 (1)	-0.073	1.531(4)
ICPL 215	8(4)	0.917 (2)	-0.083	2.381(5)
ICPL 7035	10(8)	2.051 (10)	1.051	49.724(10)
Mean	9	1.000	0.000	10.261

( )+ Ranks are given in parenthesis.

gested that T21, 423/60 and Thika Line Selection were the m-
ost stable for this trait. Cultivar ICPL 312 combined wide
adaptability with good stability but had a low number of br-
anches. Although Marikebuni 7 had the highest number of pod
bearing branches it had poor stability and its adaptability
was good only in favourable environments.

4.4 WRICKLE'S STABILITY PARAMETER

The values of ecovalence (W_i) for each genotype for
all characters are shown on Table 23. Ecovalence values exp-
ressed as a percentage of genotype x environment interactio-
ns sum of squares which is an indicator of the contribution
of each genotype to the interaction sum of squares are shown
on Table 24.

The genotype with the minimum W_i (or W_i as a perce-
ntage of genotype x environment sum of squares) is more sta-
ble while those with higher W_i values have poor stability.

For grain yield, the four most stable cultivars we-
re Mariakani II, Munyenzeni II, ICPL 7035 and Marikebuni 7.
The cultivars Thika Line Selection and 423/60 had the poore-
st stability.

seven environments (5 locations) in Kenya during 1987 (short rains) and 1988 (long rains).

Genotype	Grain yield kg/ha x 10^3	Pods/plant x 10^3	Seeds/ pod	100-seed weight	Days to 50% flowering	Days to 50% maturity x 10^3	Plant height x 10^3	Length of pod bearing region	Number of pod bearing branches
423/60	5.101	22.80	1.24	10.29	0.72	1.25	2.66	276.89	39
T21	0.288	6.98	1.27	16.30	0.43	0.97	1.09	659.15	31
NPP 670	3.234	13.09	0.38	43.31	0.60	1.60	1.54	270.96	80
MUNYENZENI II	0.044	0.47	0.82	9.14	0.29	0.98	1.28	97.50	58
MARIAKANI II	0.250	0.84	0.36	13.61	0.14	1.83	0.75	18.26	123
MARIKEBUNI 7	0.222	0.29	0.71	15.65	0.26	0.64	0.42	80.19	199
THIKA LINE SEL.	3.275	22.28	1.48	18.87	0.39	1.77	0.43	134.79	43
ICPL 312	1.147	4.42	15.14	95.79	0.48	1.63	2.48	272.56	13
ICPL 215	2.654	4.79	2.14	15.01	0.38	1.60	2.91	705.81	21
ICPL 7035	0.051	7.93	10.48	268.947	0.48	1.07	5.07	358.93	439
Mean	1.627	8.389	3.40	50.69	0.42	1.33	1.863	287.50	104.6

Note: The genotype with minimum W_i is more stable.

genotypes grown at seven environments (3 locations) in Kenya in 1987 and 1988.

Genotype	Grain yield per plant	Number of pods/plant	Number of seeds/pod	100-seed weight	Days to 50% flowering	Days to 50% maturity	Plant height	Length of pod bearing region	Number of pod/ bearing branches
23/60	6.85(10)	27.14(10)	3.65(5)	2.04(2)	17.15(10)	9.35(5)	14.29(8)	11.48(7)	4.02(4)
21	0.39(5)	8.30(6)	3.75(6)	3.24(6)	10.33(6)	7.29(2)	5.88(4)	27.33(9)	3.19(3)
PP 670	4.34(8)	15.59(8)	1.12(2)	8.60(8)	14.35(9)	12.02(7)	8.32(6)	11.23(5)	8.25(7)
TUNYENZENI II	0.06(2)	0.57(2)	2.41(4)	1.81(1)	6.98(3)	7.37(3)	6.91(5)	4.04(3)	5.98(6)
ARIAKANI II	0.03(1)	1.00(3)	1.05(1)	2.70(3)	3.37(1)	13.74(10)	4.05(3)	0.75(1)	12.69(8)
ARIKEBUNI 7	0.30(4)	0.35(1)	2.09(3)	3.11(5)	6.37(2)	4.81(1)	2.26(1)	3.32(2)	20.53(9)
HIKA LINE SEL.	4.40(9)	26.52(9)	4.14(7)	3.75(7)	9.51(5)	13.25(9)	2.34(2)	5.59(4)	4.44(5)
CPL 312	1.54(6)	5.26(4)	44.52(10)	19.01(9)	11.41(7)	12.19(8)	13.34(7)	11.30(6)	1.34(1)
CPL 215	3.56(7)	5.70(5)	6.31(8)	2.98(4)	9.18(4)	11.99(6)	15.64(9)	29.27(10)	2.16(2)
CPL 7035	0.07(3)	9.44(7)	30.81(9)	53.18(10)	11.5(8)	8.027(4)	27.22(10)	14.87(8)	45.29(10)
ean	2.154	9.987	9.985	10.04	10.01	10.00	10.02	11.92	10.79

+Ranks according to magnitude in ascending order are given in parenthesis.

