ASSESSMENT OF GENOTYPE X ENVIRONMENT INTERACTION ON COMMON BEAN (*Phaseolus vulgaris* L.) IN THE SOUTHERN HIGHLANDS OF TANZANIA

BY

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ABSTRACT

The present study is aimed at assessing genotype x environment interaction on common bean in Southern highlands of Tanzania. The experiment was conducted during the season of 2006/07 in different locations, (Uyole, Mbimba, and Inyala) of Mbeya region. Lines (main plots) SARBYT, EAI L101, CAL 143, SUG 131, NJANO, WANJA and UYOLE 96, and 4 fertilizer levels (sub plots) were laid in split plot in randomized complete block design with three replications at each location. Plot size was 1.5m x 4.0m, with four rows of plants spaced at 50cm x 10cm. Twelve microenvironments were used viz. a combination of three locations and four fertilizer levels 40kg/ha P, 30kg/ha N; 70kg/ha P, 20kg/ha N; 60kg/ha P, 30kg/ha N and 0kg/ha P, 0kg/ha N as a check. Genotypic differences ($P \leq 0.05$) for all traits except yield were significant. The varieties yielded most at Uyole (2056.5kg/ha) followed by Inyala (1551.5kg/ha) and lastly Mbimba (736.25kg/ha). At Uyole and Mbimba fertilizer levels of (60kg/ha P, 30kg/ha N) gave the best response, while at Inyala fertilizer levels of (40kg/ha P, 30kg/ha N) showed best response. Hence fertilizer rate recommendations should be location specific. SARBYT, and EAI L110 had above average response with small variance of deviation from regression and high seed yield thus could be grown in high yielding environments. SUG 131 and NJANO had average response, small variance of deviation from regression and high seed yield hence could be grown in wide range. NJANO and WANJA were stable for flowering trait and they are earliest hence could be recommended to be grown in marginal areas. SARBYT and EAI L110 were least attacked by diseases. Plant height, pods/plant, 100 seed weight and days to 80% maturity were highly correlated. These results contribute important information about the diversity and breeding

values of the bean breeding lines in the Southern Highlands of Tanzania and will be relevant to breeders interested in bean improvement.

DECLARATION

I, Ndimbo Mary Amos, do hereby declare to the senate of Sokoine University of Agriculture that this dissertation is my original work and has not been submitted for a degree award in any other University.

.....Sign:-..... 15/8/2008

Mary Amos Ndimbo Date

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The above declaration confirmed

..... 15/8/2008

Prof. Reuben S.W.O.M Date

(MSc. Supervisor)

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DEDICATION

To my parents the late Amos and Aneth Ndimbo, who laid the foundation for my education. The work is also dedicated to my children Dua and David.

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LIST OF ABBREVIATION AND SYMBOLS

%	Percent
*	Significant at 5%
**	Significant at 1%
ANOVA	Analysis of variance
b	Regression coefficient
CV	Coefficient of variation
CIAT	Centro Internacional de Agricultura Tropical
Cm	Centimeter
g	Grams
Kg/ha	Kilogram per hectare
Kg	Kilogram
LSD	Least Significant Difference
N	Nitrogen
P	Phosphorus
°C	Degree-Celsius
P	Probability
SE	Standard error
S^2d	Variance of deviation
≤	Less or equal to
>	Greater than
m.a.s.l	Meters above sea level
KJ	Kilojoules
R^2	Coefficient of determination

S	South
E	East
RCBD	Randomized complete block design
IRRI	International Rice Research Institute
OC	Organic Carbon
Mg/kg	Milligram per kilogram
Mol/kg	Moles per kilogram
Fig.	Figure

CHAPTER ONE

INTRODUCTION

Common bean (*Phaseolus vulgaris* L) originated in Andean South and Middle America, but is now cultivated worldwide in diverse environments. Common bean is the most widely cultivated species in a group of more than sixty legume species referred to as pulse crops. All pulse crops have gone through a process of agricultural domestication and adaptation to farming systems. Many pulses are now grown in regions far from the geographical origin of the crop. Beans were introduced into Africa some 400 years ago (Leaky, 1970; Purseglove, 1974).

Phaseolus vulgaris L., belongs to the tribe Phaseoleae, subfamily Papilionoideae, Family Leguminosae, or Rosales (CIAT, 1986). The tribe Phaseoleae includes approximately 55 species of which five are cultivated viz. *Phaseolus vulgaris* L., the common bean; *Phaseolus lunatus* L., Lima bean; *Phaseolus coccineus* L., scarlet runner bean; *Phaseolus acultifolius* L., Gray Tepary bean and *Phaseolus polyanthus* Greenman, year-bean and all are diploids (2n =2x =22) (Debouck, 1991).

Plants of the common beans may be either bushy or viny (trailing). Bushy beans are determinate in growth habit and stem elongation ceases when the terminal flower racemes have developed. The leaves are pinnately trifoliolate, both leaves and stems are pubescent. The flowers are self compatible, and almost all of them can be self-pollinated and produce fertile seeds (Summerfield and Roberts, 1985). Flowers are white yellow or bluish purple. The pods are straight or distinctly curved 4-8 inches long, and end in a distinct spur. The seeds of the common bean are highly variable

and consumer preferences are very refined, particularly in Latin America (Voysest and Dessert, 1991). The seed may be white, brown, pink, red, bluish black or speckled in colour. Beans are normally self-pollinated with less than one percent natural crossing (Martin and Leonard, 1967).

The crops are adapted to temperate and cool tropical climates under diverse climatic conditions. It is also adapted to altitudes ranging from 800 – 2300 meters above sea level (m.a.s.l.) with diverse cropping systems (Mushi, 1994). The common bean is a short day crop (White and Laing, 1989) and its growth and development are favoured by mildly cool environments with 16 to 18°C mean growing temperatures of about 12hrs day length, and free from abiotic and biotic stresses. Most cultivars complete their growing cycles i.e from germination to seed maturity in 100 to 130 days.

World production of dry beans for 2005 was 18 million metric tons from an area of over 25 million hectares. The global bean harvest of 18 million tons annually has an estimated value of US dollar 11 billion. Latin America produces nearly half of the world's supply of dry beans with Brazil, Mexico and Central America being the major producers in this continent. Africa is considered to be a secondary centre for bean genetic diversity (CIAT, 2007). Of all agricultural commodities produced in African regions, beans are considered the second most important source of human dietary protein after maize and the third most important source of calories after maize and cassava (Pachico, 1993). In Tanzania the crop is used not only as a less expensive source of dietary protein to both urban and rural communities, but also as

a cash crop. In Southern highlands of Tanzania, beans are chiefly grown for food and as a source of income.

Beans are grown in the majority of the African countries, but most production is in Burundi, Rwanda, Kenya, Uganda, Tanzania, Zaire, Malawi, and Mozambique with annual estimated total area under cultivation of approximately 3.9 million hectares (Wortmann and Allen, 1994).

The common bean is cultivated for its green pods, fresh vegetables and dry beans. The cultivars for green pod harvests are also called French, garden, green, snap, or string less beans. Fully developed green pods of these cultivars have reduced fibers. In some central and Eastern African and Latin American countries, young tender leaves or flowers are also harvested as fresh vegetables. However, the largest production (> 14 million hectares) and consumption are of dry beans, followed by a much lower level of production for snap bean cultivars. In addition, bean is used as a soil fertility improving crop because of its N- fixing attribute. Green leaves, stems, and shelled pods are fed to cattle and dry plant stubbles are used as feed for cattle, ploughed under in order to increase soil organic matter or used as fuel for cooking (Shree, 1999).

Nutritionists agree that beans are one of the most nutritionally complete staple foods. Beans constitute the second and fourth most important source of dietary protein in dry bean consuming countries of Africa and Latin America respectively. In addition beans provide needed calories (up to 30% of the dietary energy), folic acid, Vitamin

B, dietary fiber, essential inorganic micronutrients (Fe, Zn, Ca, Mg and Cu), Flavones, antioxidants and ant carcinogenic compounds (Messina, 2007). Its use as a vegetable can involve fresh pods (French beans) and fresh grain. Dry bean is one of the major constituents in human diet, normally complementing cereals especially in developing countries (Escribano *et al.*, 1997).

The mature dried seed contains per 100g of edible matter: 10g water, 22.6g proteins, 1.4g fat, 62g carbohydrate, 4.3g fibre and 3.7g ash. The energy value is 1453KJ per 100g. The composition of the green pods per 100g is as follows: 91g water, 1.8g proteins, 0.2g fat, 6.6g carbohydrate, 1g fibre and 0.7g ash. The energy value is 126KJ per 100g. Fresh leaves contain per 100g: 3.6g protein, 110mg vitamin C, and a high content of the precursors of vitamin A. The energy content of the leaves is 151KJ per100g. Naturally, the chemical composition of the harvested plant parts depends on the genotypes and ecological factors. In the plant kingdom, the seed of common beans are appreciated not only for their high protein content (20-26%) but also for their potassium (average of 1.47%) (Raemaekers, 2001).

The major health benefit of common beans is their rich source of cholesterol lowering fiber. The higher fiber content of beans prevents blood sugar levels from rising too rapidly after a meal, making these beans an especially good choice for individuals with diabetes, insulin resistance or hypoglycemia. Diets rich in legumes are being used to lower cholesterol levels improve blood glucose control in diabetics and reduce risk of many cancers (Messina, 2007). The common bean contribution to heart health lies also in the significant amount of antioxidants, folic acid, Vitamin B6

and Magnesium. Folic acid and B6 help lower levels of homocysteine, an amino acid that is an intermediate product in an important metabolic process called the methylation cycle (Messina, 2007).

Despite the importance and the role played by beans in the Southern Highlands, there are factors limiting performance of bean varieties which include insect pests and diseases, poor cultural practices, climatic factors, drought, poor soil fertility and use of non improved varieties. Genotype x environment (G x E) interaction is commonly seen as one of the major complications in plant breeding, particularly in relation to the choice selection and production environment(s). The phenomenon is almost unanimously considered to be among the major factors limiting response to selection and it is considered a hindrance to crop improvement and in production areas (Kang, 1998). Such effects may contribute, together with purely environmental effects, to the temporal and spatial instability of crop yields. Temporal instability in particular has a negative effect on farmer's income and in the case of staple crops, contributes to food insecurity at national and household levels.

The G x E interaction is of major importance to the plant breeder in developing improved varieties. When varieties are assessed over a series of environments the relative ranking may differ. This causes difficulty in demonstrating the significant superiority of any variety particularly when performances of varieties are averaged across environments (Eberhart and Russell, 1966). A genotype superior at one location or year would have been superior at all other locations and in all other years, but unfortunately the effect of both the environment and the interaction are much

more than the effects of the genotype in most variety trials (Delacy *et al.*, 1996; Gauch, 1992).

Growing awareness of the importance of G x E interactions has led to crop genotypes being assessed in multi-environments, regional trials for cultivar recommendations or during final stages of elite breeding materials selection. G x E effects enable exploration of the potential opportunities for production over wide or specific areas. Information from these trials help breeders to better understand the type and size of the G x E interactions expected in a given region and the reasons for their occurrence. The information also helps to define, if necessary, a strategy to successfully cope with the effects of interactions (Annicchiarico, 2002). Cultivars testing programmes generate phenotypic data for seed yield and other traits that enable us obtain the most accurate estimate of cultivars performance that is possible within the limitations imposed by time and cost. Baker (1988) indicated that in the quantitative genetic sense and in accordance with available resources, the goal of cultivars testing is to minimize the variance of a cultivars mean. Decreasing the variance of a cultivars mean improves the probability of detecting significant differences among cultivars (Cramer and Beversdrof, 1984). Knowledge of the size of the variance component associated with G x E interactions can be used in conjunction with combinations of years, locations and replications to determine the most efficient allocation of resources for cultivars testing (Rasmussen and Lambert, 1961).

Despite the importance and the role played by beans, production in the southern highlands of Tanzania is often constrained by a number of factors resulting to low yields ranging between 300-600 kg/ha while under research conditions it is normally 1500-2500 kg/ha. Environments in Southern highlands of Tanzania are characterized by drastic changes in altitude, which affect temperatures, combined with variable rainfall, and soil types are important environmental attributes that change within short distances. Similarly seasonal changes are common with respect to rainfall and temperature regimes that may bring differential performance of varieties in the field. Stability parameters for bean genotypes have not been studied before in the Southern Highland Zone of Tanzania. The present study is aimed at assessing the relative performance of genotypes of bean across environments in the Southern Highlands of Tanzania and estimating stability parameters for each genotype on variables of agronomic importance in advanced breeding lines of beans. This will assist to identify stable genotypes for production or as sources of genes in breeding programmes. Since new and promising breeding materials are still coming out, it is necessary to test and evaluate them in various bean-growing environments.

Different attempts have been made to solve the problems created by G x E interactions (Comstock and Moll, 1963). Most of the estimates, however, only provide information on their existence and magnitude, but give no measurements on the individual genotypes with the environment and therefore no measurements of stability of individual cultivars.

High yield stability usually refers to a genotype ability to perform consistently, whether at high or low yield level, across a wide range of environments (Annichiarico, 2002). Genotypes respond in some manner to different environments while the changes in response are usually not identical among genotypes. The resulting problem for breeders or evaluators during selection is that some genotypes are better in some locations/years while others are better in other locations/years. One way to look at it is through stability analyses to determine varieties that are more stable (Annichiarico, 2002).

More widely used methods, are those based on regression. Finlay and Wilkinson (1963) adopted the linear regression technique of Yates and Cochran (1938) to measure the adaptation of barley cultivars. A linear regression coefficient, which was used as stability parameter, was determined for each genotype by regressing individual genotype yield performance against environmental means. Eberhart and Russell (1966) proposed the use of variance of deviations from regression (s^2d_i) to measure cultivar stability, and regression coefficient (b_i) to evaluate cultivar adaptation. Pinthus (1973); Bilbro and Ray (1976) favoured the coefficient of determination (R^2) over variance of deviations from regression as a measure of the predictability of the estimated response (stability). However, high yield stability may be associated with low mean yield or low stability with high mean yield, which complicates genotype selection or recommendation. The mean yield and the yield stability traits are combined into a unique measure of genotype merit. Genotypic and phenotypic correlation coefficients provide a measure of the associations between characters. These values suggest which characters may be useful as indicators of

important traits under consideration and also help identify characters that have little or no importance in the selection program (Johnson *et al.*, 1955).

The present investigation is set to identify advanced breeding lines of beans in the Southern Highlands Zone that have good performance with stable expression of traits of agronomic importance. Such genotypes will hold promise for production and source of genes for genetic improvement in the study areas.

1.1 Main objective

To assess the effect of genotype x environment interaction and stability of common bean varieties.

1.1.1 Specific objectives

(i) Assess genotypic variability and stability parameters of yield and yield components.

(ii) Determine genotypes x environment interaction effects for yield components and disease severities.

(iii) Assess the relationship between stability parameters and mean performance of genotypes in the studied variables.

(iv) Assess interrelations among components of yield in the breeding lines.

CHAPTER TWO

LITERATURE REVIEW

2.1 Effect of environmental conditions

2.1.1 Light

Penetration of light through the canopy is critical and depends to a large extent on the orientation and distribution of leaves. The pulvinus of the beans leaflets and the trifoliolate leaf structure allows the bean plant to orient its leaves in relation to the sun and maximize canopy light interception (Wien and Wallace, 1973).

2.1.2 Temperature

There is more recent evidence that cultivars, which are adapted to different temperatures, show differences in the optimum temperatures for photosynthesis (Laing *et al.*, 1984). Beans are very sensitive to temperatures above 30^0C at flowering time, showing increased abscission of flower buds, flowers and young pods, poor fertilization and seed development in the pods. Greater tolerance of high temperatures would be very desirable and there is some evidence for genetic variation (Ofir *et al.*, 1993). Beans are also sensitive to low temperatures, which can limit their production during early part of the season (Farlow, 1981).

2.1.3 Water

Beans are very sensitive to both drought stress and excessive rainfall. The most critical period is flowering and early pod set, when moisture stress will cause flowers and pods to drop. Early moisture stress at the stage of two trifoliolates can have a

lasting effect by reducing vegetative growth and affecting floral initiation so that crop maturity becomes more uneven.

2.1.4 Soil nutrient

Beans respond well to high fertility levels. Being a short season crop, most of the fertilizer is applied at planting time in order to establish optimum vegetative growth before flowering. Beans like all legumes have relatively high nitrogen demand during pod fill, and senescence and abscission may result from competition for N (Sinclair and de Wilt, 1976). Phosphorus is probably the factor most commonly limiting nitrogen fixation in common beans in developing countries (Graham, 1981). Genotypes vary in their response to phosphorus (Schettin *et al.*, 1987; Fagaria, 1989). However, varieties efficient in using phosphorus appear to be efficient also in using nitrogen (CIAT, 1980). Soil pH should preferably be between 6.0 and 6.6 but critical problems seldom develop unless it falls below 5.2 or rises above 7.0 (Kay, 1979).

2.2 Genotype x environment interaction

Baker (1988) defined G x E as the failure of genotypes to achieve the same relative performance in different environments. To avoid genetic vulnerability associated with the narrowing of the genetic base of any crop, information on the G x E interaction of the germplasms is important (Kang, 1998).

With regard to the comparison of plant material in a set of multi-environment yield trials, the term genotype refers to cultivars with material genetically homogenous,

such as pure lines or clones, or heterogeneous, such as open pollinated populations rather than to an individual's genetic make up. The term environment relates to the set of climatic, soil, biotic (insect pests and diseases) and management conditions in an individual trial carried out at a given location in one year (in the case of annual crops) or over several years (in case of perennials).

