GENETIC DIVERSITY IN TANZANIAN PIGEONPEA [*CAJANUS CAJAN (L.) MILLSP.]* LANDRACES

By

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This thesis is my original work and has not been presented for a degree in any other university. No part of this thesis may be produced without prior permission of the author, Nairobi University and /or International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

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Dedication

This work is dedicated to my parents Mwalimu Gerry Manyasa (late) and Mama Florence Manyasa who taught me the value of knowledge and dedication to a worthy course.

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Abstract

A total of 123 pigeonpea landraces from farmers' fields in four pigeonpea growing regions (low altitude Coastal , Eastern and Southern plains and Northern highlands) of Tanzania were characterized for 16 qualitative and 14 quantitative traits and their response to variability across three pigeonpea production environments in Tanzania (Ilonga) and Kenya (Kampi ya Mawe and Kabete). The trials were grown in 2002/2003 rainy season at Ilonga and during 2004/2005 rainy season at both Kampi ya Mawe and Kabete using a 12x12 lattice in three replications, single rows of 4m length with inter-row and intra-row spacings of 1.5m and 0.5m respectively. Data on qualitative traits were recorded on each plant in the plot except for seed traits which were recorded on a sample from a whole plot. Data on quantitative traits were taken on 5 randomly selected plants in each plot except pod length, pod width and number of seeds per pod which were recorded on 10 pods selected randomly from 5 plants also randomly chosen. Days to 50% flowering, days to maturity and pod and grain yield were taken on plot basis.

Significant polymorphism in the qualitative traits was recorded in base flower colour, pod colour, flowering pattern, streak pattern, second seed colour, seed colour pattern, and seed shape. There was relatively low diversity in qualitative traits within the accessions and between collection regions. Collections from Northern Highlands exhibited low diversity in qualitative traits (especially physical grain traits) relative to the other 3 regions an indication of selection response to market preferences. High significant differences ($P<0.05$) were recorded in agronomic traits among accessions and in GxE interaction. Medium and long duration genotypes were adapted to warmer (Kampi ya Mawe and Ilonga) and cooler highland areas (Kabete) respectively. High heritabilities were recorded for days to flower, days to maturity, plant heights, raceme number and 100 seed mass an indication of possibility of improvement through selection. Grain yield had positive significant correlations with pods per plant, pod yield, racemes per plant and both

primary and secondary branches per plant, traits that were also correlated with plant heights. Principal component analysis separated the variability in the accessions based on days to flower, days to maturity, plant heights, number of primary and secondary branches and number of racemes per plant with Highland collections showing a strong positive loading for these traits on PC1. Cluster analysis separated the accessions into 6 clusters based on the same traits. There was close clustering within and between materials from Coastal Zone, Eastern Plains and Southern Plains with Northern materials distinctly separated and with wide dispersion within. Overall though, two major diversity groups were evident with Coastal, Eastern and Southern materials in one diversity cluster and Northern Highlands materials in another cluster. The diversity grouping in this study has helped establish the possible heterotic groups which may be used in intercrossing to maximize hybrid vigor and generate varieties adapted to different pigeonpea growing environments with consumer acceptability. And as much as this grouping based on reproductive and morphological traits can form the basis of forming a core collection of this germplasm representing the variability groups identified, there is need to extend collection and characterization to all other pigeonpea areas in Tanzania to capture the actual diversity and especially now that new improved pigeonpea types are getting adopted by farmers.

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Acronyms

KVL- Royal Veterinary and Agricultural University, Denmark

ICRAF – International Centre for Research in Agroforestry

ICRISAT – International Crops Research Institute for the Semi-Arid Tropics

DANIDA – Danish International Development Agency

NARS – National Agricultural Research Systems

ESA – Eastern and Southern Africa

ARI Ilonga – Agricultural Research Institute Ilonga, Tanzania

IBPGR – International Board for Plant Genetic Resources (now Bioversity International)

CHAPTER 1

1.0 General Introduction

1.1 Background

Pigeonpea (*Cajanus cajan* (L) Millsp) belongs to the genus *Cajanus* of the sub-tribe *Cajaninae,* tribe *Phaseoleae* of the sub-family *Papilionoideae* and family *Leguminosae*. The crop is reported to have originated in India due to the large diversity of the crop found there (van der Maesen, 1986,1990). The crop then moved to Africa over 4000 years ago and it is from eastern Africa that it moved on to tropical America. Eastern Africa is known to be the secondary center of diversity. Other secondary centres of diversity include south east and south Asia, Caribbean Islands and parts of south and central America (Singh 1991; Remanandan *et al.,* 1991). Although the pigeonpea plant is a perennial, it is more often cultivated as an annual (Saxena and Sharma, 1990).

Pigeonpea is a legume crop of the tropics and subtropics and is the fifth most important pulse crop in the world (Whiteman *et al*., 1985). It is a perennial and woody shrub that is cropped annually in many farming systems. The crop has several unique characteristics that have made it find an important place in the small holder farming systems in many developing countries (Nene and Sheila, 1990). The crop's slow and non competitive early growth, makes it suitable as an intercrop with sorghum, maize, millets, where the cereal is harvested before pigeonpea completes its vegetative phase (Lateef, 1991; Singh, 1991). Pigeonpea is also intercropped with cassava, cotton, cowpea, beans and castor and more recently it is used in agro-forestry systems. The use of pigeonpea in inter-cropping systems with cereals usually results in very high land equivalent ratio (LER) values due to its slow canopy development (Sivakumar and Virmani, 1980).

Until the early 1980s, the Indian sub-continent accounted for about 90% of the 2.2 million t world's pigeonpea production, but this has since come down to 84% indicating that pigeonpea production is increasing in other regions. In Africa, pigeonpea is produced mostly in Kenya (34% area; 18% production), Malawi (33% area; 39% production) Uganda (17% area; 23% production) and Tanzania (16% area; 19% production) (Joshi, et al, 2001). Although area under pigeonpea in Mozambique is not known, it is believed to be higher than in Malawi (Joshi, *et al*, 2001). Small scale and backyard crop establishments are also found in Sudan, Ethiopia, Zambia, Sierra Leone and Burundi. Other countries where pigeonpea is grown are found in Latin America and the Caribbean which account for only 1% of pigeonpea area and production. Most of the varieties grown in Africa are landraces which are long duration and are often found in inter-crops or mixed cropping systems with short maturity crops where they thrive on residual moisture after harvest of the short duration crops (Nene and Sheila, 1990). The short duration cultivars which have been developed by the Internatiuonal Crops Research Institute for Semi-Arid Tropics (ICRISAT) are mainly found in sole cropping intensive production systems in India and have not picked up in Africa mainly due to their vulnerability to insect pest damage. Globally average pigeonpea grain yields have remained stagnant at 0.7 t ha^{-1} (Joshi, *et al.*, 2001) (Table 1).

The pigeonpea grain is an important source of protein (grain has about 21% protein) in the diets of people where the crop is grown (Lateef, 1991). Besides its main use as dry grain (whole or split), the green seed is also eaten as vegetable (Nene and Sheila, 1990, Lateef, 1991). Although global statistics are incomplete, Kenya and Tanzania have been among the important exporters during the last 10-15 years. In 1998, Kenya, Malawi and Tanzania exported over 40,000, 20,000 and 8,000 tons respectively with Kenya and Malawi exporting whole grain to India and dhal (split grain) to South Africa, Europe and North America. However, it is believed that significant proportion of the Malawi pigeonpea was sourced from Mozambique through informal border trade (Joshi et al., 2001). In Kenya and Tanzania, green pigeonpea is an important source of income for people in peri-urban areas who get access to urban markets. However, small quantities of green pigeonpea are exported to United Kingdom from Kenya (Joshi *et al.*, 2001; Silim et al., 2005).

Pigeonpea dry crashed seed (husks and pod walls) and green leaf are used as animal feed and fodder respectively whereas stems are used for firewood and building. The medicinal value of pigeonpea dry roots, leaves, flowers and seeds has also been reported in different countries (Morton, 1976). In the semi-arid areas where soils are poor, temperatures are high and rainfall is low and erratic, pigeonpea plays an important role, where its deep and extensive roots enable it withstand drought through efficient moisture and nutrient utilization. Pigeonpea crop is an important component in soil fertility management based on its ability to fix nitrogen and the massive litter it adds to the soil through leaf drop. The leaves and roots on the average contribute about 40kg Nitrogen ha-1 (Sheldrake and Narayanan 1979; Rao and Wiley, 1981). Pigeonpea root exudates contain substances which solubilize phosphorus from an iron-bound form hence the crop is able to grow well in alfisols where phosphorus may be low (Ae *et al.*, 1990).

Table 1: Pigeonpea area, yield and production in Africa.

	Area ('000 ha)			**Yield Kg ha^{-1}**			**Production ('000 t)**		
Country	*1980-82*	*1990-92*	*1996-98*	*1980-82*	*1990-92*	*1996-98*	*1980-82*	*1990-92*	*1996-98*
Burundi	2.4	2.3	2.3	1041.7	1043.5	1000.0	2.5	2.4	2.3
Kenya	66.3	78.1	147.5	434.4	850.2	304.4	28.8	66.4	44.9
Malawi	127.3	142.3	143.0	667.7	683.8	687.4	85.0	97.3	98.3
Tanzania	36.7	56.0	68.0	618.5	673.2	691.2	22.7	37.7	47.0
Uganda	55.0	61.3	71.3	478.2	827.1	817.7	26.3	50.7	58.3
Total	**287.7**	**340.1**	**432.2**	**574.6**	**748.3**	**580.5**	**165.3**	**254.5**	**250.9**
World	**3275.3**	**4109.5**	**4392.9**	**681.9**	**682.7**	**657.2**	**2233.3**	**2805.4**	**2887.0**

Source: Joshi *et al.*, 2001.

Despite the importance of pigeonpea in eastern and southern Africa region, little concerted research effort has been directed at crop improvement. Yields on farmers' fields are still low averaging about 400-600kg ha^{-1} due to a combination of lack of improved varieties, poor crop husbandry, insect pests and diseases. Pigeonpea production systems in the region are based on intercropping of unimproved long and medium duration landraces with cereals or various other short/long duration crops (Mligo, 1995; Singh *et al.*, 1991). Although breeding activities were initiated in the early 60's, efforts were accelerated in early 1990s when ICRISAT started its regional program to backstop the National Agricultural Research Systems (NARS) in the region. Attempts to introduce new varieties developed from Indian germplasm have been less successful due to lack of adaptation of introduced improved varieties to photoperiod and temperature (Silim and Omanga, 2001). In Eastern and Southern Africa, pigeonpea is cultivated at altitudes varying from sea level to about 2000 m. The sensitivity of pigeonpea to temperature and photoperiod however calls for the development of stable and predictable varieties, management practices, and production systems (Silim *et al.*, 1995). With this knowledge, ICRISAT initiated its breeding work by using landraces from the region and this has resulted in release or identification of high yielding varieties in Tanzania, Kenya, Mozambique, Malawi and Uganda (ICRISAT, 2003).

As better yielding varieties are adopted by farmers and/or as farmers shift to other crops which give better returns, pigeonpea landraces and diversity may be lost. This concern led ICRISAT and national partners in Tanzania to conduct a comprehensive collection mission in 2001 in major pigeonpea growing areas (Silim *et al.*, 2005). The knowledge of the amount, extent and distribution of genetic variations in germplasm is the key to its improvement and development of effective conservation strategies (Hodgkin, 1997). The study of morphological and agronomic traits is the classic way of assessing genetic diversity. Agro-morphological traits together with sound statistical procedures that characterize genetic divergence using the criterion of similarity or dissimilarity based on aggregate effect (e.g. hierarchical Euclidean cluster analysis) have been successfully used in characterization of germplasm for conservation and in selecting superior individuals for crop improvement programs (Mead *et al.*, 2002). This approach usually involves the description of variation for morphological traits, particularly agro-morphological characters of direct interest to users (Ntundu, 2002).

1.2 Genetic Resources

The International Crops Research Institute for Semi-Arid Tropics (ICRISAT) acts as a world repository for genetic resources of pigeonpea. The major activities of ICRISAT Genetic Resources Unit are to collect, maintain, conserve, evaluate, document and distribute germplasm to various pigeonpea researchers. The ICRISAT Genebank at Patncheru, India, holds 13077 pigeonpea accessions from 62 countries with a wide range of variability out of which 1266 accessions are from Africa (Table 2). The genebank also has 555 accessions of the wild species related to pigeonpea (Upadhyaya et al., 2005).

Table 2. Number of accessions from Africa in the world collection of pigeonpea held at the Genebank, ICRISAT Centre, India, by Country, 2005.

Country	Number of accessions
Ethiopia	14
Ghana	2
Kenya	337
Malagasy Republic	1
Malawi	249
Mozambique	11
Nigeria	182
Rwanda	5
Senegal	11
Sierra Leone	3
South Africa	40
Tanzania	234
Uganda	84
Zambia	93
Total	**1266**

Source: Upadhyaya *et al.*, 2005.

In earlier evaluations done at ICRISAT in India, eastern and southern African pigeonpea germplasm were particularly found to have large white or cream seeds and long pods (Remanandan, 1990). Valuable resistance to insect pests and diseases has also been found in this germplasm (Odeny, 2001; Silim Nahdy *et al.*, 1999). Extensive collection of landraces has already been done in Kenya (Kimani, 2001) but no systematic collection of germplasm and information of farming systems and uses have been carried out in Tanzania (Silim *et al.*, 2005). Increase in human population and increasing pigeonpea commercialization is forcing farmers in the region to search for either high yielding varieties or alternative crops with better productivity and returns. The likelihood of losing germplasm from the region and hence biodiversity is therefore high. In addition the uniqueness of the material has not been determined (Silim *et al.*, 2005).

1.3 Pigeonpea in Tanzania

Pigeonpea in Tanzania is ranked third among the major legumes found in the country and is grown on about 63,000 hectares with an average total production of 44000 ton per annum (Table 3) (Shiferaw et al., 2005). Yields are low (0.7 t/ha) (Table 3) due to lack of high yielding varieties, diseases (*Fusarium* wilt) and insect pests (pod borers, pod suckers and podfly). The major regions of production are Lindi and Mtwara in the low altitude south, Babati, Kilimanjaro and Arusha in the medium and high altitude north and Shinyanga in Lake Zone. The crop is also extensively cultivated along the Coast, Dar es Salaam, Tanga and Morogoro in eastern Zone (Mligo and Myaka, 1994; Shiferaw *et al.*, 2005). Most of the crop is raised on individuals' farms ranging in size from 0.25 to 1.0 ha and is intercropped with maize, sorghum, beans, cowpea, cassava and sweet potatoes (Maingu and Mligo, 1991). In Kondoa, Babati, Karatu and Arumeru districts, pigeonpea is now rapidly getting commercialized with dry grain exports to Asia, Europe and Kenya. Currently the popular varieties are medium and long duration landraces though in the commercialized northern region (Babati) where mainly long duration types are grown, improved types are now being adopted by many farmers (Silim et al., 2005; Kimani, 2001; Shiferaw et al., 2005). Fusarium wilt incidence ranging from 10-95 % and insect damage to grain of upto 14% have been reported in farmers' fields in Tanzania (Siferaw *et al.*, 2005; Minja, 1997).