Cultivar Marikebuni 7 was the most stable genotype for pods per plant followed by Munyenzeni II and then Mariakani II, all of which were coast farmers' varieties. The least stable genotypes for this trait were 423/60 and Thika Line Selection.

For seeds per pod cultivars NPP 670 and Mariakani II were the most stable followed by Marikebuni 7 and Munyenzeni II. The least stable genotypes for this trait were ICPL 312 and ICPL 7035.

The 100 seed weight was most stable in Munyenzeni II, 423/60 and Mariakani II.

The genotypes ICPL 312 and ICPL 7035 were the least stable for this trait.

The most stable genotypes for days to 50% flowering were Mariakani II, Marikebuni 7 and Munyenzeni II while entries with poorest stability were NPP 670 and 423/60.

For days to 50% pod maturity Marikebuni 7, NPP 670 and Munyenzeni II had the best stability while Thika Line Selection and Mariakani II had the poorest stability.

Cultivars Marikebuni 7, Thika Line Selection and Mariakani II were more stable for plant height compared to ICPL 215 and ICPL 7035.

For length of pod bearing region Mariakani II, Mar-

;kebuni 7 and Munyenzeni II were the most stable genotypes while ICPL 215 and T21 were the least stable.

The most stable genotypes for number of pod bearing branches were ICPL 312, ICPL 215 and T21 while the least stable genotypes were ICPL 7035 and Marikebuni 7.

4.5 Rank correlations

The ranked correlation coefficients between the different stability parameters (Table 25) indicated that for all the characters there was no significant difference between the ranks except for a few cases.

For grain yield only the ranks between (W_i) and regression coefficient (b_i) was significant. For number of pods per plant there was a significant positive correlation between Wrickles stability parameter (W_i) and the phenotypic regression coefficient (b_i).

For number of seeds per pod the ranks between the mean seeds per pod ($\bar{x}$) and (W_i) indicated a positive significant correlation. The rank correlation between Wrickles stability parameter (W_i) and phenotypic regression coefficient

Parameters	Grain yield/ plant	Number of pods per plant	Number of seeds/pod	100-seed weight	Days to 50% flowering	Days to 50% maturity	Mean plant height	Length of pod bearing region	Number of pod bearing branches
$\bar{X}_i$ vs W_i	0.16	−0.28	0.78*	0.006	−0.08	0.16	−0.49	−0.13	−0.45
$\bar{X}_i$ vs s^2d_i	0.07	0.39	0.43	−0.31	−0.25	−0.08	0.15	0.14	0.56
$\bar{X}_i$ vs b_i	−0.23	−0.08	0.72	0.53	−0.43	0.06	−0.44	−0.21	0.42
W_i vs s^2d_i	0.04	0.61	0.47	0.42	0.83**	0.50	0.6	0.33	−0.42
W_i vs b_i	0.75*	0.89**	0.91**	0.55	0.53	0.16	0.87**	0.68	−0.09
s^2d_i vs b_i	0.51	−0.31	0.29	0.29	0.62	−0.72*	0.27	0.13	0.30

** Significant at P = 0.01

* Significant at P = 0.05

b_i) was positive and highly significant.

For 100 seed weight there was no significant association between the rankings. There was a highly significant positive correlation between the ranks of ($s^2_{d_i}$) and W_i for days to 50% flowering.

For days to 50% maturity a negative correlation of ranks between $s^2_{d_i}$ and b_i was observed which was significant at P = 0.05. For plant height only the rank correlation between b_i and W_i was significant at P = 0.01.

Length of pod bearing region and the number of pod bearing branches showed no significant correlation in the ranks. The general trend of rank correlation shows that all the parameters were effective in estimating genotype stability.

CHAPTER V

DISCUSSION

5.1 Mean performance of genotypes

The objectives of any breeding programme will depend on problems to be solved and the expected end product. The end product is usually a plant genotype that overcomes some of the limitations of existing genotypes. The major objective of pigeonpea breeding in Kenya is to overcome the yield limiting factors. Important objectives in pigeonpea breeding in Kenya include seed yield, early maturity, reduced height, tolerance to drought and adaptation to different ecological zones (Kimani, 1987).