Cultivars are grown in a wide range of conditions. They are exposed to different soil types, soil fertility and moisture levels, temperature and cultural practices. All of the variables encountered in producing a crop can be described collectively as environment. When cultivars are compared in different environments, their performance relative to each other may not be the same. One cultivar may have the highest yield in some environments and a second cultivar may excel in others. Changes in the relative performance of genotypes across different environments are referred to as G x E interaction (Fehr, 1987).

The relative performance of genotypes across environments determines the importance of an interaction. There is no G x E interaction when the relative performance among genotypes remains constant across environments. The ranks among cultivars may change across environments resulting to G x E interaction. The most important G x E interaction for the plant breeder is one caused by changes in rank among genotypes (Fehr, 1987).

G x E interaction leading to inconsistency of best yielding materials across cropping environments, challenges plant breeders and complicates cultivar recommendations.

However it may also offer opportunities for example, raising yields through materials specifically adapted to given areas or crop management practices, or limiting yield reduction in unfavourable years through the cultivation of stable- yielding material.

Gene expression is subject to modification by the environment, therefore, genotypic expression of the phenotype is environmentally dependent (Kang, 1998). The development of new cultivars involves breeding of cultivars with desired characteristics such as economic yield, tolerance or resistance to biotic and abiotic stresses, traits that add value to the product, and stability of these traits in target environments. Inconsistent genotypic responses to environmental factors such as temperature, soil moisture, and soil type or fertility level from location to location is a function of G x E interaction. Identification of yield contributing traits and knowledge of G x E interaction and yield stability are important for breeding new cultivars with improved adaptation to environmental constraints prevailing in the target environments.

Several studies have been conducted on G x E interaction for different crops elsewhere. Cooper and DeLacy (1994) and Cooper *et al.*, (1996) showed that investigation of the phenotypic correlations amongst environments were important to understand the discrimination among genotypes grown in them. Gridley (1991) also determined G x E interaction in breeding for improved bean seed yield in Uganda; he reported that in 73% of the trials, significant lines x site interactions were detected.

Egesi *et al.*, (2007) were looking for genetic variation and G x E interaction for yield and other agronomic traits in cassava in Nigeria. Their analysis revealed that G x E interaction was a major source of fresh root yield variation and the different testing sites discriminated among the genotypes. Gebeyehu and Assefa (2003) assessed G x E interaction and stability analysis of seed yield in 16 navy bean genotypes grown in Ethiopia. They found that there was a considerable variation in seed yield within and across environments. Mekbib (2001) also aimed at evaluating common bean (*Phaseolus vulgaris* L.) genotypes for yield performance in Ethiopia for three years. Results showed that the significant G x E interaction indicated that relative performance of the varieties altered in the different environments. Muhammad (2002) assessed correlation and path analysis in yard long bean. He found that genotypic correlation of pods per plant with yield was highly significant. Corte *et al.*, (2002) aimed at estimating the genetic variability for earliness in five common bean cultivars and nine lines. The adaptability and phenotypic stability for grain yield was also assessed. The results showed the presence of genetic variability among the cultivars and lines assessed for days to flowering and maturity. Results also showed that there was wide adaptability and stable performance of the cultivars and lines in different environments on common bean. Carbonell *et al.*, (2004) were looking for the adaptability and stability of grain yield of 18 common bean cultivars and lines in 23 environments and found genetic variability among cultivars. In Tanzania, Mushi (1994) determined the estimates of G x E interactions and their significance on breeding for yield of common beans in the medium altitude zone where he found that G x E interaction effects were highly significant in all trials. With respect to relationships among variables, days to maturity and number of pods per plant had

high positive correlations (Mushi 1994) while Mduruma *et al.*, (1998) evaluating maturity characteristics and yield components of high protein bean varieties got a negative correlation between yield and days to 85% maturity.

2.3 Types of interaction

Every factor that is a part of the environment of a plant has the potential to cause differential performance that is associated with G x E interaction. Environmental variables can be classified as either predictable or unpredictable factors (Allard and Bradshaw, 1964). Predictable factors are those that occur in a systematic manner or are under human control, such as soil type, planting date, row spacing, plant population and rates of nutrient application. Predictable factors can be evaluated individually and collectively for their interaction with genotypes. Studies have been made of genotype x soil type, genotype x row spacing, and genotype x planting. Unpredictable factors are those that fluctuate inconsistently, including rainfall, temperature, and relative humidity. Unpredictable factors contribute to the interactions of genotypes with locations and years.

Genotype x location, genotype x year and genotype x location x year interactions have been evaluated in many crop species. G x E interactions can occur in two ways, first is when difference among genotypes varies without any alteration in their rank while the other is when the rank among cultivars changes across environments. The change in rank between cultivars results in a G x E interaction and this is the most important interaction for a plant breeder.

2.4 Reasons for occurrence of genotype x environment interaction

The reasons for the occurrence of G x E interactions are thoroughly discussed elsewhere (Bidinger *et al.*, 1996; Kang, 1998). Major interaction can be expected when there is wide variation between genotypes for morphophysiological characters conferring resistance to one or more stresses, and wide variation between environments for incidence of some stresses as determined by climatic, soil, biotic and management factors. Other examples may concern the differential response of genotypes to variable levels of stress, such as low temperature, soil salinity, nutrient deficiency, insect pests, diseases, lodging, grazing or inter specific competition, (Annicchiarico, 2002).

The genetic structure of plant materials may also have a bearing on the extent of G x E interaction. Variety types characterized by low levels of heterogeneity such as pure lines, clones, tend to interact with the environment more than types with opposite features such as open – pollinated population mixture of pure lines, because the lower richness in adaptive genes implied by their genetic structure makes them more susceptible to variation in environmental conditions (Brancourt – Hulmel *et al.*, 2000 and Becker and Leon, 1988).

No cultivar can assemble genes conferring superior performance in all environmental types within a relatively large region. This derives from genetically-based trade – offs between yield potential and tolerance to major stress, such as drought (Ludlow and Muchow, 1990; Acevedo and Fereres, 1993), as well as from the need to choose

between incompatible levels of a key adaptive trait, such as earliness of flowering and yield potential (Wallace *et al.*, 1993).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental sites

The study was conducted during the season of 2006/2007 in Southern Highlands of Tanzania at three locations viz. Uyole, Mbimba and Inyala sites (Appendix 1).

3.2 Experimental design

The experiment was a split plot laid in a randomized complete block design (RCBD) with three replications in three locations. Four fertilizer levels being factor A and seven bean genotypes as factor B were used as test materials.

3.3 Crop husbandry

Seven bean lines/varieties were used in the trials viz. SARBYT, EA1 L110, CAL 143, SUG 13, NJANO, WANJA and UYOLE 96, all collected at Uyole research institute. Fields were disc ploughed and harrowed in early January 2007. Hand hoes were used for field leveling followed by experimental layout. At Uyole site planting date was on 30/01/2007, Mbimba site on 01/02/2007 and Inyala site was on 04/02/2007. The spacing was 50cm x 10cm between and within rows, respectively. The rows were 4m long and the plot size was 6.0m^2. Each plot had four rows each with twenty plants. Two rows were used for data collection while the other two rows were used as guard rows. For measurements ten plants in a plot were used and the average recorded. Twelve environments were used viz. a combination of 3 locations viz. Uyole, Mbimba, Inyala, and 4 fertilizer levels viz.40kg/ha P, 30kg/ha N; 70kg/ha P, 20kg/ha N; 60kg/ha P, 30kg/ha N; and 0kg/ha P, 0kg/ha N as a check. High and

medium rates of fertilizers were used to increase the number of microenvironments so as to provide a greater range of environmental conditions. Recommended agronomic packages such as weeding and spraying were used for the management of the trial.

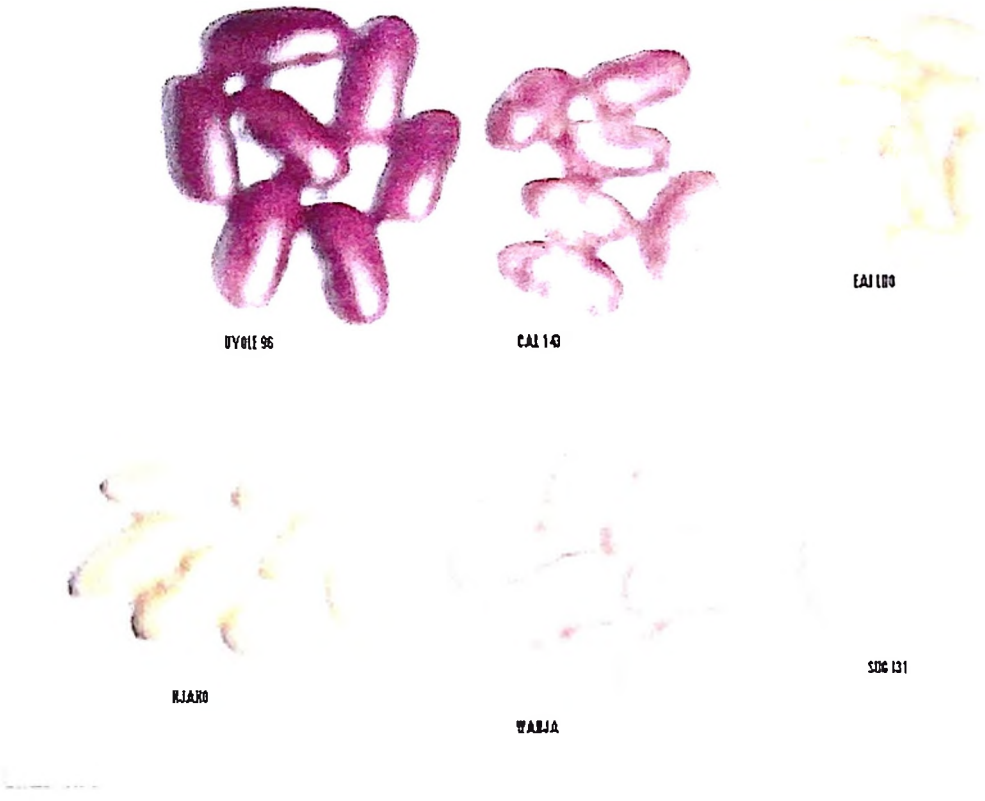


Figure: 1. Six genotypes used in the experiment

3.4. Soil sampling

Soil samples were collected from each of the three sites before ploughing. Physical and chemical properties were determined which are soil texture, soil pH, total nitrogen, organic carbon, available P and cation exchange capacity.

3.5 Data collection

3.5.1 Days to 50% flowering

Days to 50% flowering was measured as days after planting to the time coinciding with the initiation of developmental stage R6 when 50% of the plants had one or more flowers.

3.5.2 Days to 80% maturity

Days to 80% maturity were measured as days after planting to the time coinciding with the initiation of developmental stage R9 when 80% of the plants had reached maturity.

3.5.3 Plant height (cm)

Plant height was taken by measuring distance from the plant base to the tip of the main shoot. Mean value of 10 plants in each plot was recorded.

3.5.4 Number of pods per plant

Number of pods was taken by counting total number present from the 10 plants and average computed to give value per plant.

3.5.5 100 seed weight (g)

100 seed weight was taken by weighing 100 seeds from each plot taken as a representative sample

3.5.6 Seed yield (kg/ha)

Seed yields were taken by weighing total seeds harvested from each plot of $2m^2$ after sun drying to constant weight and measurements converted to kg/ha.

3.5.7 Disease severity score (0 to 9)

Disease scores were taken by scoring using 0 to 9 range, whereas 1 to 3 means resistance (no symptoms or very light symptoms), 4 to 6 intermediate visible and conspicuous symptoms, 7-9 susceptible that is severe to very severe symptoms (CIAT, 1987).

3.6 Data analysis

3.6.1 Analysis of variance

3.6.1.1 Single site analysis

Collected data were analyzed using MSTAT-C software.

Data were firstly subjected to analysis of variance for each location using the procedure given by Gomez and Gomez (1984) for RCBD in split plot. Statistical model used for each location was; $\mathbf{Y_{ijk} = \mu + A_i + B_j + AB_j + e_{ijk}}$

Where by:

$\mathbf{Y_{ijk}}$ = the measurement obtained for the unit in i^{th} genotype of the k^{th} replicate of the j^{th} observation

μ = Overall mean

$\mathbf{A_i}$ = Effect of ith level of factor A (Fertilizer)

$\mathbf{B_j}$ = effect of j^{th} level of factor B (Genotype)

$\mathbf{A_i B_j}$ = the interaction of Fertilizer and Genotype

$\mathbf{e_{ijk}}$ = random error

3.6.1.2 Combined analysis

Combined analysis of variance was performed using MSTAT-C package. The statistical model used was $\mathbf{Y_{ijkl\,m} = \mu + L_i + R_{j(i)} + F_k + LF_{(ik)} + E_{(a)} + G_l + LG_{(il)} + FG_{(ml)} + LFG_{(ikl)} + E_{(b)}}$

Where:

$\mathbf{L_i}$ = i^{th} location effect

$\mathbf{R_{j(i)}}$ = j^{th} replication within i^{th} location effect

$\mathbf{F_k}$ = k^{th} fertilizer effect

$\mathbf{LF_{(ik)}}$ = interaction effect of i^{th} location and ik fertilizer

$\mathbf{E_{(a)}}$ = Error a

$\mathbf{G_l}$ = l^{th} genotype effect

$\mathbf{LG_{(il)}}$ = interaction of l^{th} location and l^{th} genotype

$\mathbf{FG_{(ml)}}$ = interaction effect of k^{th} fertilizer and l^{th} genotype

$\mathbf{LFG_{(ikl)}}$ = interaction effect of i^{th} location, k^{th} fertilizer and l^{th} genotype

$\mathbf{E_{(b)}}$ = Error b

3.6.2 Simple correlation analysis

Simple correlations among yield components and disease severity were measured using MSTAT-C package for each location and for combined locations.

3.6.3 Genotypic and phenotypic correlations

Genotypic and phenotypic correlations were computed using the formulae cited by Robinson *et al.*, (1951).

Genotypic correlation $\mathbf{r = (\delta g_{12} / (\delta g_1) (\delta g_2)}$

Where as:

δg_{12} = the genotypic covariance between the two traits

δg_1= the genotypic variance of the first trait

δg_2 = the genotypic variance of the second trait

Phenotypic correlation $\mathbf{r = (\delta ph_{12}) / (\delta ph_1)\ (\delta ph_2)}$

Where as:

$\delta \mathbf{ph}_{12}$ = the phenotypic covariance between two traits

$\delta \mathbf{ph}_1$= the phenotypic variance of the first trait

$\delta \mathbf{ph}_2$ = the phenotypic variance of the second trait

3.6.4 Path coefficient analysis

Path coefficient is simply a standardized partial regression coefficient and measures the direct influence of one variable upon another and permits the separation of the correlation coefficient into components of direct and indirect effects. Path coefficient analysis was used to determine the direct and indirect effects of days to 50% flowering, days to 80% maturity, plant height, 100 seed weight and number of pods per plant on seed yield. This was performed following the method outlined by Wright (1921) and adopted by Dewey and Lu (1959). The method involved solving unknowns (path coefficients) from a series of simultaneous equations. Computation was done using the following formula:

$\mathbf{r_{16}} = P_{16} + r_{12}P_{26} + r_{13}P_{36} + r_{14}P_{46} + r_{15}P_{56}$

$\mathbf{r_{26}} = P_{26} + r_{12}P_{16} + r_{23}P_{36} + r_{24}P_{46} + r_{25}P_{56}$

$\mathbf{r_{36}} = P_{36} + r_{13}P_{16} + r_{23}P_{26} + r_{34}P_{46} + r_{35}P_{56}$

$\mathbf{r_{46}} = P_{46} + r_{14}P_{16} + r_{24}P_{26} + r_{34}P_{36} + r_{45}P_{56}$

$\mathbf{r_{56}} = P_{56} + r_{15}P_{16} + r_{25}P_{26} + r_{35}P_{36} + r_{45}P_{56}$

The residual factor (PX_6) was computed from the last simultaneous equation.

$$I = P^2X_6 + P^2_{26} + P^2_{36} + P^2_{46} + P^2_{56} + 2P_{16}r_{12}P_{26} + 2P_{16}\, r_{13}P_{36} + 2P_{16}r_{14}P_{46} + 2P_{16}r_{15}P_{56} + 2P_{26}r_{23}P_{36} + 2P_{26}r_{24}P_{46} + 2P_{26}r_{25}P_{56} + 2P_{36}r_{34}P_{46} + 2P_{36}r_{35}P_{56} + 2P_{46}r_{45}P_{56}$$

3.6.5 Stability analysis

A linear regression analysis for genotype performance assessed across environments was performed according to the method proposed by IRRI (2005). Eberhart and Russel (1966) advocated the importance of deviation from regression when deciding the suitability of genotypes for different environmental conditions. In this case a genotype with deviation from regression approaching zero and regression coefficient equal to unity will be suitable for a given environment. The regression model is as follows:

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

Where as:

Y_{ij} = mean of the i^{th} variety at j^{th} environment

μ_i = the i^{th} variety mean over all environments

β_i = the regression coefficient that measures the response of the i^{th} variety to varying environments

I_j = the environmental index

δ_{ij} = the deviation from regression of the i^{th} variety at the j^{th} environment

According to Finlay and Wilkinson (1963), varieties with b value around 1 have average response. When average response is associated with high yield, varieties are specifically adapted to high yielding environments and are optimally responding to inputs. If associated with low yield, varieties are specifically adapted to low yielding environments. b>1 implies high sensitivity to environmental change. Eberhart and

Russell (1966) proposed the use of variance of deviations from regression (s^2d_i) to measure cultivar stability and reliability of response. In this case a genotype with deviation from regression approaching zero and regression coefficient equal to unity will be suitable for a given set of environment.