The national pigeonpea breeding program has been geared towards identifying suitable bold-white seeded varieties with acceptable food qualities in each maturity group (Mligo, 1995). Research efforts in pigeonpea breeding have been accelerated since 1990s after collaboration with ICRISAT started (Kimani, 2001), but introductions from India were less successful due to poor adaptation. Current successes are emanating from medium and long duration improved types selected from local landraces in Kenyan and Tanzanian germplasm by ICRISAT (Silim, *et al.*, 2005). ICEAP 00040, the most preferred improved high yielding and fusarium wilt resistant variety is a selction from local landrace in Kenya (Shiferaw *et al.*, 2005). Although some germplasm has been collected in the past and grown for seed increase and purification (Maingu and Mligo, 1991), no systematic characterization to determine diversity in the germplasm has been done.

Table 3: Area, production, yield and exports of pigeonpea in Tanzania.

Year	Area (1000 ha)	Production (1000 t)	Yield (t/ha)	Exports (1000 t)
1992/93	55	38	0.69	23.39
1993/94	50	34	0.68	22.80
1994/95	60	42	0.70	27.69
1995/96	79	55	0.70	34.61
1996/97	60	41	0.68	25.69
1997/98	65	45	0.69	27.13
1998/99	65	47	0.72	28.58
1999/00	66	47	0.71	29.41
2000/01	66	47	0.71	30.29

Source: FAOSTAT (2004) in Shiferaw et al., 2005.

During the pigeonpea germplasm collection mission in the four main pigeonpea production regions in the country (Figure 1) in 2001, the following were noted (Silim *et al.*, 2005).

- A considerable variation in cropping systems exists in Tanzania, with characteristic differences between the zones.
- Pigeonpea was most often planted with the onset of rain, however dry-planting before the rain or late planting was also used in all zones except in the Northern Highlands.
- Intercropped pigeonpea was the most common in all areas, accounting for 90 % of all fields, but sole cropping, and planting in field borders were also practiced.
- The most common intercrops were maize and cassava in the Coastal Zone and Eastern Plains; maize, sorghum, and cassava in the Southern Plains and maize in the Northern Highlands.

- In the Northern Highlands, the crop is considered a cash crop and a large proportion of the production is sold. A market for green pigeonpea (in Zanzibar and Dar es Salaam) for growers from the Coastal Zone and the Eastern Plains exists.
- Pigeonpea in Tanzania is used in three ways: as green peas, whole dry grains, or split into dhal. Dehulling was used in all areas except in the Northern Highlands, and was especially frequent in the Southern Plain where pigeonpea is the most important grain legume.
- Most of the varieties were classified as long-duration types, and medium-duration types were found only in the Coastal Zone.
- About half of the varieties in the Coastal Zone and the Eastern and Southern Plains were cream and about three quarters of the varieties in the Northern Highlands were white or cream with mostly medium to large seed size.
- The major pests reported by farmers were pod borers, pod suckers and bruchids. Pod borers which are field pests were present in all regions, with the highest level in the Eastern and Southern Plains. Some varieties in the Southern Plain appeared to have some resistance.
- High levels of field infestation of bruchids in the Southern Plains were observed and there appeared to be a level of resistance in some varieties in the Eastern Plains, and some resistant lines were identified in Southern Plain.
- Fusarium wilt was prevalent in all regions. Even in the Northern Highlands where the incidence appeared low the disease was severe in concentrated pockets of high incidence. Insufficient crop rotation seems to be a major cause for the spread of fusarium wilt. Some varieties collected appeared resistant to fusarium wilt.

- Although farmers in Tanzania mainly grow their own landraces, medium and long duration varieties developed by ICRISAT are now being introduced by the national research system. Especially in areas in the Northern Highlands, where pigeonpea plays an important role as a cash crop, local germplasm may rapidly be lost as bold seeded, higher yielding and wilt resistant varieties are introduced.

Inspite of the importance notable in the local germplasm in Tanzania, limited or no agro-morphological characterization of the germplasm has been done. There was therefore an urgent need to conserve and characterize existing genetic resources of pigeonpea. With the adoption of new varieties coupled with the search for either high yielding or alternative crops with better productivity and returns as population increases, the likelihood of losing germplasm hence diversity in pigeonpea in Tanzania becomes apparent. This is even more worrying considering the fact that the uniqueness of the material has not been determined (Silim *et al.*, 2005).

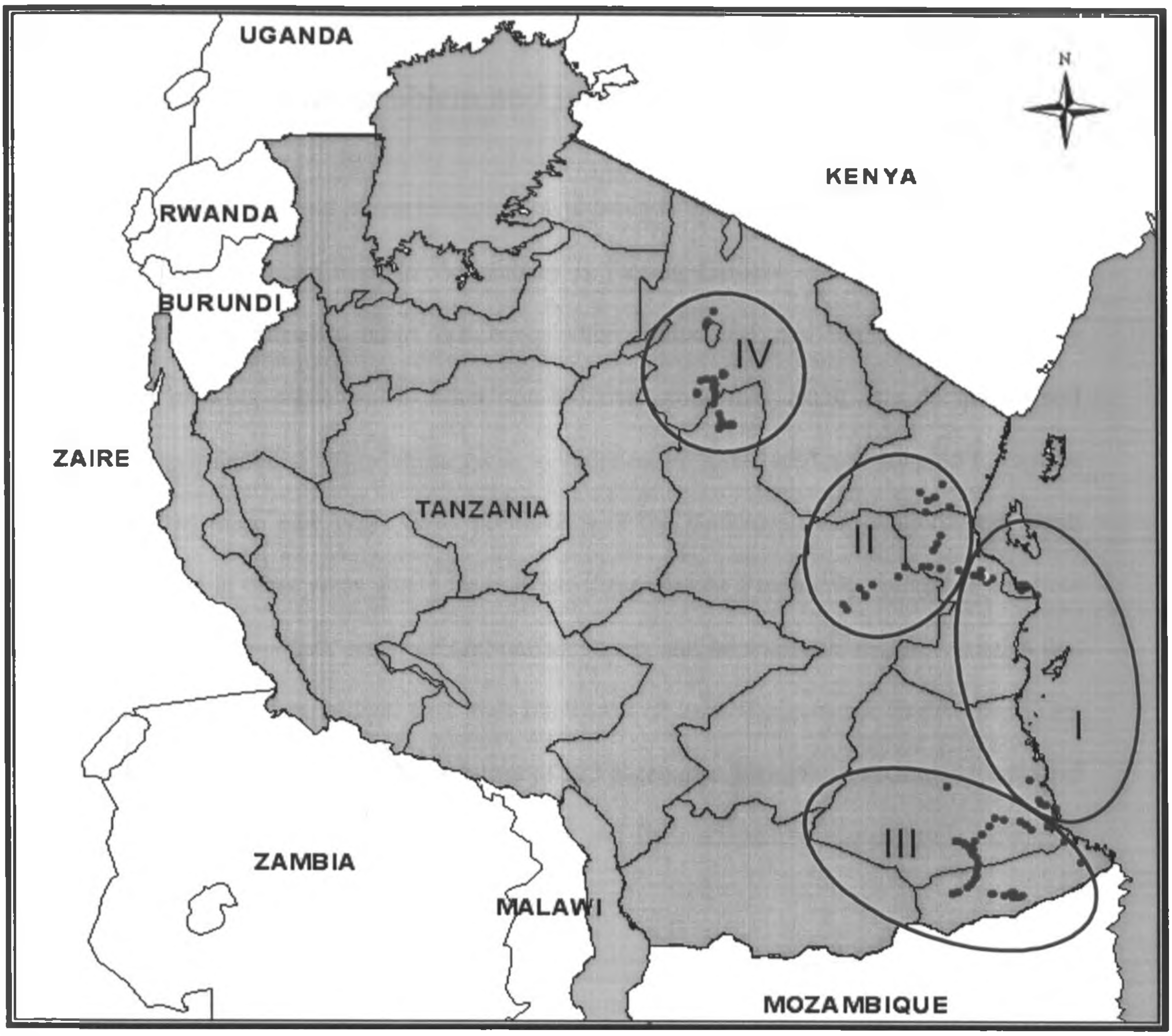


Figure 1. Map of Tanzania showing collection sites for the 123 pigeonpea accessions characterized in this study. Regions: I-Coastal Zone; II-Eastern Plain; III-Southern Plain; IV-Northern Highlands.

1.4 Statement of the problem and justification

No systematic collection and characterization of pigeonpea germplasm has been carried out in Tanzania. Increase in population in the country is forcing farmers to search for either high yielding varieties or alternate crops that have better productivity and returns. The move by farmers from growing pigeonpea to other non-N-fixing crops may result in a decline in soil fertility and environmental degradation. As new varieties are introduced and adapted to replace landraces and as these new types cross pollinate with the landraces, loss of biodiversity will occur. In addition in those areas where farmers use pigeonpea as a cash crop, genetically narrow base is used because markets prefer certain uniform traits and farmers also require varieties that are uniform. All these factors lead to a high likelihood of loss of pigeonpea biodiversity. This study involved characterization and evaluation of 123 pigeonpea germplasm accessions collected from Tanzania for their agro-morphological traits and their adaptation across three pigeonpea production environments in Kenya and Tanzania.

1.4.1 Main objective of the study

The main aim of the study was to determine the extent of genetic divergence in pigeonpea landraces collected from Tanzania based on agro-morphological traits to provide information that would enable germplasm management and use in breeding programs.

1.4.2 Specific objectives of the study

i. Determine genetic variation within Tanzanian pigeonpea germplasm based on agro-morphological characteristics

ii. Determine contributions of different components towards total genetic diversity in the germplasm

iii. Determine the genetic variability wirthin Tanzanian pigeonpea germplasm in response to temperature and altitude for precise future use in suitable agro-ecologies in the Eastern Africa `region.

iv. Determine direct and indirect associations between various morphological traits

1.4.3 Hypotheses

i. That there is genetic variation within and among the pigeonpea landraces cultivated in Tanzania

ii. That specific traits have major contribution to the variability among the landraces

iii. That agro-ecology has an influence on agronomic traits and determines the suitability of certain landraces in particular agro-ecologies.

iv. That in areas where farmers are linked to the market, there is loss in diversity

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Botanical Characteristics and Diversity

2.1.1 Growth habit

On germination, the first two leaves of the pigeonpea plant are simple and opposite. The second and third nodes show either a simple leaf or a compound leaf with only two leaflets. Later leaves are compound, pinately trifoliate and arranged in a 2/5 type of spiral phylotaxy. Petiole lengths range from 2.4 to 6.0 cm, prominently grooved on the adaxial side. Leaves are lanceolate or elliptic with acute or obtuse apices. Terminal leaflets are usually bigger than lateral leaflets. Leaf size and shape are influenced by genotypic and environmental variations with leaf size consistently increasing under extended day-length conditions (Reddy, 1990). Leaf areas range from 13.0 to 93.5 cm^2 (Murthi and van der Maesen, 1979).

Pigeonpea stems are predominantly green with purple, dark purple and sun-red being quite common and measure upto 15 cm in diameter. They are ribbed and become woody with age (Remanandan *et al.*, 1988). Plant growth habit in pigeonpea is dependent on the number of primary and secondary branches and angle of the branches on stem on which they are borne leading to various forms ranging from upright compact to spreading types (Remanandan *et al.*, 1988). Most of the landraces are semi-spreading types. Growth habit is influenced by plant population and cropping system (intercrop situations). Branching is reduced under high populations and in intercrop systems. Semi-spreading types are reported to possess higher branching habit plasticity than the other types hence are more suitable for intercropping systems (Baldev, 1988). The number of primary branches is highly correlated to grain yield (Beohar and Nigam, 1972). Plants with higher number of secondary branches exhibit a spreading growth habit and high secondary branching is also considered a positive attribute to grain yield (Dasappa and Mahadevappa, 1970).

Pigeonpea plant height is dependent on maturity, photoperiod and temperature (Reddy, 1990; Sharma, 1981; Silim *et al.*, 1995). Because of their prolonged vegetative phase, long duration types are generally tall but they will have a height reduction if they are induced to flower early. Plants are taller under warm temperatures. However, genetic dwarfs do retain their dwarfness over a wide range of environments (Remanandan, 1990).

2.1.2 Flowering and pollination

Most landraces are indeterminate in flowering habit with high biomass and a low harvest index. However, intermediate (semi-determinate) cultivars and determinate types are present (Saxena and Sharma, 1990). Though easier to spray and mechanically harvest, short-determinate types are highly susceptible to insect pests (ICRISAT, 1980). Sharma *et al.,* (1981) reported that pigeonpea is a quantitative short day plant with a critical day length of 13 hrs. Days to 50% flowering and maturity duration have a high positive correlation. Maturity duration will determine the adaptation of varieties to various agro-ecologies and cropping systems. Based on days to flower, pigeonpea has been classified into early, medium and late maturity groups (Sharma *et al.*, 1981). Studies on flowering potential in pigeonpea indicate that whereas the plant produces numerous flowers, about 90% are shed without pod set (Pathak, 1970; Pandey and Singh 1981). The flowers are borne on short racemes. Racemes on a stem in pigeonpea germplasm accessions evaluated at ICRISAT-India ranged from 6 to 915 with peduncles 1 to 8cm and thin pedicels 7 to 15mm long

(Reddy, 1990). Medium and mid-late maturity types produce large numbers of racemes (Remanandan, 1990). The base flower colour is predominantly yellow with other colours being light yellow, ivory, orange, red and purple. The secondary flower colour which basically describes the colour of streaks on the dorsal side of the flag falls in three classes of none, purple and red with red streak being predominant (Reddy, 1990). Intensity of streaks is classified as none, few, medium, dense and uniform coverage.

Pigeonpea outcrosses to various degrees under field conditions making purity maintenance of the crop difficult and expensive. Out-crossing is mostly by insects (Williams, 1977; Khan and Rachie, 1972; Onim, 1981). Diversity within pigeonpea varieties with respect to qualitative traits especially flower, pod and seed colours are always evident. Maintenance of purity can however be achieved by isolation or selfing individual plant branches or whole plants using muslin/hesian/nylon clothing. Best yields are obtained when flowering and podding coincide with receding rainfall patterns (Remanandan, 1990).