Breeding genotypes with potential to produce high seed yields of acceptable characteristics is the major abjective in the breeding of pigeonpea. All other objectives are directly or indirectly related to yield improvement. Most local pigeonpea genotypes are late maturity with a strong perennial tendency. The long duration to maturity may be undesirable for subsistence farming family. It is therefore desirable to select genotypes that can mature early since rainfall is usually a limiting factor in the semi-arid areas

Genotypes that flower early have the potential of escaping moisture stress prevalent in these areas. Most local pigeonpea genotypes are tall and have average height in excess of two metres, such plants present difficulties in harvesting or spraying and cannot be grown in close association with low height plants due to shading effects. Short or medium stature genotypes may be more desirable.

Although pigeonpea has a wide adaptability to different climates and soils and is cultivated in most tropical and sub-tropical environments each maturity group has its specific area of adaptation.

For grain yield (kg/ha) the best yielding genotypes were in order 423/60, Thika Line selection, Mariakani II, Marikebuni 7, T21 and Munyenzeni II. The other genotypes, ICPL 215, ICPL 7035, NPP 670, and ICPL 312 were poor yielding. 423/60 is a locally adapted cultivar which was able to adapt itself favourably except at Thika and Kabete in the 1987 short rains. It can be recommended especially for Mtwapa, Thika and Kiboko in the long rains.

The breeding line selection was best suited to all environments except at Kiboko in the short rains. Its best yields were recorded at Mtwapa and Thika in the 1988 long rains as well as in Kabete in the short rains.

The farmers varieties from the Coast were all good yielders and seemed suited to all the environments. T21 which is an exotic line was average yielding and was best suited to Machakos in the 1988 long rains and Kabete in the 1987 short rains. Other exotic cultivars had poor performance over all environments except ICPL 215 which was the best yielding genotype at Kiboko in the 1987 short rains. NPP 670, an improved cultivar was a poor yielder across all environments except Kabete in the 1987 short rains where it ranked third.

The differences observed may be attributed to the climatic and soil conditions occuring in the different environments in the cropping season. Appendices 4-8 show some of these conditions existing in the seven environments included in this study. The optimum environment in this study was that which would produce maximum performance of a given genotype. This environment include a complex of factors, but those considered of primary importance are adequate moisture, favourable temperatures throughout the growing season and adequate fertility. These factors are necessary for the attainment of optimum plant growth. Other factors such as radiation and sunshine are important for grain filling but are influenced by other conditions such as high plant densities, narrow row spacings and early planting (which were all fixed

in this study.)

Mtwapa was the best environment for grain yield and thus had the best combination of factors favouring grain filling especially for cultivar 423/60 and Thika Line selection. The ranking of genotypes across the agroecological zones was variety specific indicating that each genotype was suited to specific environmental conditions.

Over all environments Thika Line selection had the highest number of pods per plant (Table 3) and was followed by 423/60 (90% of pods per plant in Thika line selection) and T21 (with pods per plant 32% above the overall mean). The exotic lines were very poor for this trait except for T 21 which ranked third overall and was best at Machakos in the 1988 long rains and Kabete in the 1987 short rains.NPP670 performed poorly across locations.The coast farmers varieties were average. The general trend for pods per plant was a similar trend to that observed for grain yield except for the different rankings of genotypes.

The number of seeds per pod were only slightly affected by the environment. This is true because it is a highly heritable trait and therefore not much affected by environment (Kimani, 1988). Cultivars Mariakani II Munyenzeni II and Marikebuni 7 had more seeds than other genotypes (Table

4) . The trait thus had its phenotypic superiority among the three coast farmers' varieties. The exotic lines had the poorest performance while the remaining genotypes had average performance.(Table 4).

Very small differences were observed for 100 seed weight across the environments but large genotypic differences were obvious, with NPP 670 having the largest seed. This cultivar was followed by exotic lines ICPL 7035 and ICPL 215. However the poorest performers were the exotic lines ICPL 312 and T21. Farmers' varieties were average in their performance.

The data in Table 6 indicates that there were large genotypic and environmental influences on duration to 50% flowering.This is a confirmation of an earlier report that flowering and maturing are considerably affected by environmental conditions (Kimani,1988).In the 1987 short rains genotypes were earliest at Kabete, followed by Thika and Kiboko. In the 1988 long rains the genotypes were earliest at Kiboko followed by Mtwapa, Machakos and Thika. In the first season days to flowering increased with increasing temperature and decreasi radiation. In the second season there was no clear cut relationship between days to flowering, temperature and radiation. Akinola and Whiteman (1975) reported that among early and

late maturing pigeonpea cultivars, days to flowering depended on day length, photoperiod and radiation. It is known that these factors influence flowering but no data was available in this study to support this fact. Although it is generally assumed that tropical latitudes hardly differ in photoperiod duration, recent evidence suggest that small differences in light duration in Kenya exist and could affect the onset of the reproductive phase and performance of photoperiod sensitive crops such as pigeonpea. (Coulson, Personal Communication).