CHAPTER FOUR

RESULTS

4.1 Soils

Soil characteristics were slightly different across locations as shown in Appendix 2. Uyole site had clay loam type of soil; Mbimba had clay while Inyala had sandy loam type of soil. Uyole and Inyala had slightly acidic type of soils of pH 6.83 and 6.80 respectively where Mbimba had pH value of 5.91. Results also showed that Uyole and Mbimba had a little bit higher cation exchange capacity compared to Inyala being; 20.6, 22.8 and 13.6cmol/kg respectively. All sites had medium organic carbon percent (OC %) being; 2.30% (Uyole), 2.11% (Mbimba) and 2.2% (Inyala). Results also showed that Uyole and Mbimba sites had low available P compared to Inyala. Uyole had 5.69mg/kg, Mbimba 3.23mg/kg and Inyala 19.6 mg/kg. All sites had low total N, Uyole being 0.140, Mbimba 0.154 and Inyala 0.19 mg/kg.

4.2 Analysis of variance (ANOVA) summary

Summary of analysis of variance of the studied variables is shown in Table 1. Locations showed significant variations for all the variables except rust severity. Significant differences between fertilizer levels (factor A) were observed for plant height only, while genotypes (factor B) displayed significant variation in all variables except yield. Significant effects were also observed on location x genotype for all variables except yield. Interaction between fertilizer and genotype was observed only for 100 seed weight.

Table 1: Analysis of variance for the variables studied (mean squares)

Source of variation	df	Days to 50% flowering	Days to 80% Maturity	Pods/ Plant (no)	Plant Height (cm)	Yield (kg/ha)	100 Seed weight(g)	Rust severity (1-9)	Angular Leaf spot Severity (1-9)	Common bacterial blight severity (1-9)
Location	2	366.15***	2274.9***	780.4***	7546***	128.47***	253.9***	0.587	45.01***	0.123
R(L)	6	50.738***	6.694	18.333	233.110	1.6504	9.135	6.925**	2.46*	1.353
Fertilizer (F)	3	0.343	3.168	76.630	1902***	9.9060	2.642	0.173	0.603	0.386
LxF	6	1.311	3.462	6.820	42.858	0.7330	2.816	3.519	1.107	0.446
Error (a)	18	1.060	4.499	12.947	197.511	0.046	7.284	1.856	0.772	0.533
Genotype (G)	6	403.41***	482.21***	209.9***	17435.8***	0.268	416.18***	8.80***	10.2***	57.78
LxG	12	34.165***	56.454***	19.98***	297.97***	0.078	54.52***	6.73***	1.93***	2.804
FxG	18	2.910	4.230	4.546	117.745	0.031	8.274**	0.825	0.708	0.741
LxFxG	36	1.675	4.482	2.371	76.717	0.026	4.891*	0.897	0.615	0.453
Error (b)	144	3.728	7.969	3.428	91.443	0.015	4.320	0.896	0.523	0.738

Comparisons are within columns
* = Significant at 0.05
** = Significant at 0.01 and
*** = Significant at 0.001

4.3 Effect of location for the studied variables

Effects of location on the variables studied are indicated in (Table 2). Locations differed significantly from each other on days to 50% flowering where Mbimba was the latest at 40.07 days, followed by Uyole (38.79 days) and finally Inyala was the earliest (35.99 days). For days to 80% maturity Uyole was the latest at 89.90 days followed by Mbimba 80.50 days while Inyala was the earliest (74.54 days). Uyole had the tallest plants (70.19cm) but did not differ significantly from Inyala (68.90cm) while Mbimba produced the shortest plants (53.17cm) that differed significantly from the other sites. Uyole had the highest number of pods per plant (12.62) but did not differ significantly from Inyala (11.98) while Mbimba produced the lowest (7.048), the difference was significant from the other sites. Locations also differed significantly from each other on seed yield where, Uyole yielded the highest (2056.50kg/ha) followed by Inyala (1551.25kg/ha) and finally was Mbimba (736.25kg/ha) (see also Fig. 2). Significant difference was also observed for 100 seed weight where Uyole had the heaviest (38.17g) followed by Inyala (37.93g) which did not differ significantly from Uyole, and the least was Mbimba (35.05g). There was significant difference on common bacterial blight severity among locations where Inyala had the highest (3.762) followed by Mbimba (3.036) while the lowest was Uyole (2.298).

Table 2: Main effects of locations for the different variables

Variety/ location	Days to 50% flowering	Days to 80% maturity	Plant height (cm)	Pods/ Plant (no)	Seed yield (kg/ha)	100 seed weight (g)	Rust severity (1-9)	Angular leaf spot Severity (1-9)	Common bacterial blight Severity (1-9)
Uyole	38.79	89.90	70.19	12.62	2056.50	38.17	4.202	6.131	2.298
Mbimba	40.07	80.50	53.17	7.048	736.25	35.05	4.274	6.071	3.036
Inyala	35.99	74.54	68.90	11.98	1551.25	37.93	4.107	6.060	3.762
Mean	38.282	79.980	64.085	10.548	0.579	37.051	4.194	6.087	3.032
SE±	0.1123	0.2314	1.5534	0.3926	0.0235	0.2945	0.1486	0.0797	0.0959
CV%	5.04	3.53	14.92	17.55	21.46	5.61	22.57	14.11	23.86
$LSD_{0.05}$	0.3338	0.6876	4.556	1.166	0.06953	0.8749	ns	0.2367	0.2848

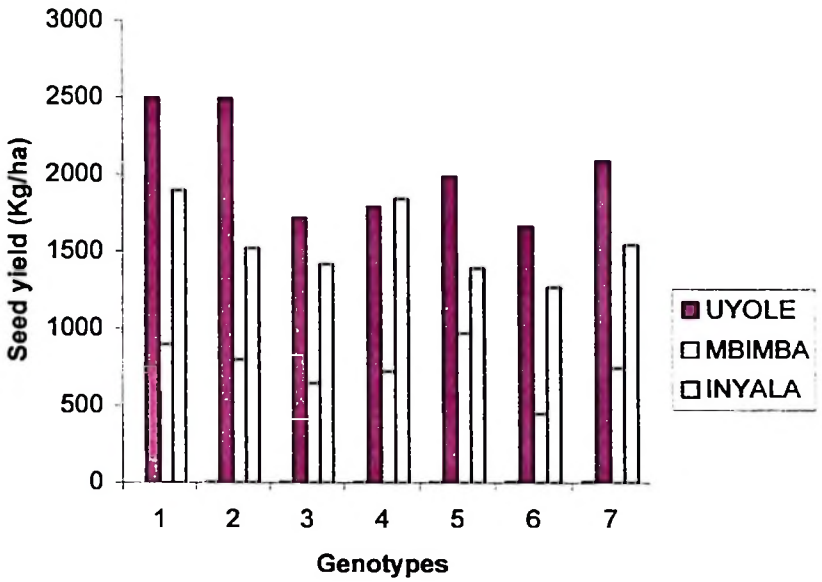


Figure 2a: Seed yield for three locations

4.4 Main effect of fertilizer for the different variables

Plant height differed significantly for different fertilizer rates tested. At Uyole site fertilizer rate 70 kg/ha P, 20 kg/ha N had the tallest plants (75.089cm) followed by fertilizer rate 60 kg/ha P, 30 kg N (74.587cm) (Table 3a). Fertilizer rate 40 kg/ha P, 30 kg/ha N had (71.887cm) while fertilizer rate 0 kg/ha P and 0 kg/ha N produced the shortest plants (61.367cm). Mbimba had the tallest plants at fertilizer rate 60 kg/ha P, 30 kg/ha N (57.24cm), followed by fertilizer rate 70 kg/ha P, 20 kg/ha N (56.99cm) (Table 3b). At Inyala fertilizer rate 60 kg/ha P, 30 kg/ha N produced the tallest plants (71.66cm), followed by fertilizer rate 70 kg/ha P, 20 kg/ha N (70.66cm) (Table 3c). The shortest plants were produced by fertilizer 0 kg/ha P and 0 kg/ha N

(60.33). For combined analysis, fertilizer rate 70 kg/ha P, 20 kg/ha N had the tallest plants (67.89cm) but did not differ significantly from fertilizer rate 60 kg/ha P, 30 kg/ha N (67.84cm) (Table 3d). Fertilizer rate 0 kg/ha P and 0 kg/ha N produced the shortest plants (56.22cm).

Table 3a: Main effect of fertilizers for the different variables at Uyole site

Fertilizers levels (factor A) (kg/ha)	Days to 50% flowering	Days to 80% maturity	Plant height (cm)	Pods/ Plant (no)	Seed yield (kg/ha	100 seed weight (g)	Rust severity (1-9)	Angular Leaf spot Severity (1-9)	Common bacterial blight severity (1-9)
0P and 0N	38.905	84.905	61.367	11.00	1725	37.81	4.71	6.050	2.76
40P,30N	38.571	84.905	71.887	13.00	2125	38.34	4.33	6.38	2.19
70P,20N	38.714	84.905	75.089	13.00	2125	37.95	4.05	6.14	2.10
60P,30N	38.952	84.905	74.587	14.00	2275	38.61	3.71	5.95	2.14
Mean	38.786	84.905	70.732	13.00	2050	38.15	4.20	6.13	2..30
Se±	0.1776	0.000	1.643	0.783	0.043	0.323	0.235	0.125	0.26
CV	1.91	2.80	8.54	11.95	13.79	4.00	26.63	12.39	25.79
$LSD_{0.05}$	0.615	0.998	5.685	2.710	0.147	1.119	0.813	0.433	0.894

Table 3b: Main effect of fertilizers for the different variables at Mbimba site

Fertilizers Kg/ha	Days to 50% flowering	Days to 80% maturity	Plant height (cm)	Pods/ plant (no)	Seed yield (kg/ha)	100 seed weight(g)	Rust severity (1-9)	Angular Leaf spot Severity (1-9)	Common bacterial blight severity (1-9)
0P and 0N	40.048	80.29	44.62	5.71	500	34.90	4.10	5.95	3.14
40P,30N	40.286	80.95	53.81	7.00	675	34.71	3.91	6.05	3.00
70P,20N	39.33	80.52	56.99	7.38	875	35.29	4.67	6.19	3.14
60P,30N	39.74	80.52	57.24	8.19	900	35.91	4.43	6.10	2.86
Mean	39.845	80.57	53.17	7.07	725	35.20	4.27	6.07	3.036
Se±	0.313	0.289	3.88	0.686	0.057	0.78	0.444	0.213	0.105
CV	5.16	2.17	13.79	23.15	29.28	7.21	21.28	17.27	28.03
$LSD_{0.05}$	1.082	0.999	2.375	13.420	0.197	2.701	1.536	0.738	0.571

Table 3c: Main effect of fertilizers for the different variables at Inyala site

Fertilizers Kg/ha	Days to 50% flowering	Days to 80% maturity	Plant height (cm)	Pods/ plant (no)	Seed yield (kg/ha)	100 seed weight (g)	Rust severity (1-9)	Angular Leaf spot Severity (1-9)	Common bacterial blight severity (1-9)
0P and 0N	35.71	74.42	60.33	10.00	1150	37.47	4.00	6.00	3.57
40P,30N	35.95	74.57	68.43	12.57	1725	38.43	4.24	6.14	3.86
70P,20N	36.19	74.67	70.66	13.24	1700	38.15	3.86	5.91	3.86
60P,30N	36.09	74.57	71.66	11.62	1625	37.67	4.33	5.91	3.76
Mean	35.988	74.61	67.77	11.86	1550	37.93	4.11	6.06	3.76
Se±	0.228	0.09	1.78	0.94	9.039	0.52	0.113	0.122	0.128
CV	7.83	0.95	9.76	19.81	26.28	5.23	19.00	12.10	18.68
$LSD_{0.05}$ ±	0.789	0.316	6.174	3.264	0.135	1.815	0.392	0.421	0.442

Table 3d: Main effect of fertilizers for the different variables combined over 3 locations

Fertilizers (kg/ha)	Plant height (cm)	Days to 50% flowering	80%	Pods/ plant	100 seed	Yield	Rust	Angular	Blight
0P and 0N	56.22	38.25	80.03	8.952	36.76	1 725	4.270	6.000	3.159
40P,30N	64.39	38.29	80.14	10.67	37.12	2 125	4.159	6.190	3.016
70P,20N	67.89	38.21	79.65	11.30	37.08	2 125	4.190	6.079	3.032
60P,30N	67.84	38.38	80.10	11.27	37.24	2 275	4.159	6.079	2.921
Mean	64.09	38.28	79.98	10.55	37.05	2 050	4.195	6.087	3.032
SE ±	1.771	0.1297	0.2672	0.4533	0.3400	0.027	0.1716	0.0919	0.1107
$LSD_{0.05}$ ±	5.261	0.385	0.794	1.347	1.010	0.080	0.510	0.273	0.329
CV%	8.54	1.91	2.80	11.95	4.00	13.79	26.63	12.39	25.7

4.5 Main effect of genotypes (factor B)

Main effects of genotypes for various variables are shown in Tables 4a, 4b, 4c and 4d.

4.5.1 Days to 50% flowering

Genotypes differed significantly from each other on days to 50% flowering. At Uyole SARBYT (43.00 days), SUG 131 (42.83 days) and CAL 143 (42.50 days) were the latest followed by EAI L110 (36.00 days) and NJANO (35.58 days) (Table 4a). UYOLE 96 was the earliest (35.42 days). At Mbimba SARBYT (45.00 days) and CAL 143 (45.00 days) were the latest followed by SUG 131 (42.83 days) and then WANJA (38.08 days). EAI L110 (36.25 days), NJANO (35.92 days) and UYOLE 96 (35.83 days) were the earliest (Table 4b). At Inyala SARBYT (38.58 days) and CAL 143 (37.67 days) were the latest followed by SUG 131 (37.50 days), EAI L110 (36.75 days) then NJANO (35.08 days) and UYOLE 96 (34.00 days). WANJA (34.00 days) was the earliest (Table 4c).

4.5.2 Days to 80% maturity

At Uyole CAL 143 was the latest at 90.00 days, followed by SUG 131 (87.67 days) and SARBYT (87.00 days). EAI L110 (81.00 days) and WANJA (81.00 days) was the earliest (Table 4a). At Mbimba CAL 143 (86.00 days), SUG 131 (86.00 days) and SARBYT (85.33 days) were the latest followed by EAI L110 (81.00 days). WANJA was the earliest at (72.42 days) (Table 4b). At Inyala SARBYT (77.00 days), CAL 143 (77.00 days), and SUG 131 (77.00 days) were the latest followed by EAI L110 (74.00 days) and UYOLE 96 (74.00 days). WANJA was the earliest at 71.25 days followed by NJANO (72.00 days) (Table 4c).

4.5.3 Plant height

At Uyole, UYOLE 96 had the tallest plants (94.94 cm) followed by EAI L110 (92.86 cm). WANJA had the shortest plants (32.63 cm) followed by CAL 143 (34.85) (Table 4a). At Mbimba EAI L110 (74.04 cm), NJANO (69.46 cm) and UYOLE 96 (69.30 cm) were the tallest (Table 4b). The shortest were CAL 143 (24.32 cm) and WANJA (24.29 cm). At Inyala the tallest was UYOLE 96 (87.79 cm) followed by EAI L110 (82.13 cm) while the shortest were WANJA (37.38 cm) and CAL 143 (33.37 cm) (Table 4c).

4.5.4 Number of pods per plant

At Uyole, SARBYT was the genotype with the highest number of pods per plant (14.83) followed by EAI L110 (13.92), CAL 143 (13.75) and NJANO (13.67) (Table 4a) while the lowest was WANJA (8.417). At Mbimba, NJANO (9.750) had the highest followed by SARBYT (9.083) and CAL 143 (8.500). The lowest number of pods was obtained with WANJA and UYOLE 96 (4.167) (Table 4b). At Inyala SARBYT had the highest number of pods per plant (16.75) (Table 4c), the lowest number of pods were obtained in genotypes UYOLE 96 (9.333) and WANJA (8.250).

4.5.5 100 seed weight

Genotypes differed significantly from each other on 100 seed weight. At Uyole, UYOLE 96 had the heaviest seeds (46.04g) followed by WANJA (41.45g) (Table 4a).The least weight was with SUG 131 (31.71g) (Table 4a). At Mbimba SARBYT (39.22g), UYOLE 96 (38.55g) and EAI L110 (37.38g) were the heaviest (Table 4b).

The least weight was with SUG 131 (31.22g). At Inyala UYOLE 96 (41.72g) and SARBYT (41.54g) had the heaviest seeds followed by WANJA (39.56g) and CAL 143 (38.04g) (Table 4c). SUG 131 (34.71g) and NJANO (33.22g) had the least weights.

Table 4a: Main effects of varieties on different variables studied at Uyole site

Variety	Days to 50% flowering	Days to 80% maturity	Plant height (cm)	Pods/plant (no)	Seed yield (kg/ha)	100 seeds (g)
SARBYT	43.00 a	87.00 bc	80.69 bc	14.83 a	2542.5 a	38.95 c
EAI L110	36.00 bc	81.00 d	92.86 a	13.92 ab	2540 a	39.97 c
CAL 143	42.50 a	90.00 a	34.85 d	13.75 ab	1733.25 d	35.54 d
SUG 131	42.83 a	87.67 b	76.38 c	13.00 b	1802 cd	31.71 f
NJANO	35.58 bc	85.33 c	82.78 b	13.67 ab	2025 bc	33.38 e
WANJA	36.17 b	81.00 d	32.63 d	8.417 d	1668.75 d	41.45 b
UYOLE 96	35.42 c	82.22 d	94.94 a	10.75 c	2102 b	46.04 a
MEAN	38.786	84.905	70.732	12.619	2059.07	38.151
SE ±	0.216	0.6853	1.7446	0.4355	0.328	0.4407
CV (%)	1.91	2.80	8.54	11.95	13.79	4.00

Means within column followed by same letter(s) are not significantly different from each other according to DMRT at 5%level.