2.1.3 Pods and Seeds

Only 10% of the flowers set pods. Each raceme will produce 1 to 5 pods. Seeds mature 38 to 40 days after pollination (Sehgal and Gandhi, 1986). Pods are oblong, straight or sickle shaped, laterally compressed with lengths and widths varying from 2 to 8 cm and 0.4 to 1.0 cm respectively. Based on colour, pods are classified as dark purple, purple, mixed (green and purple) and green. About 80 to 90% of the world's pigeonpea collections have mixed pod colour (Remanandan, 1988; Upadhyaya *et al.*, 2005). There are large variations between genotypes in number of seeds per pod but these are remarkably consistent within a genotype (Sheldrake, 1984). However, studies at ICRISAT found that genotypes that produce more seeds per pod ($\geq$7) have reduced ability to fill the seeds (ICRISAT, 1975). Seed colour in pigeonpea has a significant bearing on market. Various shades of red/brown are predominant but in Eastern and Southern

Africa, the predominant and preferred colour is cream/white. Although seed coat colour has no effect on dhal, white light-seed coat colours are preferred even in mainly dhal consuming areas. In areas where pigeonpea is consumed as green seed, the large bright green-seeded at pod filling stage are preferred. Large seeds are preferred by consumers because pericarp % reduces with increase in seed size (increases dhal output), however, large seeded types are poor pod setters due to high ovule abortion (ICRISAT 1975; Gupta *et al.*, 1981; Reddy, 1990). Seed shape ranges from oval to elongate, with oval shape being predominant. Although 100 seed mass of upto 22.4 g has been reported, most genotypes have seed mass range 7 to 9.5 g (Reddy, 1990) particularly in India. However, most materials from eastern Africa have large white/cream seeds.

2.1.4 Correlation of Morphological traits in Pigeonpea

In order to identify and develop ideal plant types through effective planning of recombinations and development of selection indices, it is essential to know the association between various morphological traits. Knowledge on genetic association helps in varietal classification into cultivar groups for identification and maintenance of cultivars and also for germplasm grouping into various gene-pools for cheap and effective maintenance as mass reservoirs (Remanandan *et al.*, 1988). Table 4 based on evaluation of 852 pigeonpea accessions at ICRISAT-India gives an indication of association between various morphological characters in pigeonpea. Grain yield was found to be positively correlated with the number of primary and secondary branches, number of racemes per plant (all factors related to plant height), shelling ratio and harvest index but negatively correlated with percent protein.

Table 4. Correlation matrix of important agronomic characters on 8582 pigeonpea accessions evaluated from 1975/76 to 1982/83 at ICRISAT-India

1. FLOW50%											
2. Maturity	0.90**										
3. PLHTMAT	0.36**	0.33**									
4. NRPRBR	-0.11	-0.08	0.26								
5. NRSECBR	0.11	0.06	0.33**	0.45**							
6. RACEMNR	-0.11	-0.10	0.31**	0.42**	0.68**						
7. SEEDNR	0.03	-0.02	0.16	-0.11	-0.15	-0.11					
8. SEEDWT	0.18	0.18	0.14	-0.18	-0.30**	-0.36**	0.35**				
9. HI	-0.43**	-0.47**	-0.29	-0.06	0.00	0.25	0.00	-0.18			
10. SHRAT	-0.39**	-0.46**	0.04	0.16	0.20	0.32**	0.06	-0.15	0.67**		
11. PROTEIN	0.39**	0.35**	0.01	-0.23	-0.12	-0.21	-0.15	-0.06	-0.20	-0.26	
12. YLDPERPT	-0.17	-0.21	0.26	0.35**	0.54**	0.75**	0.06	-0.16	0.44**	0.50**	-0.36**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**

Key:

*** P<0.05. Values > 0.3 strongly correlated; 0.15-0.3 moderately correlated; <0.15 weakly correlated.*

Descriptors: FLOW50% - Days to 50% flower; PLHTMAT – Plant height at maturity; NRPRBR- # of primary branches; NRSECBR # of secondary branches; RACEMNR - # of racemes; SEEDNR-seeds per pod; SEEDWT- seed mass; HI-harvest index; SHRAT-shelling ratio

Source: Remanandan *et al*, 1988.

2.2 Insect Pests and Diseases

2.2.1 Insect Pests

Pigeonpea suffers substantial insect pest damage in all areas where it is grown with India alone recording over 200 pigeonpea insect pests species (Reed and Lateef, 1990). Some of these insects cause significant losses to be regarded as major pests, but the majority are seldom abundant enough to cause much damage. These insects may chew or suck any part of the pigeonpea plant from seedling to harvest stages. In eastern and southern Africa, pod damaging insects are the most important as pod damage can greatly reduce crop yield since pigeonpea's potential to compensate for pod damage is limited (Reed and Lateef, 1990). Pod borers (*Helicoverpa armigera* and *Maruca testuralis)* pod sucking bugs (*Clavigralla spp.* and *Nezara viridula*) and podfly (*Melanagromyza chalcosoma*) are the most damaging but blister beetles (*Mylobris amplecteus and M. convexior*) and pollen beetle *(Coryna apicicornis*) are also important. In surveys carried out by Minja (1997). Damage to grain in the field mainly caused by pod borers and suckers was estimated at 27% in Kenya, 15% in Malawi, 16% in Uganda and 14% in Tanzania. Very few farmers use insecticides due to high cost, unavailability or lack of using skills. And although no genotypes have been found with resistance to pigeonpea insect pests (ICRISAT, 1982), there are considerable differences in susceptibility to the pests and lines with considerable tolerance to field and storage pests have been noted (Silim et al., 2005; Silim Nahdy *et al.*, 1999).

Considerable differences have been observed in pest damage in respect of growth habits and the duration of the cultivars. Studies by *Reed et al.*, (1980) and Okeyo-Owuor (1979) found that the determinate (clustering) types suffered most from lepidopteran borer attack under unprotected conditions whereas the indeterminate (loose branching) types, medium and long duration cultivars got more podfly incidence (Reed *et al.*, 1980; Okeyo-Owour, 1978). The pod bunches in determinate types offer niches in which pests like *Helicoverpa* and *Maruca* larvae can conceal themselves, and thus are not exposed to predation when moving from pod to pod (Reed and Lateef, 1990). Bruchids are the most serious pests of stored pigeonpea. In eastern and southern Africa, the most prevalent are *Callosobruchus chinensis, C, maculatus, C. rhodesianus* and *C. analis* (Mphuru, 1978; Silim-Nahdy and Odong, 1994; Silim-Nahdy, 1995; Minja, 1997). Farmers use both chemical and non-chemical practices in control of bruchids and though use of chemical control option is very effective, the cost is usually beyond reach of resource poor farmers in developing countries. Certain pod characteristics like hair density and pod wall thickness are reported to offer some resistance to both larval penetration and adult emergence (Silim Nahdy *et al.*, 1999).

2.2.2 Diseases

The major diseases of pigeonpea are fusarium wilt (*Fusarium udum* Butler), cercospora leaf spot (*Cercospora cajani* Hennings) and powdery mildew (*Oidopsis taurica* (Lev) Solmon). Fusarium wilt and cercospora leaf spot cause yield losses of economic concern (Songa and King, 1994; Kannaiyan *et al.*, 1984). Onim (1980) reported yield losses of upto 80% at higher altitudes of 1200-1700 m.a.s.l., while Mbwaga (1998) reported yield losses of 10-96% on farmers' fields in Tanzania. Indications of pathogenic differences between *Fusarium udum* populations were seen when lines of known reaction to the pathogen behaved differently at different locations. Pigeonpea line ICP 9145 which was wilt resistant at Katumani –Kenya, in Malawi and India was found highly susceptible at Kiboko-Kenya (Songa *et al.*, 1995). Evidence from India also shows that *Fusarium udum* races do exist (Gupta et al., 1988 and Reddy and Raju, 1993). In Kenya and Tanzania, perennial pigeonpea was found to suffer relatively more from wilt (Reddy M.V., 1991). Though cercospora leaf spot has been reported in countries of eastern Africa, it was found particularly severe in Uganda with yield losses of upto 85% (Onim and Rubaihayo, 1976; Onim, 1980; Kannaiyan and Haciwa, 1990).

2.3 Ecological Adaptation of Pigeonpea

2.3.1 Drought tolerance

The deep and extensive root system in pigeonpea provides access to water as deep as 180-220 cm in the soil profile. This is particularly important for long duration types whose reproductive phase occurs after the rainy season and hence rely on residual soil moisture. During the period of water deficit, all reproductive structures will be shed and thereafter the crop will re-flower and set new crop once the stress is over. The crop abilities are dependent on environmental conditions, and like in other crops, if drought stress is severe and persistent during the reproductive phase, little or no yield will be realized (Sinha, 1981; Truedson, 1987). Pigeonpea is susceptible to water logging and will suffer physiological damage and effects of diseases like phytophthora blight (*Phytophthora drechsleri f. sp. cajani*) will intensify (Chauhan, 1987). Evidence however shows that the productivity of pigeonpea is enhanced where water deficits can be avoided (Chauhan *et al.*, 1987).

2.3.2 Soils and Nitrogen fixation

Pigeonpea can be grown in a wide range of soils varying both in physical and chemical characteristics. Pigeonpea reasonably tolerates pH ranges of 5 to 8.5 but it is more sensitive to strongly acid conditions (Edwards, 1981; Chong *et al.*, 1987). Genotypic differences have been noted in response to both low and high PH (Cowie *et al.*, 1987; Chauhan, 1987). Soil texture affects aeration, water holding capacity and soil strength which are factors that influence ability of pigeonpea to grow and produce yield. Pigeonpea is nodulated by several rhizobiaial strains belonging to the cowpea group (Kumar Rao, 1990; Jadhav and Moniz, 1972). Nodule formation and development depend on soil type, season and cultivar duration (Kumar Rao and Dart, 1979, Thompson *et al.*, 1981). Quantification of N_2 fixation by pigeonpea is difficult because it is not possible to estimate soil N uptake by such a deep rooted, long duration crop (Kumar Rao, 1990). However, Sen (1956) reported long duration pigeonpea in northern India to fix upto 200kg N ha^{-1} within 40 weeks.

Kumar Rao and Dart (1987) reported a range of 6 to 69kg N ha^{-1} of fixed N in pigeonpea genotypes of different maturity groups and upto 96% N ha^{-1} in an intercrop of medium duration pigeonpea with sorghum although no evidence of immediate benefit to the sorghum from the N_2 fixed by pigeonpea was seen. Nitrogen fixation will however depend on moisture level in soil, temperature, nutritional factors (Mo, Co, Fe), soil pH, root insect damage (by *Sitona spp* and *Rivellia spp.*) and agronomic practices (Kumar Rao and Dart, 1987).

2.3.4 Photoperiod and Temperature

In selecting genetically diverse parents for use in hybridization or for direct utilization in production, it is desirable to test consistency of genetic divergence under different environments. Under field conditions, the estimated threshold daily mean temperature for emergence of pigeonpea is 12.8°C. No germination will occur at both extremes of temperature i.e. <7.1°C and >46.5°C (Angus et al., 1981). Pigeonpea is sensitive to temperature and photoperiod with plant height, vegetative biomass, phenology and grain yield being most affected (Byth *et al.*, 1981; Whiteman *et al.*, 1985). Summerfield and Roberts (1985) describe pigeonpea as having a quantitative short day flowering response and the onset of flowering is hastened as day-length shortens. Troedson et al (1990) report a delay in flowering on some pigeonpea lines tested in late summer in India, and attributes this to lower temperatures in the period preceding flowering. It was also evident that the rate of progress to flowering was strongly associated with photoperiod and temperature at photoperiods below the critical photoperiod. Some pigeonpea lines however appeared to be unresponsive to photoperiod but sensitive to mean temperature. Genetic variations in response to photoperiod and temperature are such that not only time to flowering but relative rankings also vary across locations. Based on time to flowering, in sowings around the longest day in India (17^0 N), ICRISAT scientists developed a characterization of maturity types where ten maturity groups were recognized (Sharma *et al.*, 1981). These groups ranged from those flowering in less than 60days (Group 0) to those flowering in more than 160 days (Group IX) (Sharma *et al.*, 1981). This classification however could not be used to predict phenology in a new environment.

Studies on genotypes from a wide range of maturity groups indicate that the rate of progress to flowering demonstrated a broad optimum type response to temperature with most rapid flowering in the range of 20-28^{0}C (McPherson *et al.*, 1985). Similar observations were reported by Turnbull (1986) for several early genotypes which showed that optimum temperature for the rate of floral initiation was lower than that for the rate of floral development between initiation and anthesis. He also found floral initiation to be more sensitive to temperature extremes.

In eastern Africa where pigeonpea is grown from sea level upto 1800 masl, Silim *et al.*, (1995, 2006) using the three pigeonpea maturity groups found that medium and long duration types have specific adaptation. Medium types were found to have high optimum temperature (23.8^{0}C) for rapid flowering relatively similar to short duration types (23.1^{0}C). Long duration types had low optimum temperature (< 18.3^{0}C) for rapid flowering and are therefore able to flower and produce grain at intermediate and high elevations. Differences were also observed among the long duration cultivars with lines originating from high elevation (low temperature) areas exhibiting delayed flowering when grown at intermediate elevations. Growth related attributes such as plant height, number of nodes, shoot dry mass and leaf area increase with increasing temperature in the range 16-32^{0}C (McPherson *et al.*, 1985; Turnbull, 1986) and that high constant day temperature

(35^0C) increases floral abortion and decreases pod set. Conversely vegetative growth is slow and pod set is low under periods of low temperature (Morton *et al.*, 1982; Akinola and Whiteman, 1975). Pigeonpea sensitivity to low irradiance is most noted during pod formation period (4 weeks after flowering). This is the period when pod retention is strongly related to assimilation (Thirathon *et al.*, 1987). This sensitivity to low irradiance is however uncommon as in most pigeonpea production systems, pod formation starts when the rain season is getting to an end and cloud cover is reduced (Troedson *et al.*, 1990).

Understanding of phenological responses is critical in determining the role of pigeonpea in cropping systems and selection of genotypes for target agro-ecologies. Instability in height and vegetative biomass make management practices like pesticide sprays, plant density determination and harvesting difficult. In situations of short rainfall and where crop has to depend on residual moisture, sensitivity in phenology will reduce yields and also interfere with cropping sequence when succeeding crop is sown after pigeonpea (Silim *et al.*, 1995).

2.4 Characterization and Evaluation of Germplasm

The role of genetic variation from traditional landraces and wild species in the improvement of cultivated plants has been recognized (Thomas and Mathur, 1991; Rao and Bramel, 2000). It is well established that landraces are time-tested cultivars that are often not only the sources for resistance against various biotic and environmental stresses, but also for yield components (Remanandan *et al.*, 1988). The landraces are also vital to subsistence farmers as a key component of their survival strategies (Lenne *et al.*, 1997). Replacement of traditional landraces by modern, less heterogeneous high yielding cultivars as well as large scale destruction and modification of natural habitats harbouring wild species are leading to genetic erosion of important food crops. Breeding gains rely on access to useful genetic variation in the respective crop genepools and the importance of conserved germplasm depends in part on the genetic diversity it contains (Mengesha, 1984).

Until a collection has been properly evaluated and its attributes become known to breeders, it has little practical use (Thomas and Mathur, 1991). Investment in studies to determine the extent of genetic diversity is important for this knowledge enables proper organization and development of improved parents and new cultivars. Well documented analysis will also enable precise responses to the needs of research geneticists or of applied plant breeders (Ortiz, 2000). Therefore, to effectively exploit germplasm potential, it is essential to characterize and evaluate accessions for desired traits.