For days to maturity large genotypic and environmental effects were observed. The performance in both seasons followed a similar trend as for days to 50% flowering.

Results also indicated that in the 1987 short rains plants were tallest at Kiboko followed by Thika and Kabete. The 1988 long rains results indicated that plants were tallest at Mtwapa followed by Kiboko, Machakos and Thika. These results showed that increased temperatures in combination with other environmental factors like radiation and humidity influenced plant height. The tallest genotype, 423/60 also had the highest yields in both seasons. It also appeared that the shortest genotypes were very low yielding.

The length of pod bearing region (Table 9) appeared

to be related to plant height and consequently to the yields for most of the genotypes studied. Number of pod bearing branches was also influenced by both genotypic and environmental effects in both seasons.

5.2 G x E interactions

For all traits under consideration genotype x environment interaction was highly significant. This indicates that the genotypes responded differently when grown under different environments.

Genotype and environment differences were significant for all traits. Earlier studies have reported similar results. Abrams et. al. (1969) reported significant cultivar differences for all characters measured. They in contrast to this study found cultivar x location interaction sums of squares negative and insignificant except for planting date. Partly in contrast to what was observed in this study Onim (1981) reported highly significant differences between environments but found no differences among genotypes. The lack of significant genotype x environment interaction he observed for grain yield was due to use of populations in his study rather than pure lines. The genetic constitution of a population is much broader than that of a pure line and its

interaction with an environment is the mean interaction of all genotypes in that population.

The present study included both pure lines and populations. The highly significant genotype x environment interaction observed for grain yield indicates that selection for average performance over the entire area from which the locations were drawn may not be considered. If a criterion can be found for establishing sub-areas or regions this interaction variance can be reduced. Some such criteria for stratification or division into regions could be the soil type, rainfall or maturity period. If the genotype x environment interaction remains after this, sub division of the area must be controlled by making variety comparisons at a sufficient number of locations within the region (Verma and Gill, 1975).

As indicated by the results (Table 18) genotype x environment interaction for days to 50% flowering was highly significant indicating that for flowering, genotypes are influenced by seasons of short rains and long rains. The interaction appears due to difference in temperatures of the two seasons and difference in minimum temperatures of locations.

The desirable genotypes should show low genotype x environment interaction for agriculturally important traits, or may be flexible for other traits. Such genotypes are said

to be well buffered as these can adjust their genotypic and phenotypic states in response to changing environmental conditions a phenomenon called genetic homeostasis (Lerner,1954)

5.3 Regression Analysis

Estimates based on Eberhart and Russell (1966) model show that for all characters genotype x environment (linear) was highly significant showing that genotypes differed significantly for their regression on environmental index.

This means that genotype performance and environmental values were not linear. Thus breeding methods can be designed towards producing a high yielding genotype with a considerable degree of general adaptability.

Mean squares for pooled deviations from regressions were highly significant indicating that the major components for the differences in regressions were due to deviations from the linear function with exceptions for number of pods per plant and length of pod bearing region.

Tests of individual deviations from linear regression for individual genotypes were significant for most characters indicating that genotypes differed genetically for the regressions of their means (for various traits) on the environmental index.

5.4 Adaptability and Stability Parameters

A genotype is considered stable if its among environment variance is small or if its response of environments is parallel to the mean response of genotypes in the trial or if the residual mean square from the regression model on the environmental index is small. Thus stability of performance refers to the ability of the genotype to show minimum interaction with environments which may be gauged from the squared deviations from regression coefficient ($s^2_{d_i}$).

Adaptability refers to the response of a particular genotype to varying environments as defined by its mean performance ($\bar{x}_i$) and slope of its regression line (b_i) measuring the response of the genotype by the environmental index.

In this study these stability and adaptability parameters have been considered. In addition, another stability parameter considered was the ecovalence (W_i) but this is not based on the regression model and hence discussed separately.

The rank correlation coefficients between stability and adaptability parameters differed in value. They indicated

that there were no significant differences between the ranks except in a few cases. The rank correlation coefficient between stability parameters indicated that they were equivalent in ranking stability of genotypes.