Table 4b: Main effects of varieties on different variables studied at Mbimba site

Variety/ genotype	Days to 50% flowering	Days to 80% maturity	Plant height (cm)	Pods per plant (no)	Seed yield (kg/ha)	100 seed weight (g)
SARBYT	45.00 a	85.33 a	57.72 b	9.083 ab	916.75ab	39.22 a
EAI L110	36.25 d	81.00 b	74.04 a	8.083 b	795.75 bc	37.38 a
CAL 143	45.00 a	86.00 a	24.32 c	8.500 ab	652.00 c	33.47 b
SUG 131	42.83 b	86.00 a	53.04 b	5.750 c	718.75 c	31.22 c
NJANO	35.92 d	78.08 c	69.46 a	9.750 a	979.25 a	33.53 b
WANJA	38.08 c	72.42 e	24.29 c	4.167 d	456.25 d	33.05 bc
UYOLE 96	35.83 d	75.17 d	69.30 a	4.167 d	633.25 c	38.55 a
MEAN	39.845	80.57	53.167	7.071	736	35.203
SE±	0.5934	0.5043	2.1168	0.4726	0.0249	0.7325
CV (%)	5.16	2.17	13.79	23.15	29.28	7.21

Means within column followed by same letter(s) are not significantly different from each other according to DMRT at 5%level.

Table 4c: Main effects of varieties on different variables studied at Inyala site

Variety/ genotype	Days to 50% flowering	Days to 80% maturity	Plant height (cm)	Pods/plant (no)	Seed yield (kg/ha)	100 seeds weight (g)
SARBYT	38.58 a	77.00 a	81.79 b	16.75 a	1912.50 a	41.54 a
EAI L110	36.75 ab	74.00 b	82.13 b	13.50 b	1520.7 bc	36.72 c
CAL 143	37.67a	77.00 a	33.37 d	10.00 cd	1420.75 c	38.04 bc
SUG 131	37.50 ab	77.00 a	72.78 c	11.58 bc	1856.2 ab	34.71 d
NJANO	35.08 bc	72.00 c	79.13 b	13.58 b	1402.00 c	33.22 d
WANJA	32.33 d	71.25 d	37.38 d	8.250 d	1262.50 c	39.56 b
UYOLE 96	34.00 cd	74.00 b	87.79 a	9.333 d	1489.50 c	41.72 a
MEAN	35.988	74.607	67.768	11.857	1552.50	37.930
SE ±	0.8130	0.2053	1.9099	0.6781	0.0471	0.5721
CV (%)	7.83	95	9.76	19.81	26.28	5.23

Means within column followed by same letter(s) are not significantly different from each other according to DMRT at 5%level.

Table 4d: Main effects of varieties on different variables combined over 3 locations

Variety/ genotype	Days to 50% flowering	Days to 80% maturity	Plant height (cm)	Pods/plant (no)	Seed yield (kg/ha)	100 seeds weight (g)
SARBYT	42.19 a	83.11 a	73.37 b	13.83 a	1785a	39.63 b
EAI L110	36.33 b	78.50 b	83.08 a	11.83 b	1619b	37.94 c
CAL 143	41.69 a	84.33 a	32.12 d	10.75 c	1269dc	35.74 d
SUG 131	41.61 a	83.56 a	67.39 c	10.06 c	1459c	32.55 e
NJANO	35.53 bc	78.31 b	75.87 b	12.33b	1459c	33.38 e
WANJA	35.53 bc	74.89 c	33.66 d	6.944 e	1129e	38.02 c
UYOLE 96	35.08 c	77.17 b	83.18 a	8.083 d	1411cd	42.10 a
MEAN	38.282	79.980	44.083	10.548	1447.5	37.051
SE ±	0.3218	0.4705	1.5938	0.3086	0.0359	0.3464
CV (%)	5.04	3.53	14.92	17.55	21.46	5.61

Means within column followed by same letter(s) are not significantly different from each other according to DMRT at 5%level.

4.5.6 Disease reactions

Some disease incidences, Rust (*Uromyces appendiculatus* (pers.), Angular leaf spot (*Phaeoisariopsis griseola*) and Common Bacterial blight (*Xanthomonas phaseolusi*)

were observed especially from late vegetative stage to maturity at all locations. The mean disease scores were significantly different among genotypes (Tables 5a, 5b, 5c and 5d). For rust, SARBYT and CAL 143 were the least attacked by rust at Mbimba and Inyala, but at Uyole, SARBYT and EAI L110 were the least infected. SARBYT and EAI L110 were relatively least infected by angular leaf spot at all locations. At Uyole all genotypes were least attacked by common bacterial blight i.e Uyole showed least severity of bacterial blight compared to Inyala and Mbimba. At Mbimba and Inyala the least attacked varieties were SARBYT, EAI L110 and CAL 143. Inyala had a higher severity of common bacterial blight than other locations. For combined analysis SARBYT and CAL 143 were the least attacked by rust while relatively SARBYT and EAI L110 were least infected by angular leaf spot (Table 5d). All genotypes were least attacked by common bacterial blight.

Table 5a: Disease incidence at Uyole

Variety	Rust Severity (1-9)	Angular leaf spot Severity (1-9)	Common bacterial blight Severity (1-9)
SARBYT	3.00 b	4.750 d	2.333 b
EAI L110	2.917 b	3.667 e	2.167 b
CAL 143	4.167 a	6.167 c	2.000 b
SUG 131	4.583 a	6.583 bc	2.167 b
NJANO	4.833 a	7.333 a	2.833 a
WANJA	5.000 a	7.417 a	2.333 b
UYOLE 96	4.917 a	7.000 ab	2.250 b
MEAN	4.202	6.131	2.298
SE ±	0.3230	0.2194	0.711
CV (%)	26.63	12.39	25.79

Means within column followed by same letter(s) are not significantly different from each other according to DMRT at 5%level.

Table 5b: Disease incidence at Mbimba

Variety	Rust Severity (1-9)	Angular leaf spot Severity (1-9)	Common bacterial blight Severity (1-9)
SARBYT	3.667 dc	4.417 c	2.333 b
EAI L110	5.750 a	3.758 c	2.167 b
CAL 143	3.083 e	6.167 b	2.333 b
SUG 131	4.500 bc	6.833 ab	3.250 a
NJANO	3.503 dc	6.917 ab	3.917 a
WANJA	4.167 cd	7.333 a	3.917 a
UYOLE 96	5.167 ab	7.083 ab	3.333 a
MEAN	4.274	6.071	3.036
SE±	0.2626	0.3027	0.2457
CV (%)	21.28	17.27	28.03

Means within column followed by same letter(s) are not significantly different from each other according to DMRT at 5%level.

Table 5c: Disease incidence at Inyala

Variety	Rust Severity (1-9)	Angular leaf spot Severity (1-9)	Common bacterial blight Severity (1-9)
SARBYT	3.750 b	5.000 d	3.250 c
EAI L110	4.667 a	4.833 d	3.083 c
CAL 143	3.583 b	5.833 c	3.167 c
SUG 131	4.083 ab	5.333 cd	3.333 c
NJANO	3.833 b	6.750 b	4.167 b
WANJA	4.583 a	7.917 a	4.917 a
UYOLE 96	4.259	6.750 b	4.417 ab
MEAN	4.107	6.060	3.762
SE ±	0.2253	0.2117	0.2029
CV (%)	19.00	12.10	18.68

Means within column followed by same letter(s) are not significantly different from each other according to DMRT at 5%level.

Table 5d: Disease incidence over three combined locations (Uyole, Mbimba and Inyala)

Variety	Diseases		
	Rust Severity (1-9)	Angular leaf spot Severity (1-9)	Common bacterial blight Severity(1-9)
SARBYT	3.472 c	4.722 d	2.639 cd
EAI L110	4.444 ab	4.083 e	2.472 d
CAL 143	3.611 c	6.056 c	2.500 d
SUG 131	4.389 ab	6.250 c	2.917 c
NJANO	4.083 b	7.000 b	3.639 a
WANJA	4.583 a	7.556 a	3.722 a
UYOLE 96	4.778 a	6.944 b	3.333 b
MEAN	4.194	6.087	3.032
SE ±	0.1578	0.1432	0.1205
CV (%)	22.57	14.11	23.86

Means within columns followed by same letter(s) are not significantly different from each other according to DMRT at 5%level.

4.6 Effect of variety x location for the studied variables

Results of combination of variety x location interaction for the various variables are shown in tables 6a to 6j. The earliest combinations for days to 50% flowering were obtained at Inyala with WANJA (32 days) and UYOLE 96 (34 days), and Uyole for UYOLE 96 (35 days). Earliest days to 80% maturity combinations were at Inyala with NJANO (72 days) and WANJA (71 days) and Mbimba with WANJA (72 days). The shortest plants were obtained at Mbimba with CAL 143 (24.32 cm) and WANJA (26.79 cm). For number of pods per plant SARBYT produced the highest at Inyala (18) and Uyole (15). The highest yielder combination was at Uyole with SARBYT (2550kg/ha), EAI L110 (2550 kg/ha) and UYOLE 96 (2100kg/ha). For 100 seed weight the heaviest was obtained at Uyole with UYOLE 96 (46.04g) and WANJA (41.45g) and from Inyala with UYOLE 96 (41.72g) and SARBYT (41.55). The least rust attack was at Uyole, on SARBYT (3) and EAI L110 (3), while at Mbimba it was on CAL 143 (3). For angular leaf spot variety EAI L110 showed the least severity at 3.67 and 3.75 for Uyole and Mbimba respectively. EAI L110 (2.17) (Uyole and Mbimba), CAL 143 (2.00) and SUG 131 (2.17) (Uyole) were relatively least attacked by common bacterial blight. SARBYT gave the heaviest seeds at fertilizer rate 0P and 0N.

Table 6a: Mean number of days up to 50% flowering at different locations

(S.E± 0.322)

Variety/ location	SARBYT	EAIL110	CAL143	SUG131	NJANO	WANJA	UY96	Mean
Uyole	43	36	42	43	36	36	35	39
Mbimba	45	36	45	45	36	38	36	40
Inyala	36	37	38	38	35	32	34	36
Mean	42	36	42	42	36	36	35	
CV%	5.04							

Table 6b: Mean number of days up to 80% maturity at different locations (S.E± 0.47)

Variety/ location	SARBYT	EAIL110	CAL143	SUG131	NJANO	WANJA	UY96	Mean
Uyole	87	81	90	88	85	81	82	85
Mbimba	85	81	86	86	78	72	75	81
Inyala	77	74	77	77	72	71	74	74
Mean	83	77	84	84	78	75	77	
CV%	3.53							

Table 6c: Mean of plant height (cm) at different locations (S.E± 1.594)

Variety/ location	SARBYT	EAIL110	CAL143	SUG131	NJANO	WANJA	UY96	Mean
Uyole	80.69	92.86	34.85	76.34	89.03	32.63	94.94	70.17
Mbimba	57.72	74.04	24.32	53.04	69.46	26.79	66.80	53.17
Inyala	81.71	82.13	37.21	72.18	79.13	41.55	87.79	68.90
Mean	73.37	83.01	32.12	67.37	75.87	33.66	83.18	
CV%	14.92							

Table 6d: Mean number of pods / plant at different locations (S.E± 0.308)

Variety/ location	SARBYT	EAIL110	CAL143	SUG131	NJANO	WANJA	UY96	Mean
Uyole	15	14	14	13	14	8	11	13
Mbimba	9	8	9	6	10	4	4	7
Inyala	18	14	10	12	14	8	9	12
Mean	14	12	11	10	12	7	7	8
CV%	17.55							

Table 6e: Mean yield (kg/ha) at different locations (S.E± 0.021)

Variety/ location	SARBYT	EAIL110	CAL143	SUG131	NJANO	WANJA	UY96	Mean
Uyole	2550	2550	1725	1800	2000	1675	2100	2050
Mbimba	900	800	650	725	975	450	650	750
Inyala	1900	1525	1425	1850	1400	1275	1500	1550
Mean	1775	1625	1275	1450	1475	1125	1400	
CV%	21.46							

Table 6f: Mean 100 Seed weight (g) at different locations (S.E± 0.346)

Variety/ location	SARBYT	EAIL110	CAL143	SUG131	NJANO	WANJA	UY96	Mean
Uyole	38.95	39.96	35.71	31.71	33.38	41.45	46.04	38.18
Mbimba	38.39	37.14	33.47	31.22	33.53	33.05	38.54	35.05
Inyala	41.55	36.71	38.04	34.71	33.22	39.56	41.72	37.93
Mean	39.63	37.94	35.74	32.55	33.38	38.02	42.10	
CV%	5.61							

Table 6g: Mean rust score (1-9) at different locations (S.E± 0.158)

Variety/ location	SARBYT	EAIL110	CAL143	SUG131	NJANO	WANJA	UY96	Mean
Uyole	3	3	4	5	5	5	5	4.202
Mbimba	4	6	3	5	4	4	5	4.274
Inyala	4	5	4	4	4	5	4	4.102
Mean	3.4	4.44	4.61	4.39	4.05	4.66	4.66	
CV%	22.57							

Table 6h: Mean angular leaf spot score (1-9) at different location (S.E± 0.346)

Variety/ location	SARBYT	EAIL110	CAL143	SUG131	NJANO	WANJA	UY96	Mean
Uyole	4.75	3.67	6.17	6.58	7.33	7.42	7.00	6.13
Mbimba	4.42	3.75	6.17	6.83	6.92	7.33	7.08	6.07
Inyala	5.00	4.83	5.83	5.33	6.75	7.91	6.75	6.06
Mean	4.75	3.66	6.17	6.58	7.33	7.41	7.00	
CV%	14.11							

Table 6i: Mean blight score (1-9) at different locations (S.E± 0.121)

Variety/ location	SARBYT	EAIL110	CAL143	SUG131	NJANO	WANJA	UY96	Mean
Uyole	2.33	2.17	2.00	2.17	2.83	2.33	2.25	2.298
Mbimba	2.33	2.17	2.33	3.25	3.92	3.92	3.33	3.036
Inyala	3.25	3.08	3.17	3.33	4.17	4.17	4.42	3.7.62
Mean	2.64	2.47	2.50	2.92	3.64	3.64	3.33	
CV%	23.86							

Table 7: Effect of fertilizer x genotypes for 100 seed weight

Fertilizers	SARBYT (g)	EAI L110 (g)	CAL 143 (g)	SUG 131 (g)	NJANO (g)	WANJA (g)	UYOLE 96 (g)
0P and 0N	41.597	37.488	35.271	33.259	32.941	36.177	40.592
52gP, 67gN	38.272	37.946	35.830	32.154	34.028	38.696	42.931
78gP, 67gN	39.161	38.937	35.823	32.176	33.057	38.367	42.057
91gP, 44gN	39.487	37.400	36.042	32.597	33.489	38.841	42.819
Mean	39.629	37.943	35.742	32.547	33.379	38.020	42.080
CV%	5.61						

4.7Correlation analysis

4.7.1 Simple correlation analysis

Results of correlation analysis among variables are shown in tables 8a to 8d. At all sites yields were found to have positive significant correlations with plant height and number of pods per plant the correlation with height at Uyole being (r=0.602***), Mbimba (r=0.535***) and Inyala (r=0.370***), while with number of pods at Uyole was (r=0.595***), Mbimba (r=0.595***) and Inyala (r=0.415***).

There were also positive correlations between yield and 100 seed weight at Uyole (r=0.249*) and Mbimba (r=0.334**) while at Inyala the correlation was not significant. At Mbimba and Inyala correlations between yield and days to 80% were significantly positive being (r=0.212*) and (r=0.286**) respectively. Yield had significantly positive correlation with days to 50% flowering only at Inyala (r=0.270**).

Based on combined analysis, there were positive and significant correlations between yield and number of pods per plant (r= 0.707***), plant height (r = 0.539***), days to 80% maturity (r = 0.202***) and 100 seed weight (r = 0.349***). There were also positive significant correlations between 100 seed weight with plant height (r = 0.268***) and number of pods per plant (r = 0.133*). Positive significant correlation was also observed between days to 80% maturity with days to 50% flowering (r=0.638***). Number of pods per plant showed positive significant correlations with days to 80% maturity (r = 0.184**), and plant height (r = 0.481***). For disease severity, results showed positive significant correlations between rust score with

angular leaf spot (r = 0.236***) and with common bacterial blight (r = 0.192**). Positive significant correlation was also between angular leaf spot and common bacterial blight (r = 0.373***). Seed yield was significantly and negatively correlated with all disease score severities viz. rust, angular leaf spot and common bacterial blight.

Table 8a: Simple correlation among studied variables at Uyole site

S/No		1	2	3	4	5	6	7	8	9
1.	Days to 50% flowering	-								
2.	Days to 80% maturity	0.720***	-							
3.	Plant height (cm)	-0.250	-0.212*	-						
4.	Pods/ plant (no)	0.301*	0.342***	0.364***	-					
5.	Seed yield (kg/ha)	-0.041	-0.134	0.602***	0.595***	-				
6.	100 seed weight (g)	-0.484***	-0.564***	0.161	-0.301*	0.249*	-			
7.	Rust severity (1-9)	-0.169	-0.040	-0.239*	-0.432***	-0.497***	-0.049	-		
8.	Angular leaf spot severity (1-9)	-0.208	0.002	-0.310**	-0.354***	-0.479***	-0.072	0.524***	-	
9.	Common bacterial blight severity (1-9)	-0.195	-0.120	0.030	0.052	-0.140	-0.037	0.380***	0.079	-

* = Significant at 0.05
** = Significant at 0.01 and
*** = Significant at 0.001.