Morphological and agronomic traits have been widely used in the evaluation of various crops (Rick and Holle, 1990, Kaemer *et al.*, 1995). Use of such traits increases the understanding of the extent of genetic variability available and facilitates breeding for wider geographic adaptation relative to biotic and abiotic stresses. Likewise, genetic diversity needs to be described and measured if it is to be effectively incorporated into breeding strategies and management of plant genetic resources (Agong *et al.*, 2001).

Evaluation descriptors are routinely recorded in breeders' trials. Most of them exhibit quantitative variation that are highly influenced by environment and may be under polygenic control. Most useful quantitative descriptors should have high broad sense heritability (H) and must exhibit high repeatability (Ortiz, 1997). Measurement of these traits should be done with minimum error and low coefficient of variation (low random variation) to enhance the precision of the data hence the usefulness of the results obtained.

Quantitative descriptors are often used in a natural system of classification, even when the environment or the genotype-by-environment (GxE) interaction significantly affects their phenotypic expression (Abu-Alrub *et al.*, 2004 and Ortiz 1997). However, according to Goodman and Paterniani (1969), environmental effects and GxE interaction could be minimized by:

- Assessing the germplasm in several environments and using the mean values
- Evaluating the germplasm in several environments and defining similar phenotypic responses in each specific environment
- Comparing only those traits which are not affected by the environment.

Researchers have used many techniques to determine the extent of genetic variability in germplasm collections. Among these are Principal Component Analysis (PCA) and Cluster analysis. These can be used for statistical grouping of the germplasm without prior knowledge of area of origin or germplasm groupings (Smith *et al.*, 1991; Ortiz, 1997; Ogunbodede, 1997) and have been used successfully to classify and order variation observed in both quantitative and qualitative traits in many crop collections including, among others, mungbean, pea, soybean, alfalfa, *Arachis* species and quinoa (Ntundu, 2002). PCA is primarily a data reduction technique and mathematically converts the p original inter-correlated variables X_1, X_2, -----X_p into a new set of independent variables or principal components Y1, Y2, -------Yp, such that Y1 (PC1) contains as much of the variation of these p variables as possible while being genuinely independent of Y1 and so on (Mead *et al.,* 2002). PCs are functions of eigenvalues/latent roots and eigenvectors/loadings of the variance/covariance matrix (Fundora Mayor *et al.,* 2004). The new reduced data sets and the resulting combinations usually suggest a biological meaning for the grouping of variables or their components (Ntundu, 2002). Cluster analysis is a multivariate technique primarily used to group individuals based on the characteristics they possess such that individuals with similar descriptions are mathematically gathered into the same cluster. The resulting clusters of individuals will exhibit high internal (within cluster) homogeneity and high external (between clusters) heterogeneity. Individuals within a cluster will ideally be closer when plotted geometrically and different clusters will be further apart (Mohammadi and Prassana, 2003; Hair *et al.*, 1995).

According to Cui *et al.*, (2001), theoretically, phenotypic diversity could approximate genetic diversity if carefully assessed. Therefore, as the number of phenotypic traits increases in a comparison of breeding pools, the number of genes involved in the control of phenotypic traits should increase accordingly and hence improve the utility of phenotypic diversity in predicting genotypic diversity. Agro-morphological measures can therefore be used to create distance measures and examine genetic diversity in large collections of genotypes. Phenotypic diversity based on phenotypic frequencies of each trait category can also be used to compare genetic diversity within and across genotypes and regions of collection. Shanon-Weaver diversity index enables the use of hierarchical analysis of variance for testing the significance of various components of variation in the index (Jain *et al.*, 1975). And according to Yang *et al.*, (1991), the value of the index increases with increase in polymorphism and reaches maximum value when all phenotypic classes have equal frequencies.

Although the use of molecular markers in diversity assessment have become the most commonly used, especially where there is evidence of morphological duplicates and dispersions within clusters, highly heritable morphological characters are still useful as they are easy to analyse with very minimum cost and with equally very useful results obtained (Fundora-Mayor, 2004 and Klug and Cummings, 1994).

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Genetic material

One hundred and twenty three pigeonpea landrace accessions collected from Tanzania in four main pigeonpea growing regions with diverse climatic conditions in 2001 were used in this study. The accessions comprised of 23 from Coastal zone, 34 from Eastern Plain, 36 from Southern Plains and 30 from Northern Highlands. Collections were made at altitudes ranging from sea level to over 1600 m with lowest elevations recorded in the Coastal Zone (11-74 m), intermediate elevations in Eastern and Southern Plains (194-661 m and 168-785 m, respectively) and highest in the Northern Highlands (1199-1688 m) (Appendix 1). Twenty one medium and long duration cultivar checks were added to the 123 germplasm lines to make a trotal of 144 lines. The cultivar checks were those with known adaptation and released or are to be released to farmers in Tanzania, Kenya, Uganda, Malawi and Mozambique. There inclusion was to not only to balance lattice design but also to enable relating adaptation of the test accessions to the various check accessions and thus to be able to target the test accessions to agro-ecologies in the five countries in eastern and southern Africa. However the checks were only used in PCA biplots and cluster analysis to determine their separation relative to the 123 accessions

3.2 Trial site description

The experimental sites were Kampi ya Mawe and Kabete in Kenya and Ilonga in Tanzania . The two locations in Kenya are near the equator. Kampi ya Mawe in Eastern Kenya is a traditional pigeonpea growing area. It stands at an altitude of 1250 meters above sea level (masl) and lies 37° 40' E and 1°57' S in the semi-arid intermediate zone with low mean annual rainfall of 500-600 mm which is bimodal, erratic and poorly distributed. The area is characterized by mean minimum temperature of 22.0°C and mean maximum temperature of 24.8°C (Table 5). Kabete at 1960 masl lies 36°45'E and 1°14'S in the low temperature high elevation zone near Nairobi with high mean annual rainfall of 1046 mm that is bimodal and fairly well distributed. The location has mean annual minimum and maximum temperatures of 12.6°C and 23.4°C, respectively (Table 5). The trials were conducted at these two sites during the 2004-2005 cropping season.

The Agricultural Research Institute (ARI) Ilonga in the sub-humid low altitude zone of Tanzania at 506 masl lies 37° 02'E and 6° 46'S. The area has a moderate wet environment and has a bimodal rainfall pattern with the main cropping long rainy season occurring between mid-February and May. The long term annual rainfall is 978-1056 mm, and mean annual minimum and maximum temperatures of 16° C and 28° C respectively (daily mean 25° C) (Table 5). The trial at Ilonga was conducted in the rainy season 2002/03.

Table 5. Seasonal mean temperature and rainfall during the cropping season at the 3 test Sites.

Location	Latitude	Longitude	Altitude (m)	Temperature (°C)			Rainfall (mm)
				Max	Min	Mean	
Kabete	1°14′S	36°45′E	1960	23.3	13.5	18.4	950
				(23.4)	*(12.6)*	*(18.0)*	*(1046)*
Kampi ya Mawe	1°57′S	37°40′E	1250	28.1	17.4	22.8	490
				(24.8)	*(22.0)*	*(23.4)*	*(550)*
Ilonga	6°46′S	37°02′E	506	29.2	19.5	24.4	835
				(28.0)	*(16.0)*	*(22.0)*	*(1000)*

( ) Long term means

3.3 Trial design and crop management

The 123 accessions and 21 checks were planted using a 12x12 square Lattice Design in 3 replications with single row plots of 4 m length in fields with a fine tilth. The inter-row and intra-row distances were maintained at 1.5 m and 0.5 m respectively across experimental sites maintaining one plant per hill. Three manual weedings were done across the sites and regular sprays using standard recommended insecticides (Karate/Dimethoate) given to control insect pest damage during flowering and post-flowering phases. No fertilizers were applied since previous studies had shown the crop's lack of response to fertilizer application at these sites (Silim and Omanga, 2001).

3.4 Data collection

Data were collected on 16 qualitative and 14 quantitative traits in Kenya (Tables 6a and 6b.) according to IBPGR/ICRISAT Descriptors 1993. However, at Ilonga, due to limitations of trained personnel, it was not possible to take data on a similar number of traits and data were taken only on 5 qualitative (stem colour, base flower colour, pod colour, growth habit, flowering pattern) and 7 quantitative (plant height, days 50% flower, primary branches, days 75% maturity, grain yield, seeds per pod and 100 seed mass) traits. Qualitative data were recorded on each plant within the plot for each replication except for seed traits which were recorded on a sample from a whole plot. Data on quantitative traits (number of primary branches, number of secondary branches, number of racemes, pods per plant, and pod bearing length) were taken on 5 randomly selected plants in each plot. Pod length, pod width and number of seeds per pod were recorded on 10 pods selected randomly from 5 plants in the plot whereas pods per raceme and raceme length were recorded on 10 racemes randomly selected from 5 plants in the plot. Days to 50% flowering, days to maturity and pod and grain yield were taken on plot basis. Rainfall and temperature data for each experimental site during the cropping season were recorded.

Table 6a. Qualitative traits descriptors used in data collection (based on IBPGR/ICRISAT pigeonpea descriptors, 1993).

Base flower color	Main colour of the petals= 1-ivory, 2 light yellow, 3-yellow, 4-red
Second flower color	Colour of streaks on dorsal side of flag and second colour of the wings and keel= 1-red, 2 –purple
Pattern of streaks	Pattern of streaks = 1-sparse, 2-medium, 3-dense, 4-uniform
Flowering pattern	1- Determinate, 2-Semi determinate, 3-Indeterminate
Growth habit	1- Erect/compact, 2-Semispreading, 3-Spreading, 4-Trailing
Stem colour	1- Green, 2-Sun red, 3-Purple, 4- Dark purple
Pod colour	Main colour of the pod= 1-Green, 2-Purple, 3-Mixed, 4-dark purple
Pod form	1- Flat, 2-Cylindrical
Pod hairiness	1-Glabrous, 2-Pubescent
Base seed colour	1-White, 2-Cream, 3-Orange, 4-Light brown, 5-Reddish brown, 6-Light grey, 7-Grey, 8-Purple, 9-Dark purple, 10-Dark grey
Second seed colour	Second colour of seed coat= as for base seed colour above
Seed colour pattern	1- Plain, 2-Mottled, 3-Speckled, 4-Mottled and speckled, 5-Ringed
Seed eye colour	Colour around hilum coded as in base seed colour
Seed eye width	3-Narrow, 5-Medium, 7-Wide, 8-None
Seed shape	1-Oval, 2-Pea shape (globular), 3-Square, 4-Elongate
Hilum	Presence of seed strophiole = 1-Absent, 2-Present

Table 6b. Quantitative traits descriptors as used in data collection based on IBPGR/ICRISAT pigeonpea descriptors, 1993.

Trait	Descriptor/phenotypic scale
Days 50% flowering	From first rainfall/irrigation to when 50% of plants have at least 1 open flower
Days 75% maturity	Days to when 75% of plants in plot reach maturity
Plant height (cm)	At maturity. From base to top of plant
Primary branches	Branches born on main stem
Secondary branches	Branches born on primary branches
Raceme number	Mean of 5 plants in plot at flowering
Raceme length (cm)	Mean 10 racemes from 5 plants in plot at podding
Pods per raceme	Mean of 10 racemes from 5 plants
Pods per plant	Mean of 5 plants per plot
Pod bearing length (cm)	Mean of 5 plants- Distance between lowest and topmost pod on plant
Pod length (cm)	Mean of 10 pods from 5 plants
Pod width (cm)	Mean of 10 pods from 5 plants
Seeds per pod	Mean of 10 pods from 5 plants
Seed mass (g)	Weight of 100 seeds from random sample from total plot yield (13%moisture)
Pod yield (t ha^{-1})	Estimated from total plot yield
Grain yield (t ha^{-1})	Estimated from total plot yield after threshing
Shelling ratio (%)	Seed to pod ratio

3.5 Data analysis

3.5.1 Qualitative traits

Shanon-Weaver diversity indices as described by Jain et al., (1975) were calculated based on phenotypic frequencies (proportions) of each trait category to estimate phenotypic diversity among and within the accessions and within collection regions as:

$$H' = \Sigma P_i \log_e P_i \quad \text{where:}$$

P_i = proportion of accessions in the i^{th} class of an n class trait in a population. Additivity of the H' allows characters to be pooled over provinces and over regions. This allows use of hierarchical analysis of variance for testing the significance of various components of variation H' (regions and characters). H' value was standardized by dividing it by its maximum value $\log_e n$ ($SDI = H'/\log_e n$) to ensure that all scaled H' values are in the range 0-1. Monomorphic population will have zero index value. This increases with increase in polymorphism and reaches maximum value when all phenotypic classes have equal frequencies (Yang *et al.*, 1991). Frequencies of occurrence of each category in each trait were also calculated.

3.5.2 Quantitative traits

3.5.2.1 Analysis of variance

Analysis of variance, means, maximum and minimum values and variances for each trait were carried out using Genstat 8.0 Unbalanced Design instead of the Square Lattice used in planting due to missing accessions (see appendices 2 and 3). Analysis of variance was done for each site and across sites to ensure that only variables showing significant differences went into multivariate analysis and also to enable heritability estimates with combined site variance components. Broad sense heritability (**H**) was estimated using variance components following Nevado and Ortiz (1985) and Haryanto (2002) as the ratio between genetic variance (V_G) and phenotypic variance (V_P) (Table 7).

Table 7. Outline of analysis of variance used for quantitative traits replicated over environments.

Source of variation	*Degrees of freedom*	*Mean square error*	*Expected mean square*
Environments (E)	*e-1*	*M1*	$\sigma^2_{GE} + a\sigma^2_E$
Accessions (G)	*a-1*	*M2*	$\sigma^2_{GE} + e\sigma^2_G$
Interaction (GE)	*(a-1)(e-1)*	*M3*	σ^2_{GE}

Source: Ortiz, 1997

e=number of environments *σ^2_{GE}= genotype by location* *σ^2_E = [(M1-M3)/a]*

σ^2=between plot variances *a= number of accessions* *σ^2_G = [(M2-M3)/e]*

$H = \sigma^2_G / [\sigma^2_G + \sigma^2_{GxE}/L + \sigma^2_{ex}/r]$ where:

σ^2_G = Variance of accession

σ^2_{GxE} = Variance of accession by location interactions

σ^2_e = Experimental error variance

L = locations

r = number of replications at each site

Pearson's correlation matrices between the different quantitative traits were estimated using Genstat 8.0 to establish traits that contributed to yield which could be a useful guide for selection for yield if genetic in nature.

3.5.2.2 Principal Components Analysis

Quantitative traits from this study were subjected to Principal Component Analysis (PCA) using Genstat 8.0 multivariate-principal component analysers between variance-covariance matrix to determine patterns of variation and major traits contributing to the delineation. PCA is a data reduction technique that reduces the number of variables in a data set while retaining the variability in the data. It also identifies the hidden patterns in the data and classifies them according to how much of the information stored in the data they account for. The correlation matrix was standardized to avoid dealing with variables measured in different (Foucart, 1998). This was done by reducing the corresponding variable mean from each variable value and the result divided by the corresponding standard deviation. Dimension reduction in a data set by PCA enabled the data to be analysed in a visible 2 dimension or 3 dimension space with little loss of information. PCA created a new set of independent variables or principal components such that the first principal component (PC1) contained as much of the variation of these variables as possible while being genuinely independent of subsequent principal components as reported by Mead et al., 2002. PCs are functions of eigenvalues/latent roots and eigenvectors/loadings of the variance/covariance matrix (Fundora Mayor *et al*., 2004). The new reduced data sets and the resulting combinations helped to give a biological meaning for the grouping of variables and/or their components.