These results agree partly with the findings of other workers. Jowett (1972) indicated that W_i was less informative than $s^2_{d_i}$ while Becker (1981) indicated that the two parameters were equivalent as measures of stability from the agronomic concept of stability.

Prasada and Singh (1980) observed no correlation between W_i and b_i for sorghum. Qualset (1968) also found the absence of correlation between W_i and b_i for sorghum as well.

Mean performance ($\bar{x}$) and b_i are regarded in this study as measures of adaptability while summed deviations from regression ($s^2_{d_i}$) and Wrickle's ecovalence (W_i) were considered as measures of stability.

Grain yield per plant

The highest yielding genotype was 423/60 and was

specifically adapted to the favourable environments. On yield basis this was followed by Thika line selection (which was specifically adapted to the favourable environments) and Mariakani II which was specifically adapted to unfavourable environments. Marikebuni 7 was widely adapted.

Considering stability of these genotypes with respect to summed deviations from regressions ($S^2_{d_i}$) 423/60 had very poor stability. Thika line selection, Mariakani II and Marikebuni 7 had very good stability. On basis of ecovalence (W_i) only Mariakani II and Marikebuni 7 were stable compared to the others which were relatively unstable. Therefore, for grain yield Mariakani II and Marikebuni 7 were the most desirable, genotypes since they combined desirable qualities.

Number of Pods per Plant

Cultivars Thika Line Selection and 423/60 were well adapted to favourable environments while T21, Marikebuni 7 and Mariakani II were widely adapted. The genotypes T21, Thika Line Selection and 423/60 had good stability on basis of $S^2_{d_i}$. In terms of W_i and $S^2_{d_i}$ Marikebuni 7 and Mariakani II had good stability and were in general the most desirable

genotype on basis of performance, adaptability and stability. This trend is like that for grain yield discussed above.

Number of Seeds per Pod

Cultivars Mariakani II, Munyenzeni II, Marikebuni 7 and 423/60 were well adapted. All these genotypes had very good stability with respect to $s^2_{d_i}$ and W_i and so were the most desirable genotypes for this trait.

100 Seed Weight

The genotypes NPP 670,ICPL 7035 and ICPL 215 had above average weights / 100 seed. NPP 670 had poor stability on basis of $S^2_{d_i}$ and W_i. On the basis of high seed weight, good adaptation and good stability ICPL 215 was the most desirable genotype.

Days to 50% Flowering

Cultivars T21 and ICPL 312 were well adapted to favourable environments and were early flowering. Cultivars Thika Line Selection and ICPL 215 were adapted to unfavourable environments. The genotype Marikebuni 7 and Munyenzeni II were well adapted but not as early flowering. For stabil-

ity based on S^2_{di} and W_i and Marikebuni 7 Munyenzeni II and Mariakani II had good stability. For this trait Munyenzeni II and Marikebuni 7 were the most desirable genotypes in terms of earliness good stability and adaptability.

Days to 50% Maturity

Cultivars 423/60, Thika Line Selection, Marikebuni 7 and ICPL 7035 had wide adaptation. These had poor stability except for ICPL 7035 which had relatively good stability. In terms of combining the desired quantities (earliness, wide adaptation and good stability), Marikebuni 7 was the most desirable cultivar.

Plant Height

Cultivars Thika Line Selection, 121, Marikebuni 7 and Mariakani II had wide adaptation. The genotypes Marikebuni 7, ICPL 312 and NPP 670 had very poor stability based on S^2_{di}. For W_i, the cultivars, Marikebuni 7, Thika Line Selection and Mariakani II had good stability. On average therefore the most desirable genotypes were Marikebuni 7, Mariakani II and Thika Line Selection.

Length of Pod Bearing Region

The cultivars Marikebuni 7, Mariakani II, Thika Line Selection and ICPL 7035 were well adapted (widely). Of these genotypes Marikebuni 7 and Thika Line Selection had good stability with respect to $s^2_{d_i}$ and W_i. These then were the most desirable genotypes for this trait.

Number of Pod Bearing Branches

Cultivars ICPL 215, ICPL 312 and Thika Line Selection were the most desirable for this trait.

The genotypes evaluated for stability and adaptability for the various traits indicated that some were better adapted and more stable than others.For example, the most desirable genotypes were the locally adapted genotypes, followed by improved varieties and then the exotic lines. The desirable genotypes showed low genotype x environment interaction for the traits investigated. Such genotypes are said to be 'well buffered' as these can adjust their genotypic and phenotypic states in response to changing environmental conditions (Verma and Gill, 1975). The genotypes with better buffering capacities have wider adaptability and stable performance (for example Mariakani II and Marikebuni 7 in case

of grain yield in this study) compared to others. This can be explained by the different buffering mechanisms operating in these genotypes. The variation in stability among genotypes is thought to be the results of heterozygosity or heterogeneity.