Table 8b: Simple correlation among studied variables at Mbimba site

S/No		1	2	3	4	5	6	7	8	9
1.	Days to 50% flowering	-								
2.	Days to 80% maturity	0.676***	-							
3.	Plant height (cm)	-0.430***	-0.001	-						
4.	Pods/ plant (no)	0.114	0.398***	0.325***	-					
5.	Seed yield (kg/ha)	-0.034	0.212*	0.535***	0.595***	-				
6.	100 seed weight (g)	-0.126	0.003	0.415***	0.144	0.334**	-			
7.	Rust severity (1-9)	-0.350***	-0.149	0.331***	-0.207	0.095	0.203	-		
8.	Angular leaf spot severity (1-9)	-0.159	-0.394***	-0.237*	-0.354**	-0.063	-0.277**	- 0.013	-	
9.	Common bacterial blight severity (1-9)	-0.296***	-0.413***	0.056	-0.268**	-0.008	-0.319***	0.158	-0.159	-

* = Significant at 0.05
** = Significant at 0.01 and
*** = Significant at 0.001.

Table 8c: Simple correlation among studied variables at Inyala site

S/No		1	2	3	4	5	6	7	8	9
1.	Days to 50% flowering	-								
2.	Days to 80% maturity	0.578***	-							
3.	Plant height (cm)	0.105	0.033	-						
4.	Pods/ plant (no)	0.016	0.211*	0.464***	-					
5.	Seed yield (kg/ha)	0.270**	0.286**	0.370***	0.415***	-				
6.	100 seed weight (g)	-0.062	0.117	0.010	0.005	0.084	-			
7.	Rust severity (1-9)	-0.119	-0.243*	0.039	-0.115	-0.145	0.062	-		
8.	Angular leaf spot severity (1-9)	-0.522***	-0.595***	-0.314*	-0.501***	-0.341***	0.062	0.240	-	
9.	Common bacterial blight severity (1-9)	-0.386***	-0.527***	-0.147	-0.343***	-0.151	0.129	0.274	0.657***	-

* = Significant at 0.05,
** = Significant at 0.01 and
*** = Significant at 0.001.

Table 8d: Simple correlations among studied variables in combined analysis (Uyole, Mbimba and Inyala)

S/N		1	2	3	4	5	6	7	8	9
1.	Days to 50% flowering	-								
2.	Days to 80% maturity	0.638***	-							
3.	Plant height (cm)	-0.261***	-0.028	-						
4.	Pods/ plant (no)	0.024	0.184**	0.481***	-					
5.	Seed yield (kg/ha)	-0.080	0.202***	0.539***	0.707***	-				
6.	100 seed weight (g)	-0.289***	-0.121*	0.268***	0.133*	0.349***	-			
7.	Rust score (1-9)	-0.198**	-0.059	0.019	-0.222***	-0.153*	0.047	-		
8.	Angular leaf spot score (1-9)	-0.236***	-0.187**	-0.266***	-0.315***	-0.187**	-0.099	0.236***	-	
9.	Blight score (1-9)	-0.375***	-0.583***	-0.075	-0.186**	-0.209***	-0.083	0.192**	0.373***	-

* = Significant at 0.05,
** = Significant at 0.01 and
*** = Significant at 0.001.

4.7.2 Phenotypic and genotypic correlations

Table 8e shows the data for phenotypic (top) and genotypic (bottom) correlations among the nine variables studied over three locations. Seed yield had both significant positive phenotypic and genotypic correlations with plant height, number of pods per plant, 100 seed weight and days to 80% maturity. Phenotypic and genotypic correlation coefficients between days to 50% flowering with days to 80% maturity were positive and significant, similarly for number of pods per plant with plant height and days to 80% maturity. Although the phenotypic and genotypic correlations between days to 50% flowering and 100 seed weight were significant; they were in opposite directions.100 seed weight was positively correlated with plant height and pods/plant. Angular leaf spot was positively correlated with rust and common bacterial blight.

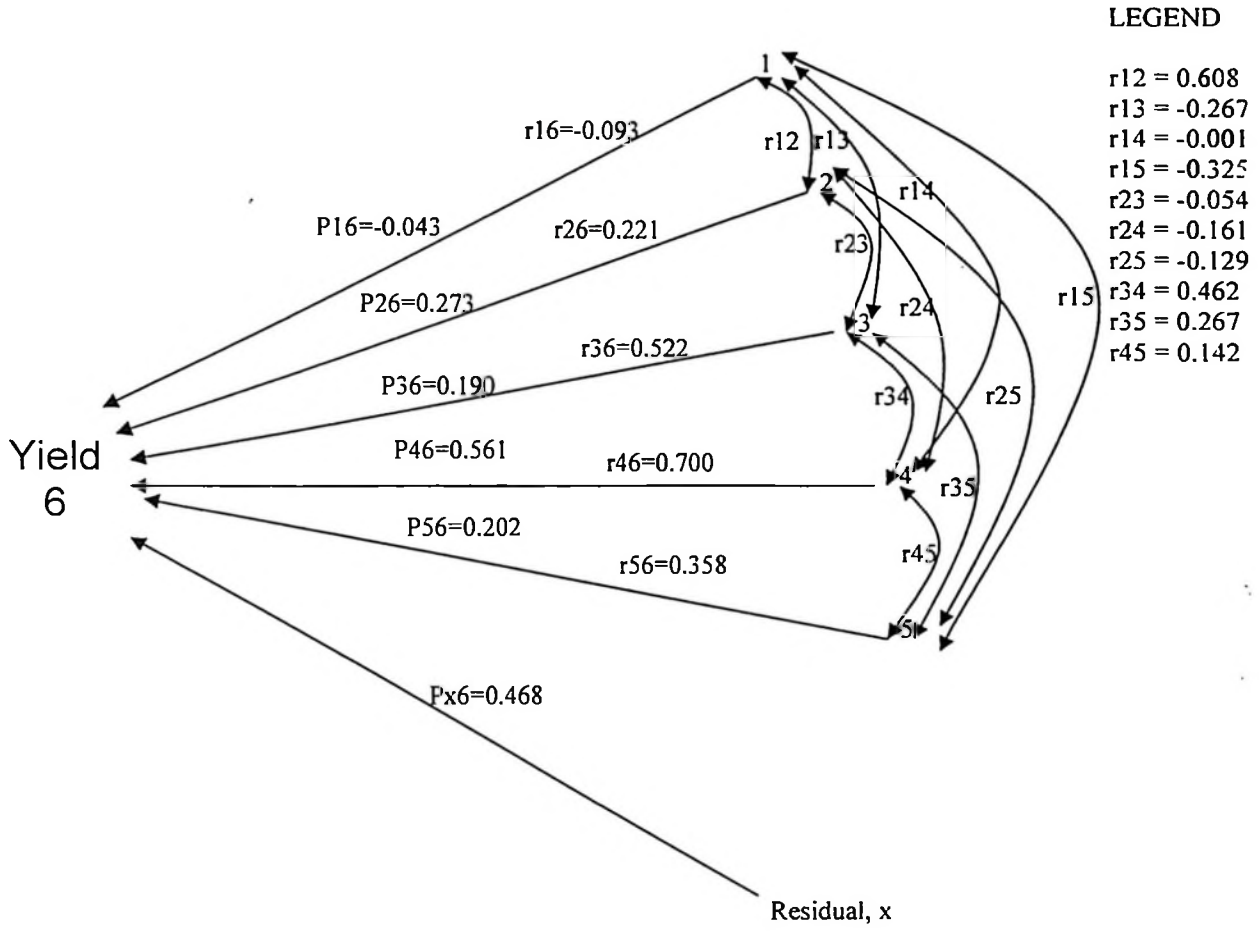
Table 8c: Phenotypic (top) and Genotypic (bottom) correlation of variables studied combined from (Uyole, Mbimba and Inyala)

S/N		1	2	3	4	5	6	7	8	9
1.	Days to 50% flowering	-								
2.	Days to 80% maturity	**0.670*** **	-							
		0.608***								
3.	Plant height (cm)	**-0.267*** **	**-0.050**	-						
		-0.267***	-0.054							
4.	Pods/ plant (no)	**-0.001**	**0.160** **	**0.46*** **	-					
		-0.001	0.161**	0.462***						
5.	Seed yield (kg/ha)	**-0.306**	**0.23*** **	**0.54*** **	**0.61*** **	-				
		-0.093	0.221***	0.522***	0.700***					
6.	100 seed weight (g)	**0.325*** **	**-0.130***	**0.27*** **	**0.142***	**0.84*** **	-			
		-0.325***	-0.129*	0.267**	0.142*	0.358***				
7.	Rust severity (1-9)	**-0.118** **	**-0.123**	**0.008**	**-0.042**	**-0.167***	**0.007**	-		
		-0.181**	-0.030	-0.008	-0.221***	-0.156*	0.037			
8.	Angular leaf spot	**-0.522*** **	**-0.595** **	**-0.002**	**-0.052**	**-0.193** **	**-0.083**	**0.236*** **	-	
	severity (1-9)	-0.207	-0.163**	-0.259**	-0.315***	-0.093	-0.083	0.236***		
9.	Common bacterial	**-0.386*** **	**-0.008**	**0.050**	**-0.189** **	**-0.073**	**-0.073**	**0.194** **	**0.375** **	-
	blight severity (1-9)	-0.347***	-0.528***	0.050	-0.189**	-0.210***	-0.073	0.192**	0.373**	

* = Significant at 0.05,
** = Significant at 0.01 and
*** = Significant at 0.001.

4.8 Path coefficient analysis

Figure 2b and Table 9b show the direct and indirect effect based on genotypic correlations on combined analysis of various characters of common beans as studied from the three locations. Results obtained in path coefficient analysis revealed that number of pods per plant had both high direct effect (0.561) and positive correlation (0.522) with seed yield. Plant height also having substantial indirect contribution on yield through number of pods per plant (0.259) had high positive relationship with seed yield (r=0.522). 100 seed weight also had a moderate direct effect on seed yield (0.230). The high and positive indirect effect of plant height on yield through number of pods was in turn attributed to the significant positive correlation (r=0.462) between plant height and number of pods per plant and a positive direct effect (0.190) of plant height on yield. The significant positive genotypic correlation between yield with days to 80% maturity (r = 0.221***) was predominantly attributed to its direct effect (r = 0.273). The significant positive genotypic correlation (r = 0.358***) between yield with 100 seed weight was largely due to its direct effect (0.202) and its indirect effect via pods/plant (0.150). The residual effect was 0.468, which indicated the contribution of remaining factors other than those studied.



Legend
1 = Days to 50% flowering
2 = Days to 80% maturity
3 = Plant height
4 = Pods per plant
5 = 100 seed weight
6 = Seed yield

Figure 2b: Path diagram and coefficients of factors influencing seed yield of Common bean. P's are the direct effects; r's are the genotypic correlation coefficients

Table 9a: Showing the genotypic relations between yield components with seed yield

1. Days to 50% flowering with yield r_{16}	**-0.093**
Direct effect P_{16}	-0.043
Indirect via 80% maturity $r_{12}P_{26}$	0.166
Via plant height $r_{13}P_{36}$	-0.0002
Via pods/ plant	-0.150
Via 100 seed weight $r_{15}P_{56}$	-0.066
Total	-0.093
2. Days to 80% maturity with yield r_{26}	**0.221**
Direct effect P_{26}	0.273
Indirect via 50% flowering $r_{12}P_{16}$	-0.026
Via plant height $r_{23}P_{36}$	0.031
Via pods/plant $r_{24}P_{46}$	-0.031
Via 100 seed weight $r_{25}P_{56}$	-0.026
Total	0.221
3. Plant height with yield r_{36}	**0.522**
Direct effect P_{36}	0.190
Indirect via 50% flowering $r_{13}P_{16}$	0.00004
Via 80% maturity $r_{23}P_{26}$	0.044
Via pods/plant $r_{34}P_{46}$	0.259
Via 100 seed weight $r_{35}P_{56}$	0.029
Total	0.522
4. Pods/plant with yield r_{46}	**0.700**
Direct effect P_{46}	0.561
Indirect via 50% flowering $r_{14}P_{16}$	0.012
Via 80% maturity $r_{24}P_{26}$	-0.015
Via plant height $r_{34}P_{36}$	0.088
Via 100 seed weight $r_{45}P_{56}$	0.054
Total	0.700
5. 100 seed weight with yield r_{56}	**0.358**
Direct effect P_{56}	0.202
Indirect via 50% flowering $r_{15}P_{16}$	0.014
Via 80% maturity $r_{25}P_{26}$	-0.035
Via plant height $r_{35}P_{36}$	0.027
Via pods/plant $r_{45}P_{46}$	0.150
Total	0.358

Table 9b: Path coefficient analysis showing the genotypic direct effect (along the diagonal) and genotypic indirect effects of five characters on seed yield

Characters	Effect via					
	Days to 50% flowering	Days to 80% maturity	Plant height	Number of Pods/plant	100 seed weight	Seed yield
Days to 50% flowering	**-0.043**	0.166	-0.0002	-0.150	-0.066	-0.093
Days to 80% maturity	-0.026	**0.273**	0.031	-0.031	-0.026	0.221
Plant height	0.00004	0.044	**0.190**	0.259	0.029	0.522
Number of pods Per plant	0.012	-0.015	0.088	**0.561**	0.054	0.700
100 seed weight	0.014	-0.035	0.027	0.150	**0.202**	0.358

Residual effects, PX6 = 0.468

4.9 Stability analysis

Results of the study showed significant differences ($P<0.001$) for environments, genotypes and the interactions between them for most variables (Table 1). The mean yields, regression coefficient (b), variances of deviation from regression (S^2d) and coefficients of determinations (R^2) are presented in Table 10 for yield, Table 11 for flowering, Table 12 maturity, Table 13 for 100 seed weight, Table 14 plant height and Table 15 for number of pods per plant.

The genotype SARBYT had regression coefficient significantly different from zero value (1.229*) for seed yield but had higher seed yield than the general mean yield over all environments which was 1450 kg/ha. SUG 131, NJANO, and CAL 143 had regression coefficients significantly less than unity while the rest responded significantly above unit value. The deviations from regressions for all genotypes were very small

approaching zero (ranged from 0 – 0.02) with SARBYT, CAL 143, WANJA and UYOLE 96 having zero values for variances of deviation. Results also showed that, for seed yield only SARBYT had a significant response and above average response while EAI L110 and UYOLE 96 did not have a significant response above average, while the rest responded significantly below average. The coefficients of determination (R^2) were high for SARBYT (100%), UYOLE 96 (81%) and CAL 143 (79%).

For flowering, genotypes SARBYT, CAL 143, NJANO and WANJA had significant positive regression coefficients (1.573*, 1.768*, 0.200* and 1.402*) respectively (Table 11). SARBYT, CAL 143, NJANO and WANJA had variances of deviation from regression approaching zero. All genotypes had regression coefficients significantly deviating a unit value. The coefficients of determination for all genotypes were high ranging from 99 to 100%. For maturity parameter, CAL 143, SUG 131 and NJANO had regression coefficients significantly greater than unit value while SARBYT, EAI L110, WANJA and UYOLE 96 responded significantly below average (Table 12). For maturity no genotype had variance of deviation equal to or approaching zero, however, CAL 143 and NJANO had relatively low variances. The coefficients of determination for all genotypes were low for most genotypes however CAL 143 and NJANO had 72% and 73% respectively.

For 100 seed weight, CAL 143, UYOLE 96 and WANJA had regression coefficients greater than a unit value (1.081, 1.934 and 2.637) respectively (Table 13), but do not differ significantly from unit value. On the other hand SARBYT, EAI L110, SUG 131

and NJANO responded significantly less than unit value of b=1. NJANO and WANJA had low values of deviations from regressions of 0.02 and 0.81 respectively. The coefficients of determination were high for NJANO (100%) and WANJA (95%). For plant height, SARBYT, SUG 131 and UYOLE 96 had regression coefficients significantly greater than unit of (1.418, 1.339 and 1.404) respectively (Table 14). The rest of the genotypes responded significantly less than unit value of b=1. CAL 143, SUG 131 and NJANO had low variances of deviations from regression. Coefficients of determination were high for CAL 143 (100%), SUG 131 (99%), NJANO (93%) and UYOLE 96 (88%). For number of pods per plants four genotypes had b value greater than unit viz. SARBYT (1.237), EAI L110 (1.080), SUG 131 (1.276) and UYOLE 96 (1.149) (Table 14). On the other hand, CAL 143, NJANO and WANJA responded significantly less than unit value. EAI L110, SUG 131, NJANO, WANJA and UYOLE 96 had low variances of deviation from regression. Coefficients of determinations were high for SUG 131 (93%), NJANO (91%) and WANJA (88%).