Geometrical distances among individuals in the scatter plot reflect the genetic distances among them with minimal distortion and individuals clustered together in such a plot will reveal sets of genetically similar individuals. And due to their orthogonal/independent nature, PCs revealed different properties of the original data and were interpreted independently hence breaking down total variation in original data set into components that were cumulative (Mohammadi *et al*., 2003). Only PCs with eigenvalues >1 were considered in determining the agronomic variability in the accessions based on the criterion established by Kaiser (1960) that there are no tests to evaluate the significance of latent roots (Rojas *et al*., 2000) and at this level very little of random variability is left. The first two PCs were plotted to enhance the dispersion of the 123 accessions and 21 checks based on their quantitative traits.

3.5.2.3 Cluster Analysis

A cluster analysis was carried out using coordinates derived from evaluation of each accession based on Euclidean distance matrix following the weighted mean distance aggregation criterion in an ascending hierarchical way (Spark, 1973; Roux, 1988 in Fundora Mayor, 2004) using Average linkage analysis in Genstat 8.0. The phenotypic distance matrix was created by calculating the distance between each pair of accessions for each quantitative trait. The distance between 2 quantitative traits was determined by averaging all the distances in the phenotypic value for each trait divided by the respective range as described by Gower (1985).

The phenotypic distances for these traits were transformed into a 0-1 scale. The phenotypic distance between 2 accessions was then calculated as the sum of by summing individual trait distances between them and dividing by the total number of traits recorded in both accessions as described by Ortiz *et al.*, (1998). To show the overall similarity between clusters, a dendrogram was constructed by plotting cluster results from the analysis using Genstat 8.0.

CHAPTER 4

4.0 RESULTS

4.1 Weather during the cropping seasons

The weather during the crop growth seasons at the 3 test locations was variable (Table 5 and Appendices 2a-c). Kampi ya Mawe received 490.0 mm of rainfall which was poorly distributed with most of it received in November and December during seedling stage and in the first week of April. Mean minimum and maximum temperatures during the season were 17.4°C and 28.1°C respectively. Kabete received a total of 950.4mm of rainfall which was fairly distributed in the cropping season and with fairly cool conditions resulting from mean minimum and maximum temperatures of 13.5°C and 23.3°C respectively. And although Ilonga received 835.3mm of rainfall, much of it (655.6mm) fell in two months (March and April). Only 16.2mm rainfall was received in June and August when most of the accessions were flowering and/or grain filling. Mean temperatures were fairly high with mean minimum and maximum for the season at 19.5°C and 29.2°C respectively. Most of the late maturing accessions therefore suffered some terminal moisture stress at both Kampi ya Mawe and Ilonga. Several accessions were also infected by *Fusarium* wilt at Kampi ya Mawe.

4.2 Qualitative traits

Frequency distribution of qualitative traits in the 123 Tanzanian pigeonpea accessions are shown in Table 8. Most accessions had predominantly green stems (97%), were semi-spreading (93%), with flat pods (96%) and white/cream base seed colour (94%). Flower streak pattern with highest diversity had 30% dense, 27% plain (no streaks), 26% sparse and 17% medium streak density.

The streaks were predominantly red (54%) with 37% none and 9% purple whereas 50 %, 29% and 21% of the accessions had mixed, green and purple/dark purple pods respectively. Yellow group (light yellow and yellow) at 73% dominated in base flower colour and most accessions had indeterminate flowering pattern (59%). Sixty percent of accessions had plain seed (no second seed colour) especially in the highlands collection where the crop is more commercialized). Pods were predominantly glabrous (75%) with oval seeds (48%) with majority (80%) having seed strophiole (hilum).

Table 8. Frequency distribution of qualitative traits in 123 Tanzanian pigeonpea accessions

Trait and category	Frequency(%)	Trait and category	Frequency(%)
Stem color		**Pod hairiness**	
Green	97	Hairy	25
Purple	3	Non-hairy	75
Growth habit		**Base seed colour**	
Erect	2	Cream	94
Semi-spread	93	Dark purple	2
Spread	5	Light grey	2
		Light brown	2
Flowering pattern		**Second seed colour**	
Determinate	1	None (plain)	60
Semi-determinate	40	Light brown	36
Indeterminate	59	Purple	3
		Reddish brown	1
Base flower colour		**Seed colour pattern**	
Ivory	14	Plain	60
Light yellow	36	Speckled	33
Yellow	37	Mottled	3
Red	13	Mottled/speckled	4
Streak pattern		**Seed eye colour**	
Sparse	26	None	67
Medium	17	Light brown	28
Dense	30	Purple	2
Plain	27	Reddish brown	1
		Grey/Dark purple/Cream	2
Second flower		**Seed eye width**	
colour	9	Narrow	25
Purple	54	Medium	26
Red	37	None	46
None		Wide	3
Pod colour		**Hilum**	
Green	29	Present	80
Purple	5	None	20
Dark purple	16		
Mixed	50		
Pod form		**Seed shape**	
Flat	96	Oval	48
Cylindrical	4	Globular	39
		Square	9
		Elongate	4

Diversity indices between accessions and between and within collection regions in the 123 accessions are presented in Table 9. The mean diversity indices of the assessed qualitative traits in the 123 accessions were generally low (0.238) and ranged from 0.044 (stem colour) to 0.447 (flower streak pattern). Between the 4 collection regions, diversity indices ranged from a low of 0.167 (Northern highlands) to 0.275 (Coastal zone). There were no significant diversity differences in stem colour, growth habit, base flower colour, pod form, pod hairiness, seed eye colour and seed eye width in the germplasm. However, highly significant differences ($P<0.05$) were recorded in flowering pattern, pod colour, pod form, streak pattern, second seed colour, seed colour pattern and seed shape.

There were no significant differences between regions of collection in stem colour, growth habit, base flower colour, pod form, pod hairiness and seed eye colour. But significant differences ($P<0.05$) were observed in streak pattern, flowering pattern, pod colour, base seed colour, second seed colour, seed colour pattern and seed shape. Coastal collections had the highest diversities in flowering pattern (0.442), second seed colour (0.263) and seed colour pattern (0.365); Southern collections with highest diversities in pod colour (0.489) and Eastern collections with highest diversity in streak pattern (0.512) and seed shape (0.337). In all the traits that the accessions had significant differences, Highlands collections had the lowest diversities. Overall, except for highland collections, there were no distinct diversity patterns in the materials relative to region of collection across traits.

Table 9. Region-wise mean diversity indices (*H′*) in the 16 qualitative traits recorded on 123 Tanzanian pigeonpea accessions.

Trait	Region				Cumulative mean diversity indices
	Coast	Eastern	Southern	Highlands	
Stem colour	0.037	0.042	0.018	0.079	0.044 ± 0.162
Growth habit	0.116	0.090	0.103	0.069	0.094 ± 0.125
Base flower colour	0.331	0.268	0.253	0.261	0.278 ± 0.062
Flower streak pattern	0.490	0.512	0.497	0.290	0.447 ± 0.072
Second flower colour	0.416	0.337	0.449	0.341	0.385 ±0.054
Flowering pattern	0.442	0.319	0.395	0.206	0.340 ±0.122
Pod colour	0.446	0.473	0.489	0.187	0.399 ±0.165
Pod form	0.063	0.094	0.034	0.106	0.074 ±0.051
Pod hair	0.347	0.409	0.424	0.220	0.350 ±0.149
Base seed colour	0.094	0.047	0.035	0.010	0.046 ±0.071
Second seed colour	0.263	0.2408	0.235	0.126	0.216 ±0.066
Seed colour pattern	0.365	0.335	0.342	0.177	0.305 ±0.081
Seed shape	0.306	0.337	0.297	0.056	0.249 ±0.139
Seed eye colour	0.141	0.094	0.090	0.119	0.111 ±0.083
Seed eye width	0.210	0.202	0.191	0.225	0.207 ±0.161
Hilum	0.333	0.395	0.136	0.191	0.264 ±0.092
Mean *H′*	0.275 ±0.232	0.262 ±0.234	0.249 ±0.221	0.167 ±0.312	0.238 ±0.097

4.3 Quantitative traits

4.3.1 Analysis of variance

Presented in Tables 10 and 11 and Appendices 3-5 are mean, minimum and maximum values of the quantitative traits at individual trial sites and within and across collection regions. There were significant variations ($P<0.05$) in the 14 quantitative traits assessed for genotypes and genotype by environment interaction except for seeds per pod at Ilonga. Between regions of collection and within and between trial sites differences were also highly significant ($P<0.05$) for most of the traits. Variability within regions of collection were significantly different at all the trial sites for most of the triats except for grain yields within Coastal, Eastern and Southern regions at Kampi ya Mawe, and within Southern material at Ilonga. Seeds per pod were similar within Coastal material at Kampi ya Mawe and Kabete. Similar observations were made at Kabete for pods per plant and within Eastern material for days to maturity (Table 10). There was a wide range of variability in the germplasm in racemes per plant (13-467), pods per plant (25-464), grain yield (0.008-4.885 t/ha), pod yield (0.021-9.371 t ha^{-1}), plant heights (62.5-259.5 cm), days to 50% flowering (81-262), pod bearing length (35.0-167.3 cm), seeds per pod (4-7), pod length (5.3-11.9 cm) and 100 seed mass (10.1-19.9 g). Seeds per pod did not vary significantly within Southern and Highlands collections.

Accessions from Southern plains had the least mean days to flowering (were early in flowering, 103 days) and plant heights (were short, 130.5 cm) across experimental sites while highland collections had the highest mean days to flowering (late, 152 days) and plant heights (tall, 182.4 cm). The accessions had the lowest mean days to flower (103) at Kabete where temperatures are cool and highest (135) at Kampi ya Mawe where temperatures are warm. Mean pod bearing lengths were highest at Kampi ya Mawe (76.8 cm) and lowest at Kabete (54.1 cm). Mean pod lengths.

***Table 10.* Mean, Min, Max, SE± and P-Values of recorded quantitative traits on 123 Tanzanian pigeonpea accessions at 3 locations**

Trait	Kampi Ya Mawe					Kabete					Ilonga				
	Min	**Max**	**Mean**	***SE±***	**P-value**	**Min**	**Max**	**Mean**	***SE±***	**P-value**	**Min**	**Max**	**Mean**	***SE±***	**P-value**
Plant height (cm)	63	220	**121**	7.597	**	84	256	**120**	6.188	**	104	265	**189**	8.062	**
Days 50% flower	98	262	**135**	7.398	**	79	164	**101**	5.483	**	90	151	**108**	3.370	**
Primary branches	2	22	**6**	1.444	**	4	21	**10**	2.210	**	5	22	**12**	2.409	**
Days 75% maturity	134	284	**174**	7.303	**	130	252	**154**	4.818	**	144	193	**164**	4.684	**
Seeds/pod	5	7	**6**	0.322	**	4	7	**6**	0.336	**	4	9	**6**	0.739	NS
Grain yield (ton/ha)	0.007	1.328	**0.363**	0.084	**	0.107	4.885	**2.011**	0.625	**	0.067	3.333	**1.551**	0.370	**
100 seed mass (g)	9.2	22.0	**14.6**	1.633	**	11.3	20.8	**15.9**	1.101	**	5.2	19.3	**12.9**	1.198	**
Secondary branches	1	36	**6**	1.839	**	2	30	**14**	3.471	**	-	-	-	-	-
Racemes/plant	11	210	**47**	4.843	**	41	502	**154**	37.500	**	-	-	-	-	-
Pod bearing length (cm)	35	167	**77**	6.248	**	32	90	**54**	6.146	**	-	-	-	-	-
Pods/plant	25	158	**66**	6.770	**	26	464	**166**	44.740	**	-	-	-	-	-
Pod length (cm)	5.3	11.9	**8.5**	0.667	**	7.3	10.7	**8.8**	0.663	**	-	-	-	-	-
Pod weight (tons/ha)	0.020	2.824	**0.740**	0.170	**	0.206	9.371	**3.414**	0.910	**	-	-	-	-	-
Threshing %	29.0	71.8	**49.2**	4.128	**	34.3	71.0	**58.8**	4.823	**	-	-	-	-	-
Pod width (cm)	-	-	-	-	-	0.9	1.5	**1.1**	0.109	**	-	-	-	-	-

*** Highly significant (P<0.05); NS- Not significant; - data not collected*

Table 11. Quantitative traits means and SE(±) recorded on 123 Tanzanian pigeonpea accessions in 3 test locations by collection region.

Trait	Test Location/Collection region											
	Kampi Ya Mawe				*Kabete*				*Ilonga*			
	Coast	*Eastern*	*Southern*	*Northern*	*Coast*	*Eastern*	*Southern*	*Northern*	*Coast*	*Eastern*	*Southern*	*Northern*
Days 50% flower	116 (±6.583)	133 (±9.930)	117 (±5.364)	198 (±9.739)	98 (±6.124)	100 (±3.601)	93 (±4.106)	120 (±5.035)	98 (±2.106)	101 (±4.138)	98 (±2.665)	138 (±4.355)
Days 75% maturity	155 (±5.819)	173 (±9.900)	157 (±5.689)	234 (±6.654)	151 (±2.857)	153 (±5.383NS)	150 (±3.819)	169 (±4.514)	154 (±4.796)	158 (±6.463)	155 (±4.355)	190 (±2.320)
Plant height (cm)	102.6 (±7.315)	127.2 (±5.617)	111.5 (±7.216)	155.8 (±6.831)	115 (±6.277)	113.4 (±7.582)	103.7 (±5.732)	163.8 (±5.261)	175.4 (±7.382)	176.5 (±7.458)	176.2 (±6.418)	227.6 (±8.400)
Primary branches	5 (±1.043)	6 (±1.261)	5 (±1.033)	9 (±2.378)	9 (±1.578)	10 (±1.640)	9 (±1.601)	11 (±2.859)	10 (±2.294)	10 (±1.652)	12 (±2.108)	14 (±1.645)
Secondary branches	4 (±1.511)	5 (±1.499)	5 (±1.722)	11 (±2.221)	14 (±2.914)	14 (±2.249)	11 (±2.921)	19 (±4.467)	-	-	-	-
Pod bearing length (cm)	65.4 (±6.392)	83.3 (±6.965)	64.4 (±5.442)	106.2 (±8.403)	52.1 (±5.297)	51.9 (±4.682)	48.8 (±4.757)	67.5 (±6.132)	-	-	-	-
Pod length (cm)	8.7 (±0.671)	8.9 (±0.777)	8.6 (±0.643)	7.7 (±0.415)	8.8 (±0.606)	9.0 (±0.915)	8.8 (±0.665)	8.5 (±0.479)	-	-	-	-
Pod width (cm)	-	-	-	-	1.1 (±0.206)	1.1 (±0.049)	1.1 (±0.694)	1.2 (±0.085)	-	-	-	-
Pods/plant	58 (±5.019)	74 (±5.570)	66 (±6.009)	70 (±1.107)	153 (±37.610NS)	171 (±25.600)	146 (±39.730)	211 (±57.800)	-	-	-	-
Pod yield (t/ha)	0.694 (±0.227)	0.791 (±0.299)	0.866 (±0.427NS)	0.453 (±0.274)	2.851 (±0.707)	3.640 (±0.673)	2.687 (±0.810)	5.185 (±1.164)	-	-	-	-
Seeds/pod	6 (±0.269)	6 (±0.242)	6 (±0.303)	6 (±0.480NS)	6 (±0.301NS)	6 (±0.220)	6 (±0.353NS)	6 (±0.280)	6 (±0.691)	6 (±0.453)	6 (±0.810)	5 (±0.732)
Grain yield (t/ha)	0.342 (±0.130NS)	0.394 (±0.093NS)	0.434 (±0.232NS)	0.225 (±0.150)	1.616 (±0.432)	2.184 (±0.397)	1.653 (±0.601)	2.889 (±0.794)	1.837 (±0.479NS)	2.117 (±0.336)	1.850 (±0.375NS)	0.471 (±0.268)
100 seed mass (g)	13.2 (±1.287)	14.8 (±2.061)	14.8 (±1.608)	15.2 (±1.155)	14.5 (±1.244)	15.8 (±1.253)	16.2 (±0.975)	16.2 (±1.195)	12.6 (±1.267)	13.4 (±1.668)	14.7 (±0.969)	10.1 (±1.410)
Threshing%	48.9 (±7.370)	49.6 (±5.074)	49.5 (±9.119NS)	48.7 (±1.909)	57.2 (±4.726)	60.4 (±3.282)	60.1 (±7.519NS)	56.6 (±6.067)	-	-	-	-

NS Non Significant; - Data not collected were relatively similar at Kampi ya Mawe and Kabete at 8.5 and 8.8 cm at the two sites respectively with longest pod (11.9 cm) recorded at Kampi ya Mawe. Most of the accessions had wide pods with widths ranging from 1.0 to 1.53 cm (recorded only at Kabete).