Allard and Bradshaw (1964) have distinguished the different mechanisms which promote the genotypic stability. The genotypes used in this study were populations or individuals which are not pure lines. A population consists of a mixture of diverse homozygous lines , which occasionally intercross and produce a new series of homozygous lines.

A hybrid like NPP 670 is a homogeneous mixture of heterozygous genotypes with individual buffering mechanisms. A variety like Mariakani II used in this study is a homogeneous mixture of homozygous genotypes with individual buffering mechanisms.

Individual buffering is the ability of an individual or a population to produce a certain narrow range of phenotypes under different environments. There is a strong evidence that individual buffering is a property of the heterozygotes (Allard and Bradshaw, 1964). On the other hand in population buffering a population can be an aggregate of a number of genotypes adapted to a somewhat different range of

environments. Like individual buffering population buffering is measurable in terms of genotype x environment interaction.

All the genotypes included have a great potential for improvement in one or more characters. This would provide genotypes with more desirable adaptability and stability especially if selection for the various characters went hand in hand with selection for improved grain yield.

CONCLUSIONS AND PRACTICAL IMPLICATIONS FOR PIGEONPEA BREEDING

1. Genotypes had varied response to specific environments for different characters considered. The genotypes showed adaptability and stability parameters that indicated great potential which can be exploited in them. It was therefore recommended that full potential of genotypes likely to show population buffering (more stable and widely adapted) be further utilized. This was more so with the locally adapted and the improved cultivars which were in general the most desirable.

2. Genotype x environment interaction effects were highly significant for all traits. Both genotypic and environment effects were individually significant for all traits. This is an important aspect in pigeonpea breeding since the interplay of genetic, non-genetic effects and genotype-environmental interaction reduces the correlation between genotype and phenotype which in turn reduces confidence in inferences from experimental data relevant to both plant improvement and inheritance mechanisms. Future breeding programs therefore will need to consider these effects.

3. A considerable portion of genotype x environment interaction sum of squares could be attributed to linear regressions in case of most characters except in a few cases. This led to some useful predictions of stability and appear to be particularly meaningful in practical plant improvement work.

4. The pooled deviations from regressions were significant for all traits except for grain yield/ha number of pods per plant and length of pod bearing region.The genetic differences among the genotypes for their regressions on environmental index showed that the relationships between genotype performance and environmental values is not linear for all characters.

5. The rank correlations of different stability parameters showed similar rankings of genotypes.

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APPENDIX 1: Sources of variation, degrees of freedom and expected mean squares when genotypes are tested at each environment.

Source of variation	df	MS	Expected MS	F-test
Replicates	(r-1)	M_1		M_1/M_3
Genotypes	(g=1)	M_2	$\sigma_e^2 + \sigma_g^2$	M_2/M_3
Error	(g-1)(r-1)	M_3	σ_e^2	

APPENDIX 2: Sources of variation, degrees of freedom and expected mean squares when genotypes are tested at different environments (combined analysis).

Source of variation	df	SS	MS	EMS
Replication in Environments	n(r-1)	Pooled over environments	RMS	
Environments	n-1	$\frac{1}{gr}\sum_j Y^2_{.j} - CF$	EMS	$\sigma^2_e + gr\frac{\Sigma E^2_j}{n-1}$
Genotypes	g-1	$\frac{1}{nr}\sum_i Y^2_{i.} - CF$	GMS	$\sigma^2_e + nr\frac{\Sigma g^2_i}{(g-1)}$
Genotypes x environments	(g-1)(n-1)	$\frac{1}{r}\sum_i\sum_j Y^2_{ij} - CF$ - Genotypes SS - environment SS	GxE MS	$\sigma^2_e + r\frac{\Sigma\Sigma(gE)^2}{(n-1)(g-1)}$
Error	n(r-1)(g-1)	Pooled over environments	eMS	σ^2_e

Appendix 3: Regression analysis (Eberhart and Russell, 1966 Model)