Table 10: Estimates of stability parameter for yield averaged in three combined locations (Uyole, Mbimba and Inyala)

Genotype	Mean seed Yield (kg/ha)	b	b-1	SE_b	S^2d	R^2 %
SARBYT	1800	1.229*	0.229**	0.005	0.00	100
EAIL110	1625	1.280	0.28**	0.300	0.01	46
CAL 143	1275	0.830	-0.17**	0.088	0.00	79
SUG 131	1450	0.874	-0.13**	0.403	0.02	9
NJANO	1475	0.766	-0.23**	0.190	0.01	60
WANJA	1125	0.925	-0.08**	0.051	0.00	69
UYOLE 96	1400	1.096	0.096**	0.040	0.00	81
Grand mean	1450					

Significantly different from unit at 1% probability level

Table 11: Estimates of stability parameters for days to flowering averaged in three combined locations (Uyole, Mbimba and Inyala)

Genotype	Days to 50% flowering	b	b-1	SE_b	S^2d	R^2 %
SARBYT	42.19	1.573*	0.573*	0.005	0.00	100
EAI L110	36.33	-0.146	-1.15*	0.110	0.11	99
CAL 143	41.69	1.768*	0.768*	0.036	0.01	100
SUG 131	41.61	1.745	0.745*	0.145	0.18	96
NJANO	35.53	0.200*	-0.808	0.019	0.00	100
WANJA	35.53	1.402*	0.402*	0.029	0.01	99
UYOLE 96	35.08	0.458	-0.54*	0.401	0.02	99

Significantly different from unit at 1% probability level and ** significant at 0.01 level

Table 12: Estimates of stability parameters for days to maturity averaged in three combined locations (Uyole, Mbimba and Inyala)

Genotype	Days to 80% maturity	b-value	b-1	SE_b	S^2d	R^2 %
SARBYT	83.11	0.995	-0.01**	0.291	4.51	0
EAI L110	78.50	0.703	-0.30**	0.278	4.12	53
CAL 143	84.33	1.277	0.277*	0.174	1.61	72
SUG 131	83.56	1.063	0.063*	0.322	5.55	4
NJANO	78.47	1.280	0.280*	0.172	1.58	73
WANJA	74.89	0.906	-0.09*	0.491	12.89	4
UYOLE 96	77.17	0.776	-0.22*	0.401	8.59	24

Significantly different from unit at 1% probability level and ** significant at 0.01 level

Table 13: Estimates of stability parameter for 100 seed weight averaged in three combined locations (Uyole, Mbimba and Inyala)

Genotype	100 seed weight (gm)	b	b-1	S^2d	R^2 %
SARBYT	39.63	0.308	-0.69**	3.55	43
EAI L110	37.94	0.483	-0.52**	5.01	23
CAL 143	35.74	1.081	0.080**	3.74	1
SUG 131	32.55	0.635	-0.37**	4.93	13
NJANO	33.38	-0.08	-1.08**	0.02	100
WANJA	38.02	2.637	1.637**	0.81	95
UYOLE 96	42.10	1.934	0.934**	7.69	38

* Significantly different from unit at 1% probability level and ** significant at 0.01 level

Table 14: Estimates of stability parameters for plant height averaged in three combined locations (Uyole, Mbimba and Inyala)

Genotype	Plant height (cm)	b value	b-1	S^2d	R^2 %
SARBYT	73.37	1.418	0.418**	15.17	67
EAI L110	83.01	0.913	-0.087**	31.98	4
CAL 143	30.71	0.599*	-0.401**	0.00	100
SUG 131	67.39	1.339	0.339**	0.19	99
NJANO	77.12	0.731	-0.269**	0.96	93
WANJA	31.24	0.597	-0.403**	18.68	60
UYOLE 96	84.01	1.404	0.404**	3.98	88

Significantly different from unit at 1% probability level and ** significant at 0.01 level

Table 15: Estimates of stability parameters for pods per plant averaged in three combined locations (Uyole, Mbimba and Inyala)

Genotype	Number of pods/pl	b value	b-1	S^2d	R^2 %
SARBYT	13.56	1.237	0.237**	4.15	20
EAI L110	11.83	1.080	0.080**	0.08	58
CAL 143	10.75	0.722	-0.278**	5.20	21
SUG 131	10.11	1.276	0.276**	0.10	93
NJANO	12.33	0.740	-0.26**	0.12	91
WANJA	6.94	0.797	-0.797**	0.10	88
UYOLE 96	8.08	1.149	0.149**	0.15	73

** Highly significant at 0.01 level

4.10 The relationship between stability parameters and mean performance of genotypes for studied variables

The relationships between yield and stability parameters show that genotype 1 (SARBYT) had high average mean value with low variances of deviation, while genotypes 7 (UYOLE 96), 3 (CAL 143) and 6(WANJA) had low variances of deviation with mean value below average (Fig. 3). Genotype 7 (UYOLE 96) had intermediate

yield with b value around unit value (Fig. 4). Genotypes 1 (SARBYT), 2 (EAI L110) and 7 (UYOLE 96) had low variances of deviation with b value above unit (Fig. 5).

The relationships between days to 50% flowering and stability parameters shows that genotypes 5 (NJANO), 6 (WANJA) and 7 (UYOLE 96) had low variances of deviation and earliest in flowering (Fig. 6) while none of the genotypes had b- value of around unit, however the earliest genotypes were 6 (WANJA) and 7 (UYOLE 96) (Fig. 7). Genotypes 1 (SARBYT), 3 (CAL 143) and 6 (WANJA) had low variances of deviation with b values above unit (Fig. 8). For days to 80% maturity, Genotype 6 (WANJA) had regression coefficient of around unit with earliest in maturity (Fig. 9) while none of the genotypes had earliness with low variances of deviation (Fig.10). No genotype had low variances of deviation with b value around unit (Fig. 11).

Relationship between plant height and stability parameters showed that genotype 1 (SARBYT) and 4 (SUG 131) had b value above unit with medium plant height (Fig. 12). Genotype 3 (CAL 143) had low variance of deviation with shorter plants (Fig. 13). Genotypes 3 (CAL 143) and 5 (NJANO) had low variances of deviation but b value far below unit while genotype 4 (SUG 131) had low variance of deviations with b value above unit (Fig.14).

Genotype 1 (SARBYT) and 2 (EAI L110) had high number of pods/plant with b values around unit while genotype 5 (NJANO) had high number of pods per plant with b values below unit (Fig.15). Genotype 2 (EAI L110) had low variance of deviations with b value

above unit (Fig.16). Genotype 1 (SARBYT) had high number of pods/plant but high variance of deviations while genotype 2 (EAI L110) and 5 (NJANO) had high number of pods/plant with low variance of deviations (Fig.17).

For 100 seed weight results shows that, genotype 7 (UYOLE 96) had high seed weight but b value greater than unit while genotype 3 (CAL 143) had intermediate seed weight and b value around unit (Fig.18). Genotype 3 (CAL 143) had b value around unit with intermediate variance of deviations (Fig.19). Genotype 5 (NJANO) had low variance of deviations but low seed weight while genotype 6 had low variance of deviations with intermediate seed weight. Genotype 7 (UYOLE 96) had high seed weight but high variance of deviations (Fig.20).

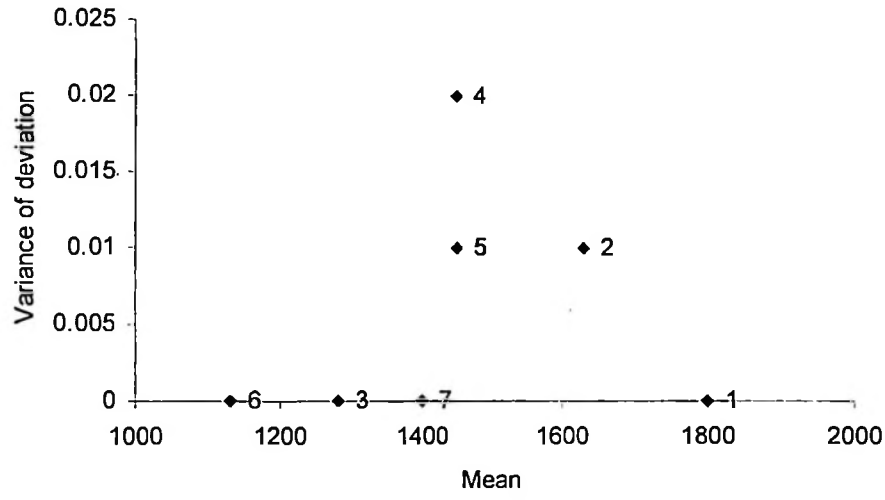


Figure 3: Scatter diagram indicating the relationship between variance of Deviation and mean for seed yield

Legend:
In this and subsequent figures,
1 stands for SARBYT,
2 for EAI L 110,
3 for CAL 143,
4 for SUG 131,
5 for NJANO,
6 for WANJA,
7 for UYOLE 96

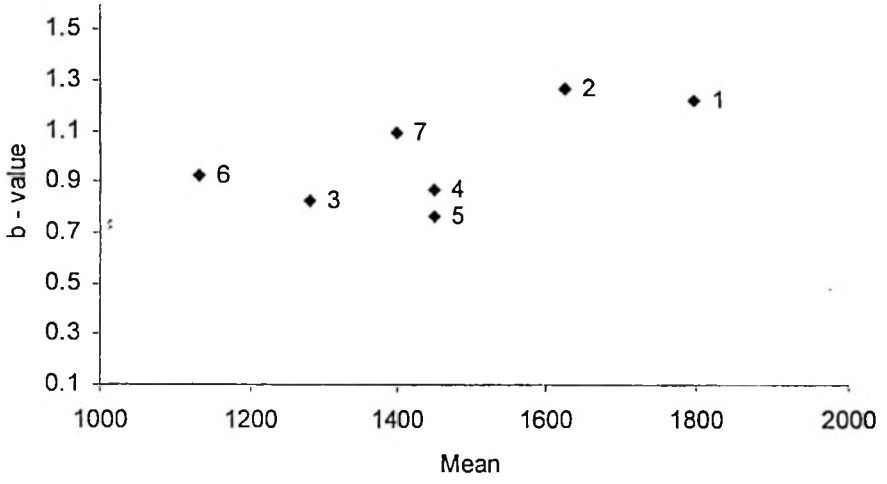


Figure 4: Scatter diagram indicating the relationship between regressions Coefficient (b) and mean for seed yield

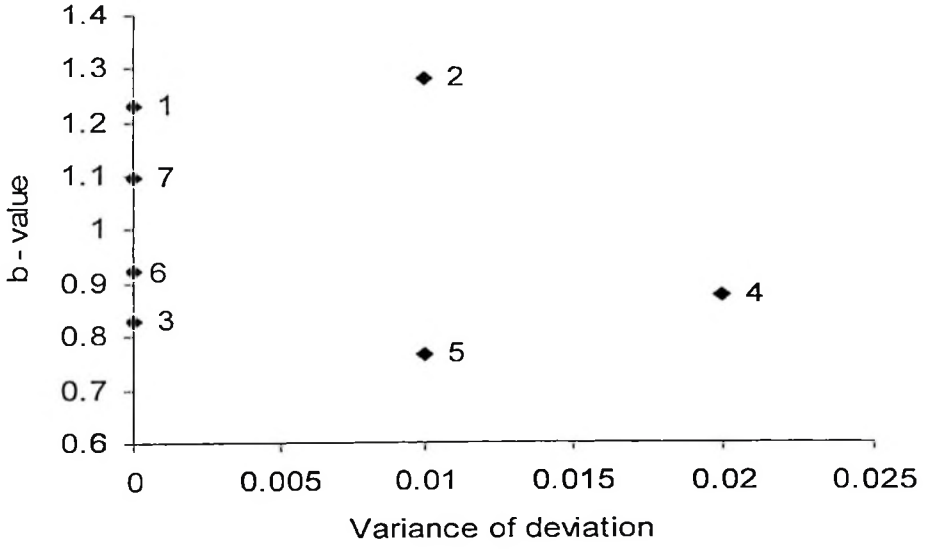


Figure 5: Scatter diagram indicating the relationship between variance of Deviation and regression coefficient (b) for seed yield

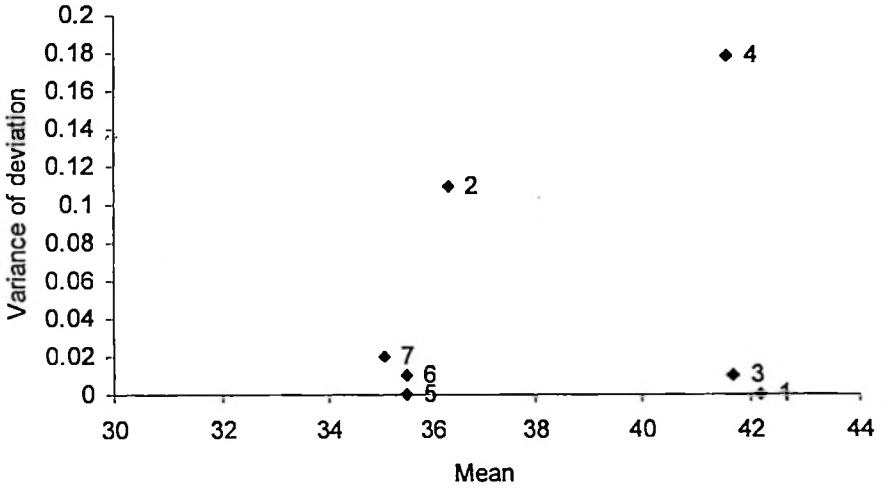


Figure 6: Scatter diagram indicating the relationship between variance of Deviation and mean for days to 50% flowering

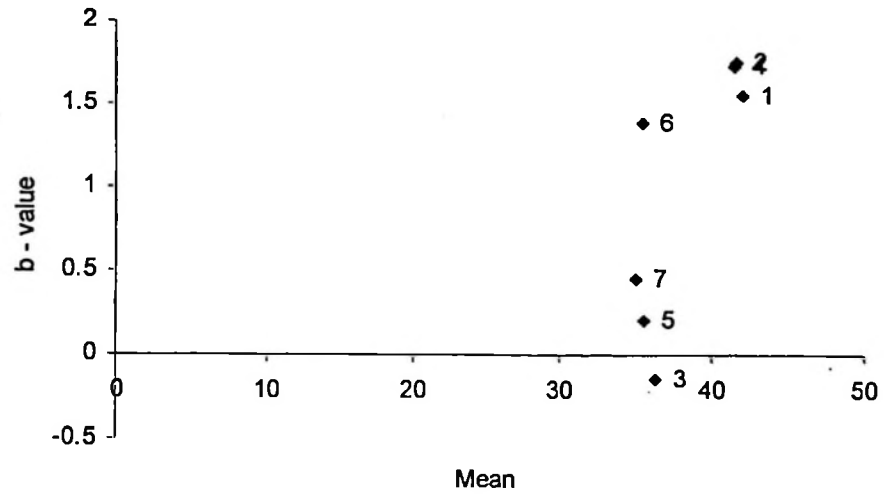


Figure 7: Scatter diagram indicating the relationship between regressions Coefficient (b) and mean for days to 50% flowering

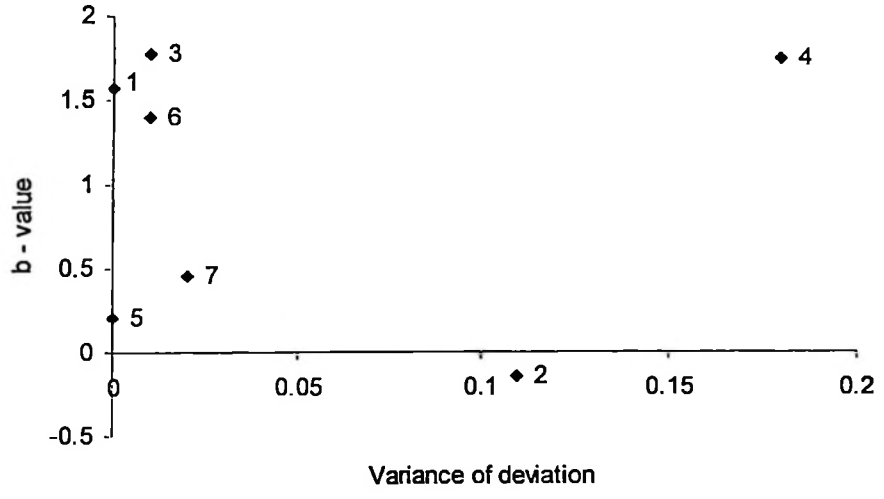


Figure 8: Scatter diagram indicating the relationship between variance of Deviation and regression coefficient (b) for days to 50% flowering

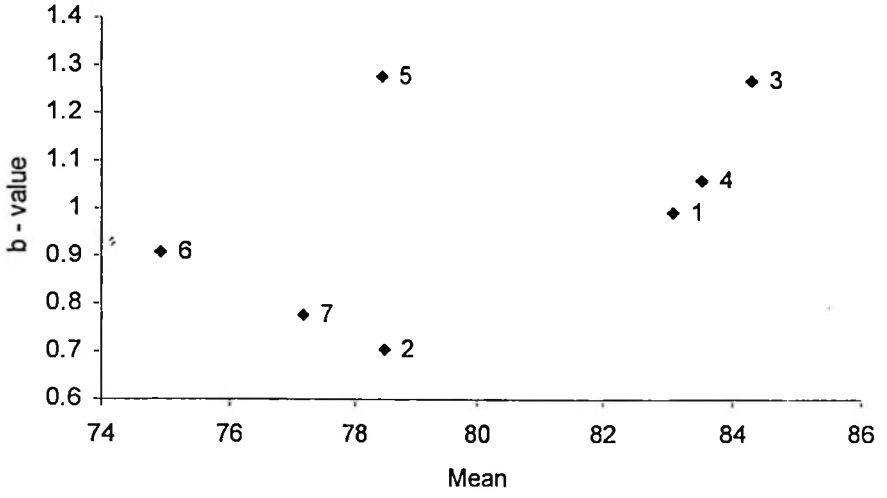


Figure 9: Scatter diagram indicating the relationship between regressions Coefficient (b) and mean for days to 80% maturity