The highest number of primary and secondary branches, and pods per plant (10, 14 and 170 respectively) were recorded at Kabete and these were mostly in highland collections. However mean number of seeds per pod were stable, showing a low significant variation across experimental sites and between collection regions and were relatively uniform with a mean of 6.0. The mean 100 seed mass was highest at Kabete (15.7 g) where collections from Southern Plains and Northern Highlands region also recorded high 100 seed mass (16.2 g). Lowest 100 mean seed mass was recorded at Ilonga (12.9 g). Within the Northern Highlands collections, accessions from Kondoa District had the highest mean seed mass (16.4 g). Collections from Morogoro (Eastern) and Kibaha (Coastal) Districts had the longest pods (8.9 cm) (Appendix 6). Considering pooled means across the 3 sites, Eastern and Southern collections had the highest mean 100 seed mass of 15.0 g. Mean grain yield potential was highest at Kabete (2.086 t ha^{-1}), where rainfall is high and temperatures cool and lowest at Kampi ya Mawe (0.372 t ha^{-1}).

Collections from Eastern Plains had the highest mean grain yields (1.56 t ha^{-1}) pooled over sites. Generally however, collections from Coast, Eastern and Southern Plains which are early in maturity performed better at Ilonga and Kampi ya Mawe whereas highland collections performed better at Kabete where the growing conditions were favourable. The results show that pod length and seeds per pod are relatively stable traits as they changed little across sites. In addition, the results also show that in warm places such as Kampi ya Mawe, later maturing accessions (from Highlands) give lower yields because they suffer more from terminal drought stress.

4.3.2 Heritability

Inspite of the high significant GxE interaction in the 123 accessions, they exhibited low to moderate broad sense heritabilities (0.19 to 0.73) across Kabete and Kampi ya Mawe in most of the traits (Table 12). Heritability estimates for the seven quantitative traits (days to flowering, days to maturity, grain yield, primary branches, seeds per pod and 100 seed mass) on pooled means across the three sites varied from 0.28 for grain yield to 0.82 for plant heights. Heritabilities were high (0.75) for days to flower across the 3 sites with seeds per pod having a low heritability (0.4) across the 3 sites but moderate (0.54) across Kampi ya Mawe and Kabete. Similar heritability patterns were evident with variance components across 2 locations (Kabete and Kampi ya Mawe) where plant height (0.73), 100 seed mass (0.70), raceme number (0.69) and days to maturity (0.63) had fairly high heritabilities. However, across the two locations low heritabilities were noted in threshing % (0.19), pod bearing length (0.25) and pod yield (0.35). Grain yield (H=0.43) across Kampi ya Mawe and Kabete) had very low H (0.28) across the 3 sites, an indication of a strong environmental effect on this trait. High genetic variance in yield components (pods per plant and raceme number), days to flower and maturity and plant heights would be useful for selection to improve yield and also for adaptation to different pigeonpea cropping systems.

Table 12. Quantitative traits variances and heritabilities in 123 Tanzanian Pigeonpea germplasm accessions.

Trait	Genotypic Mean square	GxE Mean square	Error (Environ.) Mean square	$V_{(G)}$	$V_{(GxE)}$	$V_{(P)}$	H
Across KYM-KABETE							
Days 50% flower	2923.75	1331.13	34.95	265.44	432.06	487.29	**0.54**
Days 75% maturity	6300.03	2304.22	43.55	665.97	753.56	1050.01	**0.63**
Plant heights	3890.80	1065.66	44.10	470.86	340.52	648.47	**0.73**
Grain yield	1.35	0.76	0.25	0.10	0.17	0.22	**0.43**
Pod bearing length	1348.84	1007.81	33.81	56.84	324.67	224.81	**0.25**
Pod length	2.15	0.91	0.44	0.21	0.16	0.36	**0.58**
Pods per plant	5322.00	3106.00	1213.00	369.33	631.00	887.00	**0.42**
Pod yield	3.99	2.58	0.58	0.23	0.67	0.66	**0.35**
Primary branches	15.30	8.17	3.90	1.19	1.42	2.55	**0.47**
Raceme number	15102.90	4668.40	830.60	1739.08	1279.27	2517.15	**0.69**
Secondary branches	95.88	37.65	8.59	9.70	9.69	15.98	**0.61**
Seeds/pod	0.29	0.14	0.10	0.03	0.01	0.05	**0.54**
100 seed weight	11.52	3.42	1.77	1.35	0.55	1.92	**0.70**
Threshing%	91.91	74.56	45.56	2.89	9.67	15.32	**0.19**
Across ILONGA-KYM-KBTE							
Days 50% flower	3029.40	771.27	29.40	250.90	247.29	336.60	**0.75**
Days 75% maturity	5347.97	1773.28	38.29	397.19	578.33	594.22	**0.67**
Plant heights	5267.04	958.58	48.34	478.72	303.41	585.23	**0.82**
Grain yield	0.82	1.33	0.22	0.06	0.37	0.21	**0.28**
Primary branches	26.28	10.91	4.71	1.71	2.07	2.92	**0.58**
Seeds/pod	0.48	0.29	0.20	0.02	0.03	0.05	**0.40**
100 seed weight	14.35	5.36	1.72	1.00	1.21	1.59	**0.63**

4.3.3 Correlations

Pearson's correlation matrices for 14 quantitative traits recorded are presented in Table 13 and Appendices 7-9. Positive correlations with r $\geq$0.71 were recorded in pods per plant and grain yield (r=0.78), pod yield and grain yield (r=0.98) and pods per plant and pod yield (r=0.79). However, a number of high correlations (r$\geq$0.50) were found in plant height and days to flower (r=0.62), pod bearing length and days to flower (r=0.66), plant height and days to maturity (r=0.59), racemes per plant and grain yield (r=0.54), secondary branches and grain yield (r=0.56), pod bearing length and plant height (r=0.61), racemes per plant and plant height (r=0.62), racemes per plant and pods per plant (r=0.61), secondary branches and pods per plant (r=0.62), racemes per plant and pod yield (r=0.55), secondary branches and pod yield (r=0.58) and secondary branches and racemes per plant (r=0.57). Grain yield was therefore more strongly associated with pods per plant, pod yield, secondary branches and number of racemes per branch indicating that these traits are major determinants of grain yield.

Although plant heights, number of primary branches and 100 seed mass had positive significant correlations with grain yield, they had r values <0.50. Taller plants were associated with higher yields at Kabete due to longer pod bearing lengths, higher number of racemes per plant and higher number of branches and pods per plant at the high rainfall Kabete site. Whereas positive correlations (r=0.50) between days to flower and grain yield were recorded at Kabete, there were negative correlations between the 2 traits at Ilonga (r=-0.741) and at Kampi ya Mawe (r=-0.027).

Table 13. Correlation matrix for 14 quantitative traits recorded on 123 Tanzanian pigeonpea accessions[a]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Days 50% flower														
2. Days 75% maturity	0.626**													
3. Grain yield	-0.033	0.351**												
4. Plant height	0.615**	0.59**	0.355**											
5. Pod bearing length	0.655**	0.451**	-0.042	0.605**										
6. Pod length	-0.016	0.054	0.059	0.024	-0.048									
7. Pods per plant	0.061	0.352	0.775**	0.416**	0.055	0.051								
8. Pod yield	0.000	0.381**	0.976**	0.413**	-0.009	0.08	0.786**							
9. Primary branches/plant	0.042	0.166**	0.342**	0.283**	-0.026	-0.008	0.463**	0.365**						
10. Racemes per plant	0.176**	0.425**	0.536**	0.615**	0.154**	-0.044	0.606**	0.551**	0.481**					
11. Secondary branches/plant	0.111	0.394**	0.562**	0.422**	0.031	0.037	0.623**	0.576**	0.409**	0.572**				
12. Seeds per pod	0.035	0.009	-0.071	-0.021	0.073	0.311**	-0.091	-0.086**	-0.168**	-0.161**	-0.129**			
13. 100 seed mass	0.044	0.197	0.225**	0.173	-0.02	0.243**	0.195**	0.211	0.141**	0.165**	0.172**	-0.095		
14. Threshing %	-0.308**	-0.058	0.374**	-0.180**	-0.277**	-0.043	0.202**	0.218**	0.121**	0.161**	0.18**	-0.025	0.175**	

*** Significant at $P<0.05$*

[a] Based on pooled means for 2 locations (Kampi ya Mawe and Kabete)

4.3.4 Principal Component Analysis

Principal component analyses (PCAs) were performed on variance-covariance matrix of the quantitative traits and the loadings, percentages and cumulative percentage variance for the first 4 Principal components are given in Tables 14 and 15. The four components in the PCAs performed for individual and across 3 and 2 locations accounted for between 66 to 82% of the total variability in the 123 accessions. Ilonga site had 66% of the total variability accounted for by the first PC (on 6 variables excluding non significant seeds per pod). Kampi ya Mawe and Kabete individual sites had 71% and 72% variability accounted for by the first 4 PCs respectively (on 14 variables) whereas the 3 locations combined had 75% variability accounted for by the first 4 PCs. Kampi ya Mawe and Kabete combined had 82% variability on the first 4 PCs. Specific patterns that defined the way the variables were associated to influence the first 4 PCs were identified.

At Ilonga, the first PC accounted for 66 percent of the total variance thus accounting for much of the variability with high positive contributions from days to flower, days to maturity, plant heights with high negative loading from grain yield and 100 seed mass. The second and third PCs accounted for insignificant variability with eigenvalues <1 and could not be considered for variability delineation according to Kaiser (1960) in Rojas *et al.*, (2000). At Kampi ya Mawe (14 variables), only the first three PCs had eigenvalues ≥ 1. The first PC accounted for 36% of total variability with days to flower, days to maturity, plant height, pod bearing length, number of primary and secondary branches and 100 seed mass contributing high positive loadings but with negative loadings for seeds per pod and pod length. The second PC accounted for 17% of the variance with high negative loadings from grain yield, pod yield, 100 seed mass and threshing percentage. The third PC accounted for 10% of the total variability with positive loadings from pods per plant and negative loadings from secondary branches and threshing percentage.

Table 14. Principal Components for 14 quantitative traits recorded on 123 Tanzanian pigeonpea accessions across locations.

	Across Kabete and Kampi ya Mawe				Across Ilonga, Kabete and Kampi ya Mawe			
	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4
Eigenvalue	6.851	1.580	1.090	1.001	6.341	1.691	1.446	1.028
Proportion of variance (%)	53.41	12.32	8.49	7.80	45.17	12.04	10.30	7.32
Total variance (%)	53.41	65.42	73.91	81.71	45.17	57.17	67.47	74.79
Eigenvectors (Loadings)								
Plant heights (cm)	0.34618	0.05249	-0.14884	-0.08481	0.35078	0.02612	-0.13573	-0.26702
Days 50% flower	0.34395	0.15766	-0.15175	-0.09487	0.35458	0.04784	-0.11114	-0.20442
Primary branches	0.27650	0.14240	-0.27126	-0.21575	0.29805	0.25027	0.03484	-0.21536
Seeds per pod	-0.16434	-0.44030	-0.24981	-0.52006	-0.21272	-0.31241	-0.17234	-0.43776
Days to 75% maturity	0.33374	-0.03320	-0.12454	-0.06612	0.34558	0.04784	-0.06601	-0.12604
Grain yield (t ha^{-1})	0.27248	-0.42397	0.26309	0.19611	0.13156	-0.48784	0.23815	0.38126
100 seed mass	0.10608	-0.03193	-0.53894	0.72388	-0.04361	-0.09038	0.62675	-0.35833
Pod bearing length (cm)	0.25947	0.27416	-0.31818	-0.18131	0.27674	0.26782	0.00495	-0.20899
Pod length (cm)	-0.12680	-0.55410	-0.50608	-0.05598	-0.14029	-0.52619	-0.07674	-0.49339
Pods per plant	0.32314	-0.17355	0.11671	0.02458	0.33806	-0.17645	0.15215	0.13128
Secondary branches	0.30300	-0.09100	0.09860	-0.06340	0.27472	-0.12206	0.00126	-0.04083
Raceme number	0.32058	-0.00273	0.01160	-0.19400	0.31829	-0.14006	-0.16132	0.04234
Pod yield (t ha^{-1})	0.28127	-0.39467	0.27880	0.147229	0.29911	-0.38711	0.06413	0.20416
Threshing %	0.05889	0.32292	0.62043	0.32076	0.04146	0.16121	0.65090	-0.98830

Table 15. Principal components (PC) on 14 quantitative traits recorded on 123 Tanzanian pigeonpea landraces at individual locations