Source of variation	df	SS	MS
Total	ng-1	$\sum_i \sum_j Y^2_{ij} - CF$	
Genotypes	g-1	$\frac{1}{n} \sum_i Y^2_{i.} - CF$	M_1
Env + (Genotype x Env)	g(n-1)	$\sum_i \sum_j Y^2_{ij} - \Sigma Y^2_{i.}/n$	
Environment (Linear)	1	$\frac{1}{g} (\sum_j Y_{.j} I_j)^2 / \sum_j I^2_j$	
Genotype x Environment (linear)	(g-1)	$\sum_i [(\Sigma Y_{ij} I_j)^2 / \sum_j I_j^2] -$ E (linear) SS	M_2
Pooled deviations	g(n-2)	$\sum_i \sum_j \delta^2_{ij}$ -	M_3
Genotype 1	n-2	$[\sum_j Y^2_{ij} - (Y_{i.})^2/n] - [\sum_j Y_{ij} I_j]^2 / \Sigma I^2_j = \sum_j \delta^2 I_j$	
2	n-2	$= \sum_j \delta^2_{2j}$	
3	n-2	$= \sum_j \delta^2_{3j}$	
⋮	⋮	⋮	
10	n-2	$\sum_j \delta^2_{nj}$	
Pooled error	ng(r-1)	$SS(e_{ijk})/3$ (pooled over all E)	

Season	Month	Year	Temperature (°C)			Total	Mean Humidity (%)			Mean
			Mean max	Mean	Mean min.	rainfall (mm)	0600Z	1200Z	Radiation MJ/M²	Sunshine hours
	Nov	'87	23.6	18.9	14.0	182.1	88	62	19.4	5.8
1987/88	Dec	'87	23.8	19.0	13.4	15.3	76	51	25.57	10.1
short	Jan	'88	25.1	19.5	14.0	96.2	79	47	25.31	-
rains	Feb	'88	25.8	19.6	13.4	20.5	79	41	25.97	-
	March	'88	25.8	20.2	14.6	172.0	78	48	22.98	7.3
Seasonal	mean		24.82	19.44	13.88	Tot.486.1	Mean 80	49.8	23.93	7.73
	Apr	'88	23.5	19.0	14.7	466.6	88	64	20.42	6.2
	May	'88	22.3	18.1	13.9	245.9	88	61	-	-
1988	June	'88	21.3	16.9	12.6	50.9	89	62	15.85	-
	July	'88	20.7	16.1	11.6	18.7	88	66	15.58	3.3
long	Aug	'88	20.9	16.4	11.9	46.9	88	64	10.89	3.7
rains	Sept	'88	22.6	17.3	12.1	27.1	85	57	13.15	4.6
	Oct	'88	24.5	18.5	12.8	16.7	81	48	16.27	7.6
	Seasonal Mean		22.26	17.47	12.80	Tot.872.8	86.71	60.29	15.36	5.08
	Annual mean		23.33	18.29	13.25	113.24	83.92	55.92	19.26	6.07

Annual rainfall total = 1358.9 mm

			Mean max	Mean	Mean min	rainfall (mm)	0600Z	1200Z	MJ/M²	Hrs
1987/88 short rains	Nov	1987	25.7	20.6	15.4	119.8	83	55	17.3	5.5
	Dec	1987	27.7	20.5	13.2	18.6	76	46	22.6	10.0
	Jan	1988	27.4	20.8	14.1	48.6	78	43	21.7	9.3
	Feb	1988	28.7	21.3	13.8	19.9	74	36	22.7	9.5
	March	1988	28.2	21.9	15.6	174.3	79	44	21.6	7.2
Seasonal mean		-	27.54	21.02	14.42	tot.381.2	78	44.8	21.18	8.28
1988 long rains	Apr'	1988	25.6	21.0	16.3	270.2	86	59	17.7	6.3
	May	"	24.4	19.9	15.4	118.2	85	60	15.3	-
	June	"	23.5	18.8	14.0	48.3	88	56	13.7	-
	July	"	22.8	18.0	13.2	13.1	86	57	12.2	2.5
	Aug'	"	23.1	18.4	13.7	8.9	85	56	12.1	3.6
	Sept'	"	24.7	19.1	13.4	33.4	81	51	16.0	4.0
	Oct'	"	26.8	20.2	13.5	56.6	74	42	20.6	7.4
Seasonal mean			24.41	19.34	14.21	tot.548.7	83.57	54.43	15.41	4.92
	Annual mean		25.72	20.04	14.30	77.49	81.25	50.42	17.82	6.6