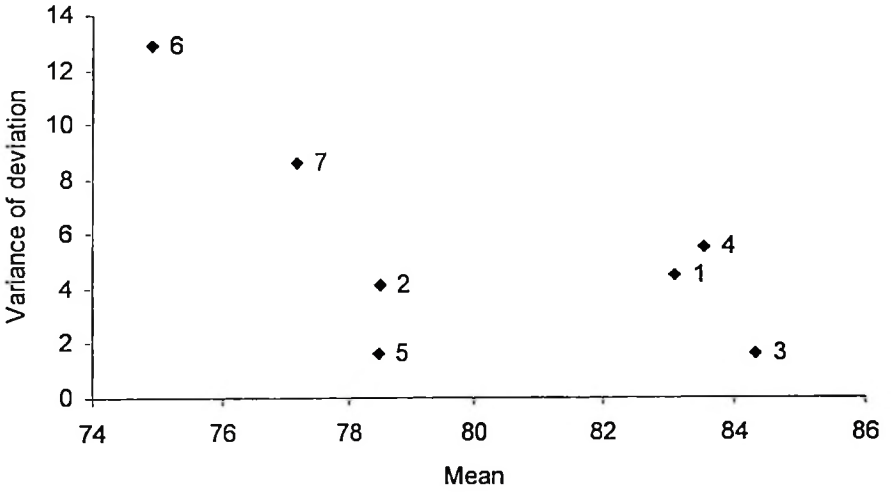


Figure 10: Scatter diagram indicating the relationship between variance of Deviation and mean for days to 80% maturity

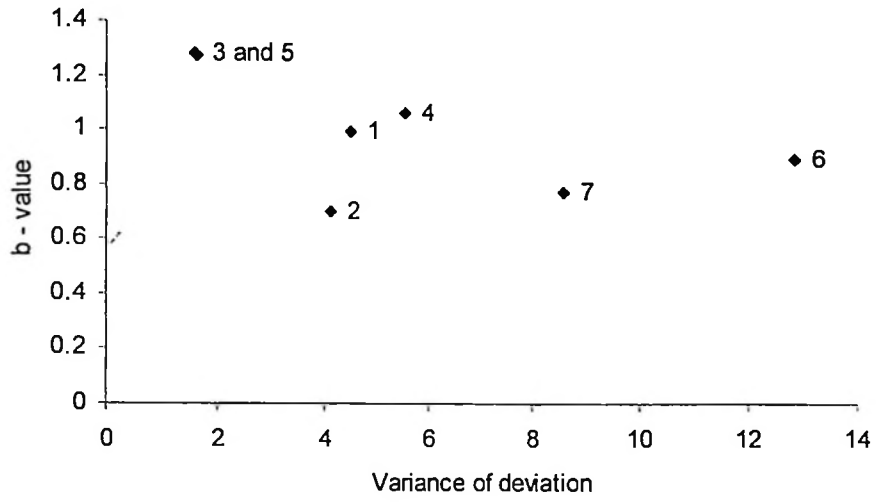


Figure 11: Scatter diagram indicating the relationship between variance Deviation and regression coefficient (b) for days to 80% maturity

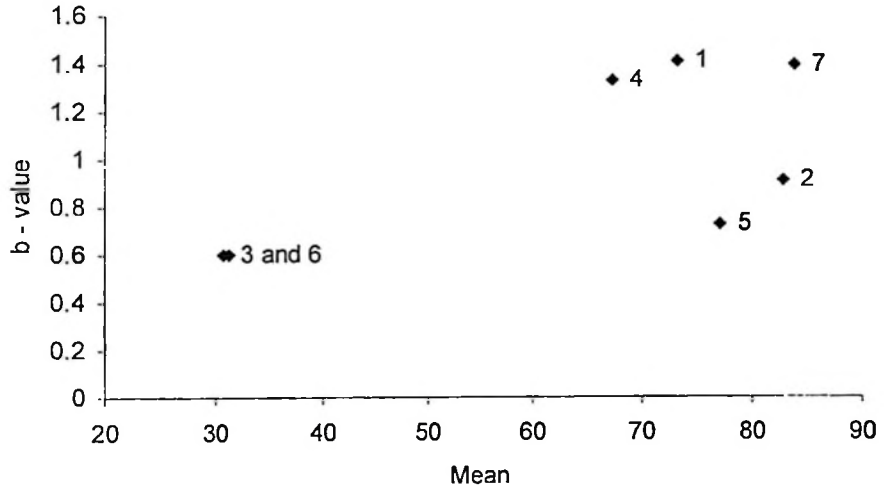


Figure 12: Scatter diagram indicating the relationship between regressions Coefficient (b) and mean for plant height

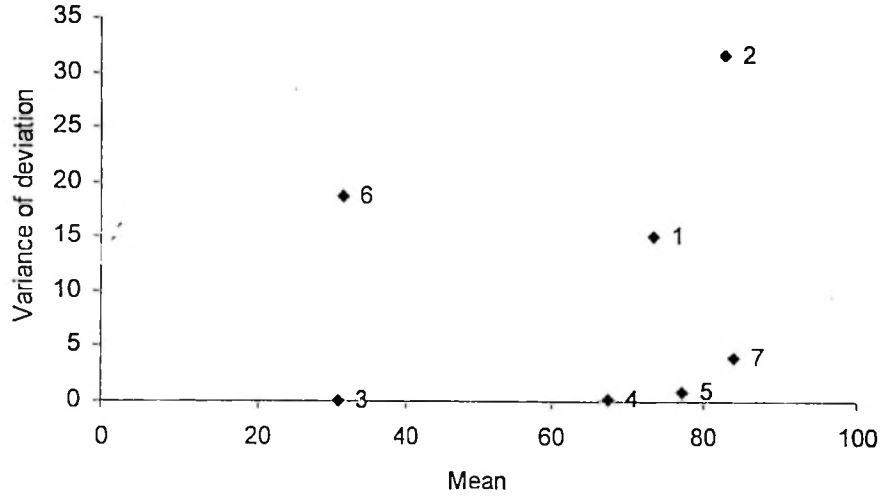


Figure 13: Scatter diagram indicating the relationship between variance of Deviation and mean for plant height

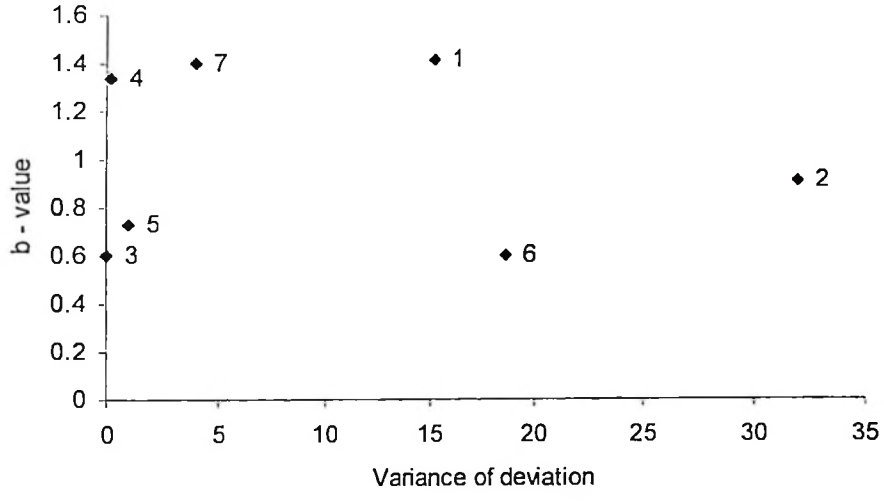


Figure 14: Scatter diagram indicating the relationship between variance of Deviation and regression coefficient (b) for plant height

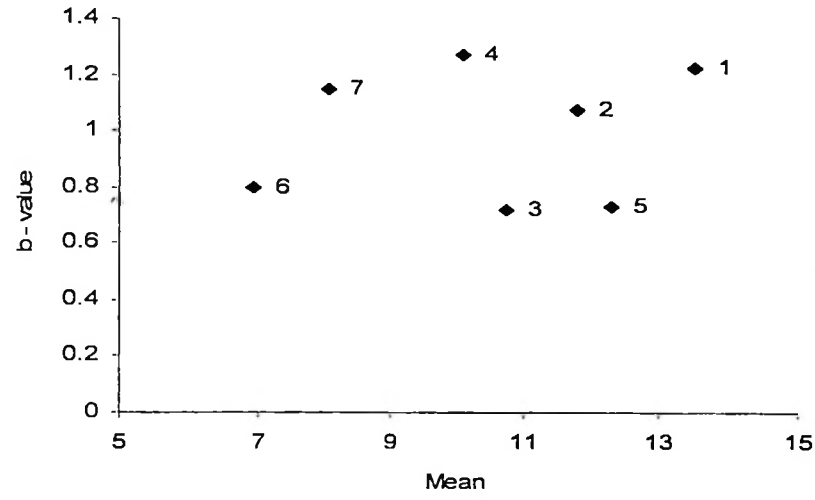


Figure 15: Scatter diagram indicating the relationship between regressions Coefficient (b) and mean for pods/plant

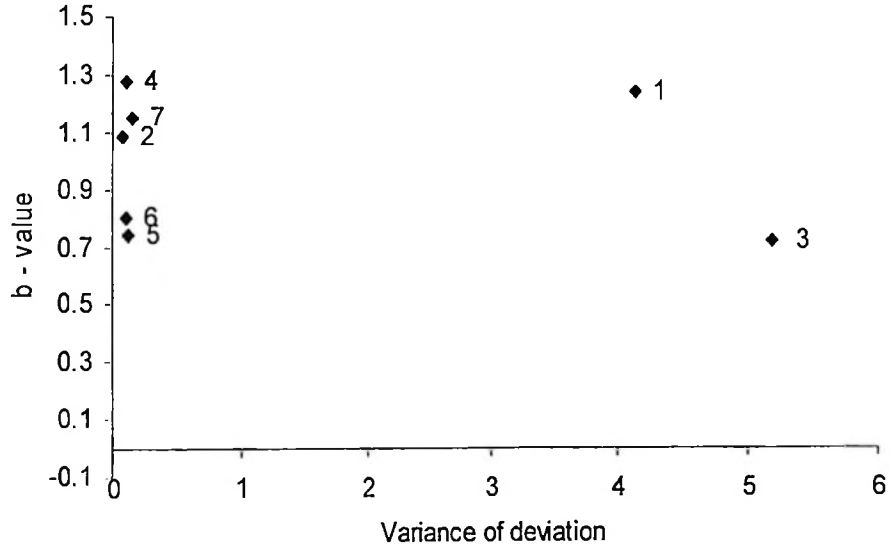


Figure 16: Scatter diagram indicating the relationship between variance of Deviation and regression coefficient (b) for pods/plant

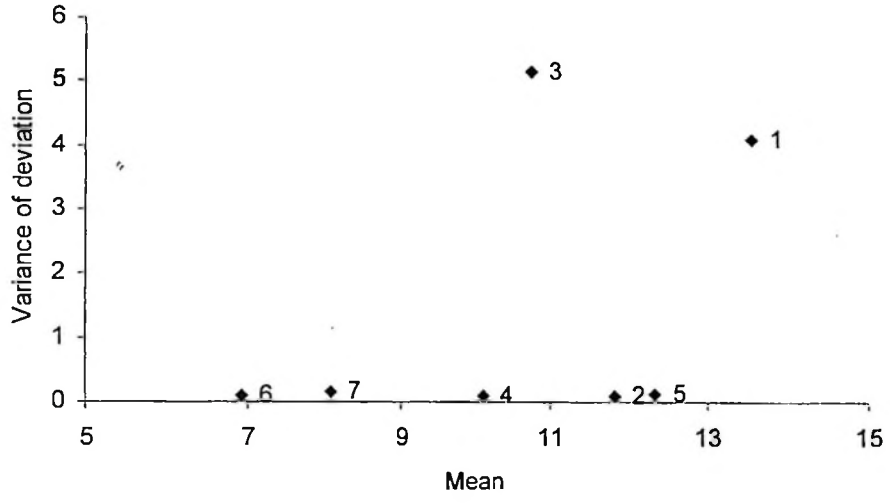


Figure 17: Scatter diagram indicating the relationship between variance of Deviation and mean for pods/plant

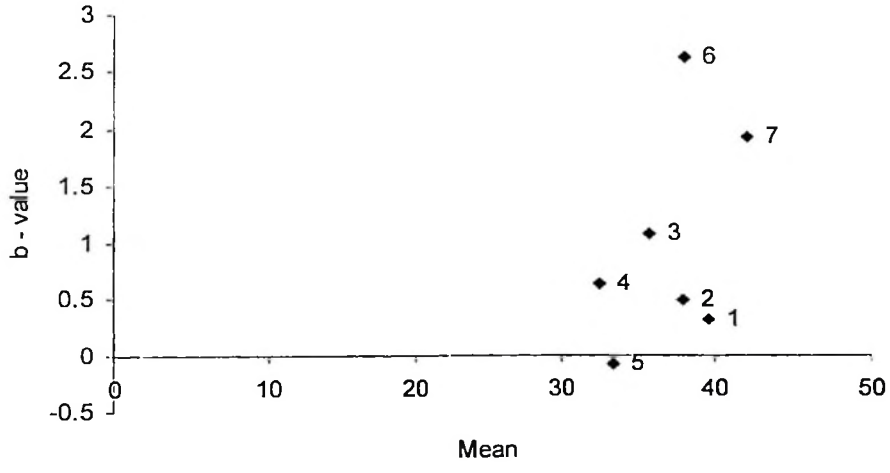


Figure 18: Scatter diagram indicating the relationship between regressions Coefficient (b) and mean for 100 seed weight

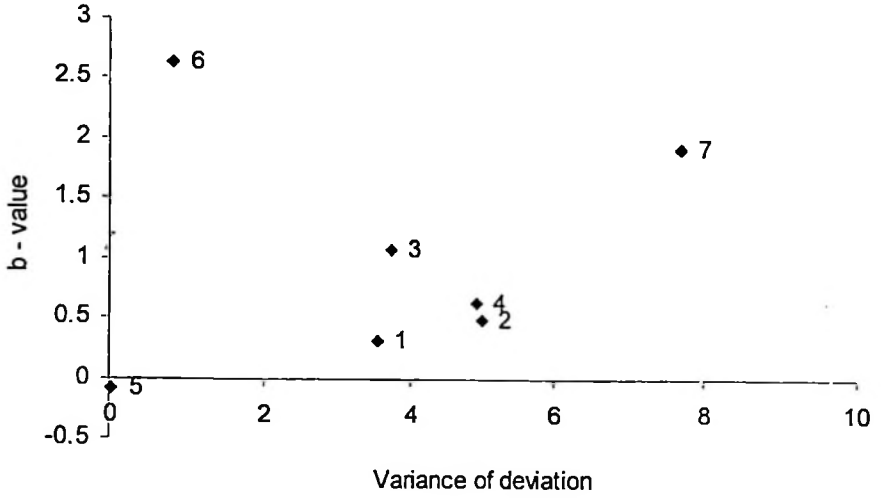


Figure 19: Scatter diagram indicating the relationship between variance of Deviation and regression coefficient (b) for 100 seed weight

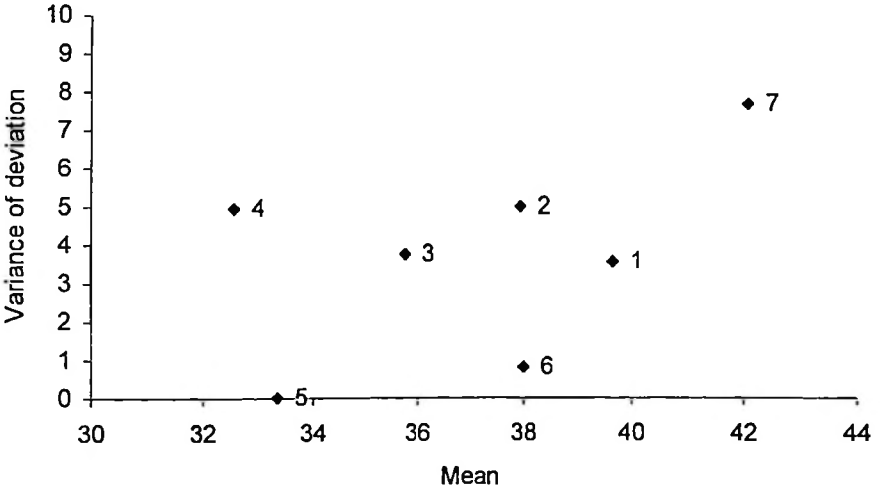


Figure 20: Scatter diagram indicating the relationship between variance of Deviation and mean for 100 seed weight

CHAPTER FIVE

DISCUSSION

Results of this study showed significant differences among genotypes for all the studied variables across locations, and within locations except for seed yield as shown in table 1. The performance of genotypes was different due to genetic differences. Becker and Leon (1988) and Brancourt – Hulmel *et al.*, (2000) noted that the genetic structure of plant materials may also have a bearing on the extent of genotype x environment interaction. Variety types characterized by low levels of heterogeneity such as pure lines and clones tend to interact with environment more than types with opposite features such as open – pollinated population mixture of pure lines. This is because the lower richness in adaptive genes implied by the genetic structure of pure lines and clones makes them more susceptible to variation in environmental conditions. De Datta (1981) and Yoshida (1981) reported also genetic variation among genotypes of beans for days to 50% flowering, days to 80% maturity, pods/plant, plant height, seed yield, 100 seed weight and diseases severity. According to these results, UYOLE 96 and WANJA could be recommended for areas with marginal rainfall due to their earliness while the remaining genotypes could be recommended for areas with medium rainfall. SARBYT and EAI L110 were the best yielder while the same genotypes showed also good resistance to diseases severity of angular leaf spot and common bacterial blight at all locations. UYOLE 96 and WANJA were susceptible to diseases and thus management practices like use of pesticides on appropriate planting times that fall within periods of low infection rates, should be employed. However, SARBYT and EAI L110 seem to be best

genotypes to grow in these areas due to their yield potential and resistance to diseases. SARBYT could as well be grown in all localities where rust is a problem.