Kabete

	PC1	PC2	PC3	PC4
Eigen value	5.902	1.639	1.371	1.112
Proportion of variance	42.16	11.71	9.80	7.94
Total variance	42.16	53.87	63.67	71.61
		Eigenvectors (loadings)		
Plant heights	0.35574	0.10630	0.17543	0.15884
Days 50% flower	0.36767	-0.04621	0.06162	0.03377
Primary branches	0.25623	0.00842	0.05123	0.22133
Seeds per pod	-0.01646	-0.48368	0.50138	-0.30082
Days to 75% maturity	0.24883	-0.04288	0.01637	-0.10670
Grain yield	0.29983	-.032501	-0.26783	-0.29159
100 seed mass	-0.03686	-0.32780	-0.30290	0.70516
Pod bearing length	0.33769	0.13384	0.15774	0.10828
Pod length	-0.04233	-0.54020	0.40827	0.32750
Pods per plant	0.32070	-0.12885	-0.22099	-0.00221
Secondary branches	0.27792	0.01336	-0.19178	0.13611
Raceme number	0.31784	0.24748	0.15395	0.06152
Pod yield	0.31885	-0.26500	-0.16558	-0.28230
Threshing %	-0.14341	-0.28222	-0.46837	-0.13963

Kampi ya Mawe

	PC1	PC2	PC3	PC4
Eigen value	4.355	2.072	1.219	0.983
Proportion of variance	35.69	16.98	9.99	8.05
Total variance	35.69	52.67	62.66	70.71
		Eigenvectors (loadings)		
Plant heights	0.40954	-0.08960	0.06959	-0.07887
Days 50% flower	0.40729	0.07146	0.05854	-0.01317
Primary branches	0.27536	-0.05387	-0.05633	-0.15756
Seeds per pod	-0.28324	0.03143	0.04146	-0.46860
Days to 75% maturity	0.41853	0.05906	0.06244	-0.01402
Grain yield	-0.05936	-0.65248	0.02891	0.12162
100 seed mass	0.22589	-0.25007	-0.25265	-0.01960
Pod bearing length	0.30962	0.03478	0.14592	-0.11023
Pod length	-0.24387	-0.10511	-0.10475	-0.51230
Pods per plant	0.10935	-0.15114	0.60919	-0.48973
Secondary branches	0.21654	-0.02136	-0.34956	0.01074
Raceme number	0.24135	-0.06197	-0.01229	-0.14198
Pod yield	-0.06009	-0.63823	0.17174	0.21825
Threshing %	0.06771	-0.21091	-0.60254	-0.38920

Ilonga

	PC1	PC2	PC3	PC4
Eigen value	3.939	0.879	0.527	0.397
Proportion of variance	66.04	14.73	8.84	6.65
Total variance	66.04	80.77	89.61	96.26
		Eigenvectors (loadings)		
Plant heights	0.40128	0.05958	-0.67751	-0.37649
Days 50% flower	0.48606	-0.03334	-0.09908	0.15768
Primary branches	0.24955	0.88032	0.34514	-0.20661
Days to 75% maturity	0.47619	-0.02917	-0.19486	0.20325
Grain yield	-0.42628	0.11345	-0.32463	-0.60018
100 seed mass	-0.36328	0.45458	-0.51835	0.62385

At Kabete 42% of total variability was accounted for by the first PC with high positive loadings from days to flower, days to maturity, grain yield, plant height, pod bearing length, pods per plant, pod yield, number of primary branches and secondary branches. PC2 with 12% of total variance was influenced by positive loadings from number of racemes per plant but with high negative loadings from pod length and seeds per pod, pod yield, grain yield, 100 seed mass, and threshing percentage. High positive loadings from pod length and seeds per pod and high negative loadings from threshing percentage and 100 seed mass had the most contribution to third PC which accounted for 10% of total variance in the accessions. Accessions that differed in days to flower, days to maturity, grain yield, plant height, pod bearing length, pods per plant, number of primary branches and secondary branches were separated on the first principal component. The second principal component separated varieties that differed in their seeds per pod, grain yield, pod length and pod yield.

PCA performed on pooled means across Kampi ya Mawe and Kabete had PC1 accounting for 53.4% of total variance with accessions differentiated based on variability in plant height, days to flower, days to maturity, grain yield, pod yield, pod bearing length, pods per plant, primary and secondary branches and number of racemes all which had high positive loadings. The second PC accounted for 12.3% of total variance negatively loaded highly by pod length, seeds per pod, grain yield, pod yield and a positive loading from pod bearing length. The third PC with 8.5% of total variance had positive loadings from pod and grain yield and high negative loadings from pod bearing length, pod length and 100 seed mass. The fourth PC delineated accessions based on 100 seed mass (high positive loadings) and seeds per pod (high negative loadings). Across the 3 locations, PC1 accounted for 45.2% of total variation with similar loading patterns as at individual locations (differentiated by days to flower, days to maturity, plant heights, racemes per plant, pods per plant, pod bearing length and primary and secondary branches). PC2 accounted for 12.0% of the total variation and was heavily loaded negatively by grain yield, pod length, pod yield and seeds per pod and positive loadings from primary branches per plant and pod bearing lengths. The delineation on the third PC was influenced by high positive loadings from grain yield and 100 seed mass. The fourth PC was mostly negatively loaded by days to 50% flowering, plant heights, primary branches, seeds per pod, 100 seed mass, pod bearing length and pod length with positive loadings from grain yield and pod yield. The observations above clearly show a similar loading pattern on the 4 PCs across the trial sites thus strongly indicating that similar traits accounted for the variability in the germplasm across the test locations.

From PCA grouping based on the 14 quantitative variables means across the trial sites and at individual sites, the bi-plot of the PC scores (PC1 and 2) distributed the accessions along the 2 axes into 2 major scatter distributions (Figure 2 and Appendices 10, 11, and 12). Accessions from Northern highlands had strong positive scatter on the first PC suggesting that they were tall, late to flower and in maturity, with long pod bearing lengths, higher number of pods per plant, a higher number of both primary and secondary branches. Collections from Coastal zone, Eastern and Southern plains tended to congregate together on the lower end of both the first PC and second PC, suggesting that they are generally shorter, early in flowering and maturity, have fewer number of pods per plant and fewer seeds per pod and lower yields but a relatively higher threshing percentage.

Accessions 20, 21, 24, 25, 41, 43, and 54 (Eastern) and 64, 67, 71 and 84 (Southern) congregated close to northern highlands collections on the PCA bi-plot. Some of these could have originated from the highlands. Check varieties ICEAP 00926, ICP 9145, ICEAP 00950, ICEAP 00020, ICEAP 00040, 00053 and ICP 13076 (all long duration types that correspond to highland material) and medium checks T-7, ICEAP 00933, QP14 and ICEAP OO790 congregated closely with the highlands collections. ICEAP 00040 has been released in the highlands of Tanzania and

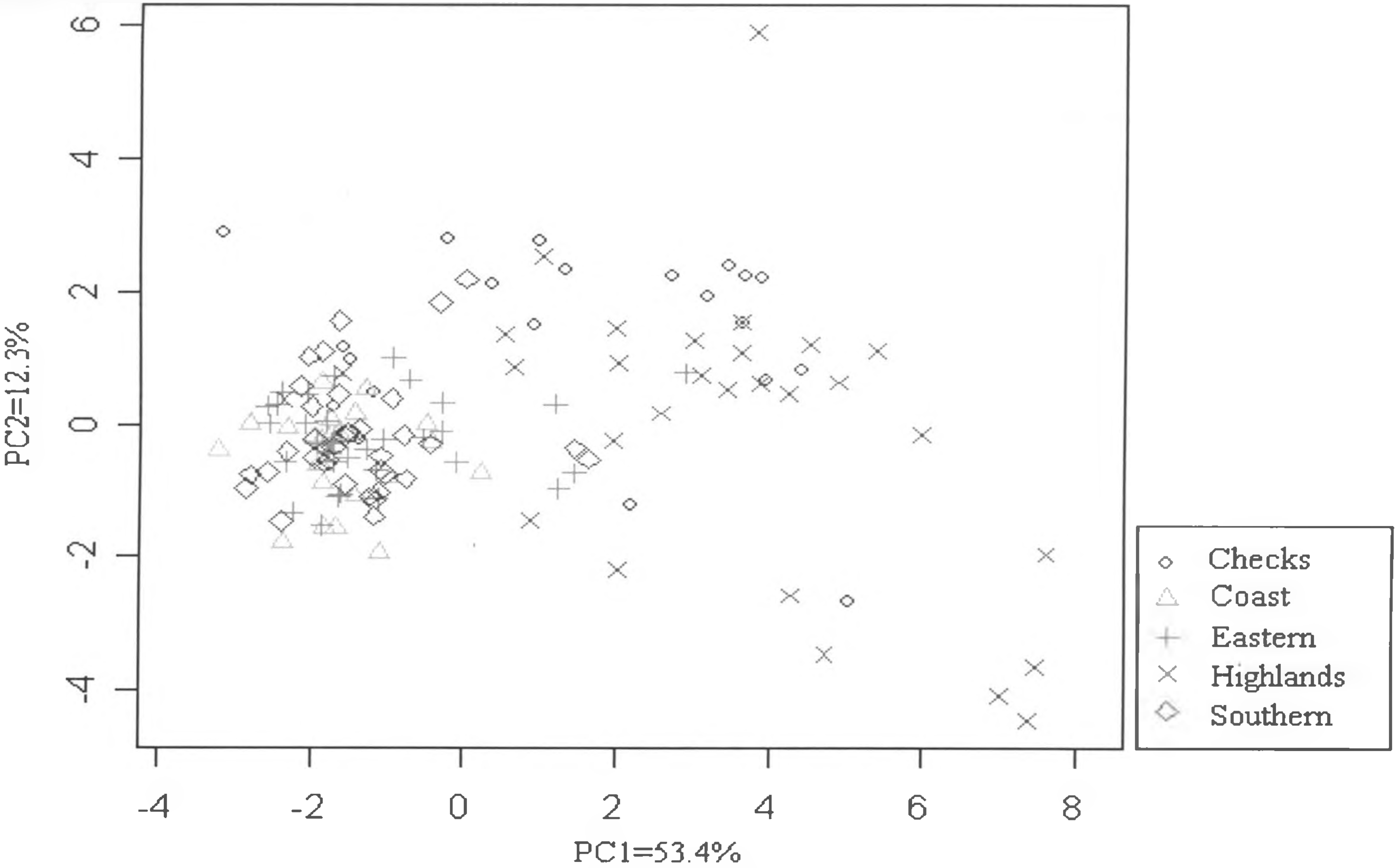


Figure 2. Scatter diagram for first two principal components based on 14 quantitative traits recorded at Kabete/Kampi ya Mawe.

ICEAP 00053 is widely grown though not yet released. Medium checks ICEAP 00540, ICEAP 00068, ICEAP 00550, ICEAP 00554 and ICEAP 00557 and highland collections 102 and 104 (both from Kondoa District) were closely associated with Coastal, Eastern and Southern collections.

It is important to note that some variables had differential loadings at different sites. Although grain yield had positive loadings on PC1 at Kabete, it had negative loadings on PC1 at both Ilonga and Kampi ya Mawe and similarly 100 seed mass with positive loadings on PC1 at Kampi ya Mawe had negative loadings on same PC at both Kabete and Ilonga. This could suggest a strong influence of environment on some traits. When the crop is grown in warm areas, late maturing types suffer from terminal drought stress hence low yields. There was very close dispersion among the Coastal, Eastern and Southern collections and a more wide dispersion within the highland collections. This reveals a bigger similarity in the 3 regions materials hence less diversity and a much more pronounced diversity in the highland material for the quantitative traits assessed.

4.3.5 Cluster analysis

Dendrograms for hierarchical average linkage cluster analysis and cluster means and proportions of each region's accessions in each cluster for the 123 accessions plus 21 checks among the accessions are shown in Figure 3, Tables 16a/b and Appendices 13 and 14. Hierarchical clustering separated the accessions into 6 clusters (groups) with each cluster having accessions that were similar. The number of accessions in each cluster ranged from 7-50. Cluster 1 had 40 accessions mostly from coastal (12), Eastern (13) and Southern (13) regions and 2 accessions from highlands. The accessions in this cluster were medium in maturity (mean 153 days), shortest in height (mean 1106cm), had fewest number of pods per plant (101),with average 100 seed mass

(15.3g) and low mean grain yields (1.017 ton ha^{-1}). The cluster also had the longest mean pod length (9.1cm), short pod bearing lengths (55.3cm) and least number of racemes per plant (76).

Cluster 2 with 50 accessions was the largest and comprised mostly of materials from Coast (11), Eastern (15), and Southern (18) regions, one from the highlands region and 5 medium checks. They were all medium duration (mean 152 days) short in height (mean 108cm), fewer pods per plant (mean 106), fewer racemes per plant (mean 86), fewer primary (mean 7) and secondary branches (mean 8) and shorter pod bearing lengths (mean 59.7cm). Cluster 3 with 9 accessions (3 Coastal, 2 Highlands, 1 Eastern and 2 Southern and 1 long duration check variety). This cluster was characterized by late maturity (mean 172 days), medium plant heights (137.4cm) high number of pods per plant (155), high mean primary (10) and secondary (13) branches, long pods (8.9cm) and highest mean 100 seed mass (17.9g). Cluster 4 had 7 accessions (2 Eastern, 1 Southern and 4 medium checks). Accessions in this cluster were medium in maturity, short (107.2 cm), with shortest pods (7.3 cm), lowest mean seeds per pod (5) and low grain yield (0.902 ton ha^{-1}).