Rainfall annual Total = 930 mm

Season	Month	Year	Temperature(°C)			Total Rainfall (mm)	Mean (3.00p.m) Humidity%	Radiation	Mean Sunshin
			Mean max	Mean	Mean min			MJ/M^2	(Hours
	Nov	1987	25.6	19.9	14.2	93.5	51	20.48	7.2
1987/88	Dec	1987	26.7	20.0	13.2	12.0	57	27.75	9.6
	Jan	1988	36.3	20.2	14.0	93.7	49	26.70	8.8
Short	Feb	"	28.6	21.4	14.2	13.8	50	28.50	10.0
rains	March	"	26.0	21.0	16.0	109.3	58	21.78	9.1
Seasonal mean			28.64	20.5	14.32	Total 322.3	Mean 53	25.04	8.94
	Apr'	1988	24.9	19.8	14.7	203.7	67	23.20	7.1
	May	1988	23.8	18.5	11.9	23.6	67	21.10	6.4
1988	June	1988	23.0	18.5	11.9	10.1	58	18.00	5.0
long	July	1988	22.6	17.4	11.0	NIL	61	17.42	4.5
rains	Aug'	"	22.7	16.8	11.2	3.0	56	17.70	4.5
	Sept	"	24.2	17.0	11.3	15.4	48	20.20	5.2
	Oct'	"	27.1	19.8	12.4	33.6	37	26.70	9.0
Seasonal mean			24.04	18.26	12.06	Total 289.4	56.29	20.62	5.96
	Mean (annual)		25.96	19.19	13.0	55.61	54.92	22.46	7.2
	Total annual rainfall					611.7			

Season	Month	Year	Temperature(°C) Max	Mean	Min		Rainfall total (mm)		Radiation (MJ/M^2)	Sunshine hours
1987/88 short rains	Nov'	'87	28.0	23.4	18.8		99.3		24.1	9.2
	Dec'	'87	28.9	24.15	19.4		10.1		25.6	9.4
	Jan	'88	30.4	24.85	19.3		55.2(1)		24.4	8.7
	Feb	'88	32.4	25.9	19.4		1.8(1&3)		27.6	8.2(3)
	March	'88	33.0(1&2)	26.5	20.0		48.3(2)		26.6(1&2)	8.5(1&2)
Seasonal	mean		30.54	24.96	19.38	Total	214.7	mean	25.66	8.8
1988 long rains	Apr.	'88	28.4	23.85	19.3		99.4		23.4	6.55(1&2)
	May	'88	28.4	22.7	17.0		6.4(1&2)		21.6	-
	June	'88	22.1(1&2)	19.15	16.2(1&3)		6.3(1)		20.0(1&3)	6.8(3)
	July	'88	27.0	21.25	15.5		1.3(2)		17.8	5.4
	Aug.	'88	26.9	21.1	15.3		1.1(3)		17.9	4.8
	Sept.	'88	27.9(1)	21.7	15.5		2.3(1&3)		20.2	6.3
	Oct.	'88	-	-	-		-		-	-
Seasonal	mean		26.78	21.63	16.50	Total	116.8		20.15	5.97
	Annual mean		28.5	23.14	17.80		27.62		22.65	7.385
	Annual rainfall total						331.5			

Numbers in parenthesis represent 1st 2nd or 3rd decade for which the data refers. A decade represent a period of 10 days.

Temperature(°C)

Season	Month	Year	Max	Mean	Min		Total rainfall (mm)		Radiation (MJ/M^2)	Sunshine hours
	Nov	1987	30.9(2)	27.05	23.2		13.5		23.0	-
1987/88	Dec	1987	-	-	-		-		-	-
	Jan.	1988	32.3(1)	28.1	23.9(1)		-		21.1	-
short	Feb.	1988	32.83	28.3	23.7		12.5		26.4	-
rains	March	1988	33.2(1)	28.7	21.4(1&2)		2.6(1&2)		26.0(1&2)	9.25
Seasonal	mean		32.31	28.04	23.72	Total	28.6	mean	24.13	9.25
	April	1988	30.7(1&3)	27.5	24.3(1&3)		281.4(1&3)		21.7(1&3)	8.4(1&3)
1988	May	1988	29.5(1&2)	26.6	23.7(1&2)		98.4		20.8	8.1
	June	1988	28.15(1&3)	25.1	22.0(1&3)		292.7		18.0(1&3)	8.5(1)
long	July	1988	27.9(1&2)	24.8	21.6		38.2		17.83	-
	Aug.	1988	25.9	23.7	21.4		125.2		19.17	8.2
rains	Sept.	1988	28.0	24.7	21.4		58.1		20.73	8.4
	Oct.	1988	-	25.8	-		31.2		24.6	9.8
Seasonal	mean		28.36	25.40	22.4		925.2		20.40	8.57
	Annual	mean	29.94	26.4	22.93		95.38		21.8	8.7

Annual rainfall = 953.8

(-) means not recorded

1, 2, or 3 refer to the decade the data was obtainable.
A decade is 10 days in a month.