Number of days to 50% flowering and number of days to 80% maturity were shorter at Inyala site compared to Mbimba and Uyole due to effect of temperatures. In March during flowering time Uyole had mean temperature of 22.9°C (Appendix: 3), while Inyala had 24.5^{0}C. Effect of temperature on flowering has been reported earlier on by Vergara (1976) and Yoshida (1981) who observed that there is sensitivity to temperature below 30°C, and that flowering is influenced by increase in temperature. Flowering is hastened by increase in temperature because temperature facilitates node development hence earlier flowering and maturity.

The study showed significant differences between genotypes for the various characters across locations. For plant height the study revealed that, Mbimba site had shortest plants compared to other sites. This was due to the fact that, the general performance of crops at Mbimba was poor, this resulted to a significant reduction of growth traits which is reflected by reduced plant height, number of pods per plant and total seed yield (Table 2). Mbimba with clay soils of compact characteristics caused insufficient soil moisture to the crop. Vergara (1976) and Ohashi, *et al.*, (2000) reported insufficient soil moisture on the reduction of plant height due to decreased photosynthates production and translocation to plant parts. All genotypes at Uyole site yielded higher compared to other sites, this is due to the fact that the overall performance of genotypes for the various traits was better at Uyole; such traits included plant height, number of pods per plant,

seed yield and 100 seed weight. This means that the environment at Uyole appears to allow easy discrimination of the best genotypes for expression of maximum potential and could thus prove to be a good breeding and production site. For disease severity, all sites had high scores for angular leaf spot as compared to other diseases. Mahuku *et al.*, (2003) also reported that angular leaf spot is one of the most devastating diseases of common bean in the tropical and subtropical countries. Practices needed to combat the disease e.g. use of fungicides, cultural practices and genetic resistance should be employed.

Results showed differences between fertilizer rates for plant height however, the yield components increased as P level increased though the increases were not significant based on combined analysis, it was only for plant height where the increase with P level was significant (Tables 1). Robinson *et al.*, (1951) reported the effect of phosphorus in stimulating root and plant growth, initiation of nodule formation as well as influencing the general efficiency of the rhizobium legume. Belle (2006) found that applying N and P fertilizers brought effect on N and P uptake, promoted height growth, trifoliate leaves, pods per plant; dry matter yield and seed yield. Redden and Herridge (1999) also found that both genotypes responded strongly to fertilizer nitrogen by increasing shoot and grain yield. Data of soil analysis indicated low levels of N at all sites and low P levels at all sites except Inyala where it was high (Appendix 2). Examination of individual sites indicated significant increments of yield components (Table 3a, 3b, and 3c) indicating the benefits of fertilizer application in these locations.

At Uyole and Mbimba sites fertilizer rate 4 (60kg/ha P, 30kg/ha N) gave more yields while at Inyala site fertilizer rate (70kg/ha P, 20kg/ha N) gave more yields. This was due to the fact that Uyole and Mbimba had soils with low P (Appendix 2) thus high P application was needed to supplement. Rate 4 (60kg/ha P, 30kg/ha N) thus could be recommended at Uyole and Mbimba sites. At Inyala site soils had high P hence a lower rate was needed, thus fertilizer rate 3 (70kg/ha P, 20kg/ha N) could be recommended at Inyala. These results indicate that fertilizer rates recommendation should be location specific. Increments of plant height, 100 seed weight and seed yield with different N and P levels were noted, though for 100 seed weight and yield the effects were not statistically significant, implying that applying N and P increases plant performance though not significantly so.

Results from this study showed that the performance of genotypes across locations were not the same due to effects of genotypes x environment interactions as indicated in Table 1 for most variables. Results showed significant interaction effect for all variables studied except seed yield and common bacterial blight. Differences for number of days to 50% flowering and number of days to maturity were due to temperature influences. Effect of temperature on flowering was reported also by Al-Muchtar and Coyne (1981). The findings are consistent with reports by Wallace (1985) that point out that processes which regulate flowering and consequently maturity, are delayed by fall in temperature. Temperatures at Inyala site were a little bit higher compared to Uyole and Mbimba and thus flowering and maturity were earlier at Inyala compared to other sites (Table 2). Different levels of N and P showed statistically insignificant increments in 100 seed

weight and seed yield (Table 1), the only parameter showing significant response to effect of fertilizer rates was plant height. This means in normal conditions applying N and P increases the amount of these nutrients in the soil and hence their availability to the plant. Two genotypes viz. EAI L110 and NJANO showed no difference in days to 50% flowering across locations; however other genotypes showed great difference across environments. Plant height, number of seeds per plant and 100 seed weight also showed great difference between locations. This is due to the fact that genotypes respond differently with environments in which they are grown and the three sites differed in altitude, temperature and soil characteristics.

The findings suggest that crop performance for some traits depends on specific locations or environments. For example, for days to 50% flowering, UYOLE 96 was the earliest at Uyole while WANJA and NJANO were earliest at Inyala. WANJA was the earliest for days to 80% maturity at Mbimba while WANJA was earliest at Inyala. SARBYT had the highest pods/plant at Uyole and Inyala. Seed yield was also different among genotypes and between environments as Rao (2001) and Nienhuis and Singh (1988) reported that both physiological and morphological characteristics which differ between genotypes of bean plants are considered to play important roles in determining yields. SARBYT is the highest yielder at both Uyole and Inyala (Table 4a and 4c). For disease severity SARBYT and EAI L110 were least attacked at Uyole while CAL 143 was least attacked at Mbimba. EAI L 110 was least attacked by angular leaf spot at Uyole and Mbimba. EAI L110 and CAL 143 were least attacked by common bacterial blight at Uyole, while EAI L110 was least attacked at Mbimba. This implies that specific

genotypes should be grown in specific locations for maximizing crop performance. NJANO was the only genotype that had highest 100 seed weight across all locations indicating that, 100 seed weight response was least influenced by environment for this variety.

Results also reveal that SARBYT, SUG 131, UYOLE 96 and EAIL 110 performed better for all studied variables at all sites hence could be recommended to be grown at all sites. NJANO performed better at Uyole and Mbimba, thus could be recommended at Uyole and Mbimba while WANJA and CAL 143 could be recommended at Uyole. Results also revealed significant effects of location x genotype interaction on disease severity. For instance only EAI L 110 showed resistance to angular leaf spot at all sites thus should be grown for resistance to angular leaf spot in the Southern highlands and be used as source of genes for improving other genotypes against the disease. The severity of common bacterial blight on all genotypes was less at Uyole and Mbimba, while at Inyala the disease severity was higher. Thus managing the disease by the use of pesticides or to synchronize with the period of low infection rates in the area is important.

Results from this study indicated positive correlations between yield and number of pods per plant, 100 seed weight. These results agree with those of Niehuis and Singh (1988); Adams (1973) who found that yield was positively correlated with number of pods per plant. These traits are indicators for yield, hence could be selected simultaneously in breeding programs. High correlations were observed also between number of days to

50% flowering and number of days to 80% maturity. These results agree with those of Mduruma and Nchimbi (1994); Cerna and Beaver (1990) who observed positive correlations between days to flowering and days to maturity, indicating a possibility of simultaneous selection for both traits. Also significant correlations were observed between days to 80% maturity with pods/plant, plant height with pods/plant, plant height with seed yield and pods with seed yield were consistently positive and significant across locations implying that, these traits have stable relations and can be selected for improvement simultaneously in breeding programmes. Other relations like days to 50% flowering with plant height, pods/ plant with days to 50% flowering, seed yield with days to 50% flowering, plant height with days to 80% maturity and days to 80% maturity with 100 seed weight were specific to locations and thus such associations depend on environment.

Generally the genotypic correlations were slightly higher than the phenotypic correlations. These results were similar to what Gebeyehu and Assefa (2003) and Escribano *et al.*, (1997) observed that genotypic correlations were slightly higher than the phenotypic correlations. This indicated that though there was a strong inherent association between various characters studied, the phenotypic expression of the correlation was reduced under influence of environment. Results from path coefficients analysis revealed that number of pods per plant had attributed to both high direct effect and positive correlation with seed yield indicating that number of pods per plant is an important determinant of seed yield. 100 seed weight had also relatively large direct effect on yield contributing to a higher relationship of seed size with yield. Plant height

interacted positively with 100 seed weight, 100 seed weight with pods per plant in influencing seed yield. Thus these pairs of variables are not antagonistic in their influence on yield.

Occurrence of genotype x environment interaction indicates that the different genotypes performed differently along environments and allows the evaluation of stability across environments. For yield variable, SARBYT and EAI L110 had above average response, small variance deviation (S^2d) with high mean yield hence according to Finlay and Wilkinson (1963) could be recommended to high yielding environments. SUG 131 and NJANO had average response, small variance of deviation (S^2d) and mean above average hence these genotypes are stable for yield parameter and could be grown in wide range of environments. Genotypes CAL 143 and WANJA had average response having regression coefficients significantly around unit value with seed yields below grand mean, hence these genotypes were relatively better adapted to poor environments and were insensitive to environmental changes. For days to 50% flowering, SARBYT, CAL 143, NJANO and WANJA had high response thus these genotypes were sensitive to environmental changes, these genotypes also had low variances of deviation thus were more stable. For days to 80% maturity no genotypes had low variance, this implies that response to days to maturity for these genotypes were not stable. NJANO was stable for 100 seed weight because it had low variances of deviation. SARBYT, CAL 143, SUG 131 and UYOLE 96 were sensitive to environmental changes for plant height while CAL 143 and SUG 131 were stable for plant height. For pods/plant, SARBYT, EAI L110, SUG 131 and UYOLE 96 had high response thus they are sensitive to

environmental changes while EAI L110, SUG 131, NJANO, WANJA and UYOLE 96 had low variance of deviation hence this signifies that they are stable genotypes for pods per plant.

Results show that, some genotypes had good attributes of one or two stability parameters but lack others in various variables including yield, thus crosses that could possibly combine all the stability and performance attributes are suggested. For yield, genotype 2 (EAI L110) had high mean yield but has high variance of deviation from regression (less stable) while genotype 6 (WANJA) has low variance of deviation from regression (more stable) but with low mean yield. Crossing of the two genotypes will likely result to segregates with high mean yield and more stable. Genotype 1 (SARBYT) a high yielder but high response can be crossed with genotype 6 (WANJA) which had average response but low mean yield to get segregates with high mean yield and average response. Genotypes 5 (NJANO), 6 (WANJA) and 7 (UYOLE 96) were earlier in flowering with low variances of deviation hence are stable in earliness. Genotype 6 (WANJA) with average response and early maturity can be crossed with genotypes 1 (SARBYT) and 4 (SUG 131) with late maturity to get segregates with average response and early maturity. Genotype 3 (CAL 143) with low variance of deviation and late maturity can be crossed with genotype 6 (WANJA) with earliest to maturity but had high variance of deviation to get segregates with low variance of deviation and earliest to maturity. Genotype 6 (WANJA) with average response but had high variance of deviation can be crossed with genotype 3 (CAL 143) and genotype 5 (NJANO) with low variances of deviation to get segregates with average response and low variance of deviation for maturity variable. Genotype 2 (EAI L110) with average response but high

variance of deviation can be crossed with genotype 3 (CAL 143) and genotype 5 (NJANO) with low variance of deviation to get segregates with average response and low variances of deviation for plant height variable. Genotype 1 (SARBYT) with high number of pods per plant but above average response can be crossed with genotype 2 (EAI L110) with average response but fewer number of pods per plant to get segregates with average response and high number of pods per plant. Genotype 3 (CAL 143) with high variances of deviation can be crossed with genotype 5 (NJANO) and 6 (WANJA) with low variance of deviation and average response to get segregates with low variance of deviation and average response for number of pods per plant. Genotype 1 (SARBYT) with high number of pods per plant but had high variance of deviation can be crossed with genotype 2 (EAI L110), genotype 4 (SUG 131), genotype 5 (NJANO), genotype 6 (WANJA) and genotype 7 (UYOLE 96) to get segregates with high number of pods per plant and low variance of deviation. Genotype 3 (CAL 143) with average response but small seed weight can be crossed with genotype 7 (UYOLE 96) with high seed weight but had high response to get segregates with high seed weight and average response. Genotype 3 (CAL 143) with average response but high variance of deviation for 100 seed weight can be crossed with genotype 5 (NJANO) with low variances of deviation but low response to get segregates with average response and low variance of deviation for 100 seed weight. Genotype 7 (UYOLE 96) with high seed weight but high variance of deviation can be crossed with genotype 5 (NJANO) with low variance of deviation but low seed weight and genotype 6 (WANJA) with low variance of deviation and intermediate seed weight to get segregates with low variances of deviation and high seed weight.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The study was conducted during the season 2006/2007, to assess the effect of genotype x environment interaction on seven common bean varieties. The genetic variations were evaluated on days to 50% flowering, 80% maturity, plant height, number of pods per plant, 100 seed weight, seed yield and disease incidences and severities. Grain yield data were analyzed to get descriptions of genotype performance across environments and discrimination among genotypes for each of the environments. Environmental conditions (e.g. soil, climate, and crop management) differed greatly between the experimental sites, which resulted to different agronomic performance for all the genotypes studied.

From this study, high yielding genotypes were identified as SARBYT, EAI L110, NJANO and SUG 131. SARBYT and EAI L110 could be recommended to be grown in high yielding environments, while NJANO and SUG 131 have ability to express their yield potential in a range of environmental conditions hence could be recommended to be grown in a wide range of environments. This study also showed that UYOLE 96, CAL 143, and WANJA could be recommended to be grown in low yielding environments.

Results show NJANO and WANJA as being stable for the flowering variable and they are earliest hence could be recommended to be grown in marginal areas. CAL 143 was the only stable genotype for plant height.

Results also revealed that, SARBYT and CAL 143 were the least attacked by rust at Inyala and Mbimba while at Uyole SARBYT and EAIL110 were the least attacked. SARBYT and EAI L110 were also relatively least infected by angular leaf spot at all locations. These genotypes can be used as donors of disease resistance/tolerance genes to other varieties that are more susceptible to the above diseases.

This study revealed that plant height, number of pods per plant, 100 seed weight and days to 80% maturity have high and positive correlations with yield. The genetic improvement of these characteristics is necessary in order to confer better yield.

Results show that, some genotypes have good attributes of one or two stability parameters but lack others in various variables including yield, thus crosses that could possibly combine all the stability and performance attributes are suggested as showed in discussion part.

These results contribute important information about the diversity of the genetic material from Southern Highlands of Tanzania and information from the evaluated populations will be relevant to breeders interested in widening genetic base of current bean cultivars.

6.2 RECOMMENDATIONS

These results and observations have been based on only one year's data. It is suggested that, data for more years be included so that the genotype x environment interaction may be partitioned into genotype x location, genotype x year and genotype x location x year interactions. This will give a better estimate of the genotype x environment interaction and more viable recommendations.

Since reducing genotype x environment interactions is difficult, it is better to select stable genotypes as a means of reducing environmental interactions.

From the present study also number of pods per plant had high positive direct effects on seed yield. This yield attribute may be recommended as a reliable selection index.

Selection of superior genotypes based on yield as such, is not effective. For a rational approach towards the improvement of yield, selection has to be made for the components of yield such as days to flowering, days to maturity, plant height, pods per plant and 100 seed weight.

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APPENDINCES

Appendix 1: Experimental sites

Location	District	Latitude	Longitude	Altitude (m)
Uyole	Mbeya urban	S 08^0 56'	E 033^0 06'	1795
Mbimba	Mbozi	S 08^0 57'	E 033^0 13'	1241
Inyala	Mbeya rural	S 08^0 51'	E 033^0 38'	1505

Appendix 2: Data for soil analysis from three sites (Uyole, Mbimba and Inyala)

	UYOLE		MBIMBA		INYALA	
Parameter	**Value**	**Comments**	**Value**	**Comments**	**Value**	**Comments**
Sand	40		33		62	
Clay	34	Clay loam	55	Clay	12	Sandy loam
Silt	26		12		14	
Soil pH (H_20)	6.83	Slightly acidic	5.91	Slightly neutral	6.80	Slightly acidic
%TN mg/kg	0.140	Low	0.154	Low	0.19	Low
%OC mg/kg	2.30	medium	2.11	medium	2.20	medium
Brl Ext.P Mg/kg	5.69	Low	3.23	low	19.60	high
CEC $cmol_c kg$	20.6	high	22.8	high	13.6	medium

Appendix 3 Weather data for Uyole and Mbimba sites

Uyole				Mbimba
Month	Rainfall (mm)	Temperature (max.)	Temperature(min)	Rainfall (mm)
September 06	0.0	24.60	11.2	0.0
October	26.00	26.70	13.2	22.4
November	62.00	25.50	14.7	367.80
December	283.80	22.70	14.6	487.10
January 07	218.00	23.30	14.9	396.20
February	143.00	22.90	14.9	402.80
March	213.80	24.40	13.2	196.00
April	137.90	24.10	12.2	111.80
May	37.60	23.30	11.1	4.0
June	7.90	22.40	7.8	6.5