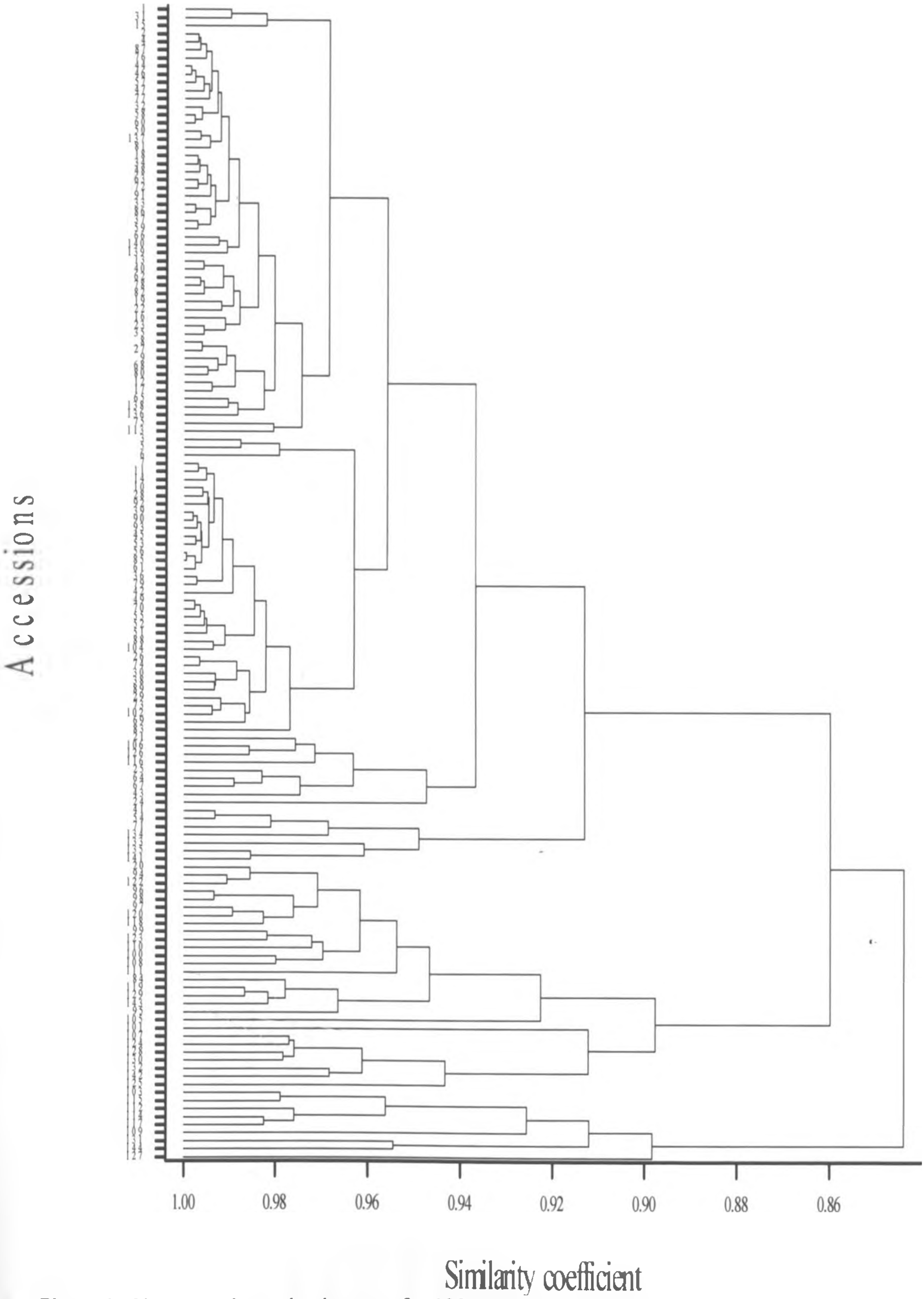


Figure 3. Cluster analyses dendrogram for 123 accessions and 21 checks based on average linkage for the 14 quantitative traits recorded across Kabete/Kampi ya Mawe

Table 16a. Cluster means and ranges (parenthesis) recorded on 123 Tanzanian pigeonpea accessions based on 14 quantitative traits at Kabete/Kampi ya Mawe.

Trait	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
Days 50% flower	106 (97-136)	104 (87-121)	128 (107-147)	102 (92-112)	164 (136-206)	139 (110-173)
Days 75% maturity	153 (145-173)	152 (140-165)	172 (150-192)	153 (134-166)	209 (190-258)	189 (147-245)
Plant height (cm)	106 (80-147)	108.1 (88-142)	137.4 (120-149)	107.2 (84.8-118.1)	158.5 (108.3-192.6)	175.9 (140.6-195.7)
Grain yield (t/ha)	1.017 (0.482-1.544)	1.038 (0.303-1.853)	1.649 (1.075-2.399)	0.902 (0.047-1.465)	1.411 (0.241-2.073)	2.870 (1.519-4.151)
Pod bearing length (cm)	55.3 (42.0-76.8)	59.7 (40.5-91.6)	77.9 (59.1-109.5)	60.8 (43.1-76.8)	92.1 (70.8-154)	87.7 (69.9-122.3)
Pod length (cm)	9.1 (7.8-10.6)	8.5 (7.7-9.2)	8.9 (7.9-10.3)	7.3 (6.9-8.4)	7.9 (7.1-9-1)	8.3 (7.0-9.6)
Pods per plant	101 (72-157)	106 (56-147)	155 (135-172)	114 (44-152)	150 (86-211)	228 (150-287)
Pod yield (t/ha)	1.808 (0.786-2.942)	1.765 (0.558-2.731)	2.748 (1.009-3.307)	1.475 (0.082-2.334)	2.486 (0.391-4.415)	4.399 (2.051-6.145)
Primary branches	7 (5-10)	7 (5-11)	10 (6-20)	9 (6-16)	11 (6-17)	11 (8-15)
Raceme number	76 (39-211)	86 (46-150)	100(63-150)	100 (70-124)	143 (51-269)	258 (116-467)
Secondary branches	8 (3-13)	8 (4-18)	13 (9-19)	8 (4-12)	13 (3-27)	23 (9-57)
Seeds/pod	6 (6-7)	6(5-6)	6 (5-6)	5 (5-5)	6 (5-6)	6 (5-6)
100 seed mass (g)	15.3 (12.0-18.1)	14.5 (12.5-15.9)	17.9 (15.3-20.8)	16.4 (14.1-19.0)	15.9 (13.6-19.3)	16.3 (13.7-18.4)
Threshing%	53.6 (46.2-59.3)	55.3 (48.8-63.2)	57.3 (50.6-66.0)	58.2 (51-75.1)	56.3 (44.1-75.3)	57.2 (45.6-61.6)

Table 16b. Proportion of each region's accessions per cluster

	% of Cluster total					
	Cluster 1 (40)	Cluster 2 (50)	Cluster 3 (9)	Cluster 4 (7)	Cluster 5 (26)	Cluster 6 (11)
Region						
Coast	30.0	22.0	33.4	0.0	0.0	0.0
Eastern	32.5	30.0	22.2	28.6	3.8	0.0
Southern	32.5	36.0	11.1	14.3	3.8	0.0
Highlands	5.0	2.0	22.2	0.0	69.2	54.5
Checks	0.0	10.0	11.1	57.1	23.2	45.5

( ) *Number of accessions in the cluster*

Cluster 5 had 18 highland accessions, 1 Eastern accession, 1 Southern accession and 6 check varieties (3 long and 3 medium durations). Accessions in this cluster were very late (209 days), tall (158.5 cm), high number of primary (11) and secondary branches (13), high number of racemes per plant (143), longest pod bearing lengths (92.1cm), high number of pods per plant (150) and average grain yields (1.411 ton ha^{-1}). Cluster 6 with 6 highland accessions, 3 long and 2 medium duration check varieties was characterized by very tall (175.5 cm) late (189 days) plants, with highest number of secondary branches (23) highest number of racemes per plant (258), highest number of pods per plant (228) and high grain yields (2.870 ton ha^{-1}). The divergence between the Eastern, Coastal and southern collections was smaller than the divergence between these groups and the northern highlands group. There was however higher divergence within the northern highlands material than within materials from the 3 other regions.

CHAPTER 5

5.0 DISCUSSION

5.1 Qualitative traits

Qualitative traits which are often simply inherited have been used in selection of genotypes by farmers and breeders alike. Farmers always identify their pigeonpea varieties by stem color, flower color, pod colour seed color and seed size (small, medium or large) other than by quantitative traits like plant height, yield, earliness and seed mass and will de-select those traits that they do not desire. Similar observations have been made in barley and wheat where farmers use grain colour as their most important selection criteria to classify barley and wheat landraces/varieties (Jaradat *et al.*, 2004 and Kebebew *et al.*, 2001).

The predominant green stem colour (97%) in Tanzanian germplasm contrasts with the findings by Saxena and Sharma (1990) who reported predominant purple stems in African pigeonpea landraces and is in agreement with findings by Upadhyaya *et al.*, (2005) who reported a predominance by green stem colour (84%) in a global collection of 11, 402 accessions. But the predominant semi-spreading growth habit is a reflection of the cropping systems in the pigeonpea growing areas of Tanzania and Eastern Africa where intercropping with maize, sorghum, cassava, cowpea and beans is widely practiced and semi-spreading pigeonpea varieties are preferred (Nene and Sheila 1990; Mligo 1995; Silim *et al.*, 2005) due to their high branching plasticity (Baldev, 1988). Most of the accessions in this study had semi-spreading growth habit (93%), indeterminate flowering pattern (59%), yellow flower colour (73%), red streaks (54%), and mixed pods (50%). These results also agree with findings by Reddy, (1990), Remanandan *et al.*, (1988) and Upadhyaya et al., (2005), who all reported a predominance of semi-spreading growth habit, indeterminate flowering pattern, yellow flower colour, red streaks, mixed pods and yellow base flower colour.

ICRISAT's breeding efforts have been to develop large seeded varieties with white/cream seed because preference by consumers and markets are for these traits. This study confirms these preferences for cream/white seed types as manifested in 94% of the accessions falling in this category which also agrees with in-situ primary reports from the collection mission (Silim *et al.*, 2005) and also with reports by Saxena and Sharma (1990) and a survey by Shiferaw et al., (2005). Even in areas where pigeonpea is eaten green, white/cream types are preferred because they are usually bright green at this stage and attractive to the eye. The frequency of plain white/cream types (with no second seed colour) was highest in the Northern highlands which could be attributed to the commercial nature of pigeonpea production in the region. Most accessions had oval seed shapes (48%) with a significant presence of globular types (39%) especially in the highland region (54%), similar to observations by Remanandan (1990) who also reported a predominance of oval seed shape in pigeonpea germplasm evaluations at ICRISAT-India. The predominance of seeds with strophiole associated with late maturing pigeonpea types (Upadhyaya *et al.*, 2005) was logical as the accessions were mostly medium and late in maturity.

Although the diversity index (*H'*) being a product of log transformation is not conveniently usable for genetic interpretation, it is still a good measure of both allelic richness and allelic evenness of a population (Brown and Weir, 1983 and Eticha *et al.*, 2005). The most valuable qualitative traits are those that show variability between the accessions. In this study there were various degrees of polymorphism in qualitative traits both within and among accessions with several classes of the same trait occurring in an accession. Base flower colour, flowering pattern, pod colour, pod form, streak pattern, second seed colour, seed colour pattern and seed shape accounted for the polymorphism in the 123 accessions. However stem colour, growth habit, base seed colour and pod hairiness were near monomorphic in the germplasm and between regions of collection.

Variability in this germplasm seemed to be more within and among accessions than between regions an observation not unique to pigeonpea germplasm. Findings by Eticha *et al.*, (2005) in tetraploid wheat in Ethiopia showed variation mainly within rather than between populations within regions of collection. However, the same study cites Bekele (1984) working on durum and bread wheats in Ethiopia to have reported total variation to be highest within populations followed by differences among populations within region and least among regions. Overall though, there was relatively low variability in the qualitative traits (H' =0.227) and save for Northern highlands collections, there was no distinct variability pattern in the germplasm relative to region of collection across traits with significant polymorphism.

5.2 Quantitative traits

5.2.1 Analysis of variance and correlations

The highly significant phenological variabilities in the 123 accessions and between accessions and environments are an indication of suitability of certain genotypes to specific environments. These results also agree with findings by Bramel *et al.*, (2004) who evaluated 638 accessions from 4 districts in Andhra Pradesh and found significant differences in quantitative traits among the accessions and between accessions and between districts. The lowest mean plant heights of 120 cm at Kabete with mean minimum temperatures of 12.6°C compared with Kampi ya Mawe (121 cm) and Ilonga (189 cm) with mean temperatures of 22°C and 16°C respectively agree with earlier findings reported by McPherson *et al.*, (1985), Turnbull (1986) and Silim *et al.*, (1995) that there is reduction in pigeonpea plant heights with reduction in temperature during the cropping season. However the low mean plant heights at Kampi ya Mawe relative to Ilonga were largely due to drought stress in the growing season. Accessions from the northern highlands were the tallest at all the three experimental sites.

The intervals between the earliest and latest accessions to flower at Kampi ya Mawe, Ilonga and Kabete were 164, 61 and 85 days respectively. Materials originating from the Northern Highlands took longer to flower at Kampi ya Mawe with higher mean temperatures than at Kabete. This behaviour pattern in pigeonpea was reported earlier by Silim *et al.*, (1995); Silim and Omanga (2001) and Silim *et al.*, (2006) who observed that long duration types originating from high elevations require low optimum temperature (<18°C) for rapid flowering hence experience delayed flowering at intermediate and low elevations.

Maturity classification of the accessions based on days to maturity as <135 early, 135-160 medium and >160 late (Omanga *et al.*, 1995) had most of the Coastal, Eastern and Southern collections falling in the medium maturity group with most of the Highlands collections falling in the late maturity group across the experimental sites. Grain and pod yields were more sensitive to high temperatures and extreme low moisture. As much as pigeonpea is a drought tolerant crop, its abilities are limited in severe and persistent moisture especially during the reproductive phase (Truedson, 1987). This explains the very low yields recorded at Kampi ya Mawe on all accessions and on Highlands collection at Ilonga (terminal drought). However the low mean pod number per plant at Kampi ya Mawe (66) could be attributed to drought stress as observed by Turnbull (1986) that at high constant day temperatures (>35^{0}C), floral abortion increases leading to low pod set.

East African pigeonpea landraces have been reported to produce not only high number of seeds per pod but also higher seed mass than Indian types and that late maturing types have highest grain mass (Gupta *et al.*, 1981; Remanandan 1990; Kimani, 2001; Silim *et al.*, 2005 and Upadhyaya *et al.*, 2005). Findings from this study reveal a high mean seed mass within the germplasm (mean 14gm) with Highlands collections that are also late maturing having the highest mean (16.2gm). The largest seed mass of 19.9gm was recorded in accession 116 (highland collection) at Kabete where moisture in the cropping season was relatively non limiting, which agrees with findings by Ong and Monteith (1985) who reported that pearl millet produced larger seeds at cooler/low temperatures because of a longer seed filling stage. The relatively uniform mean number of seeds per pod (6) across the 4 regions coupled with large seed mass is a manifestation of farmer and market preferences (Omanga *et al.*, 1995; Shiferaw *et al.*, 2005). Suitability and potential of these collections as vegetable pigeonpea is supported by the broad pod widths recorded (1.0 to 1.5 cm) at Kabete in most accessions which was comparatively higher than ranges of 0.4 to 1.0 cm reported in pigeonpea germplasm evaluated at ICRISAT (Reddy, 1990). The distinctive feature of this germplasm in terms of pod characteristics was that collections from the Northern Highlands had the largest pod widths (mean 1.2 cm), particularly in accessions from Babati and Kondoa Districts.

Determining trait pairs that vary in the same or opposite direction is usually a useful guide for plant breeders for it helps associate a set of traits during selection and reduces the number of measurements that could be taken. However several views exist on significant reliability of the coefficients. Fowler and Cohen (1990) and Goli *et al.*, (1997) report that coefficient significant reliability between pairs of traits is considered when absolute values of coefficient are >0.2. Rojas (2000), in determining genetic diversity in quinoa considers values >0.4 to be significant. But Upadhyaya and Ortiz (2001) quoting Skinner *et al.*, (1999) report an absolute value >0.71 to be meaningful so that > 50% of the variation in one trait is predicted by the other. Grain yield was found to be highly correlated with pods per plant, racemes per plant and both primary and secondary branches per plant. This corroborates findings by Remanandan (1990) and Beohar and Nigam, (1972), who reported grain yield to be highly correlated with pods per plant, racemes per plant and both primary and secondary branches per plant. These traits could therefore be useful for indirect selection for yield potential. Plants with a longer phenological cycle were taller with high number of branches, racemes and pods. In areas of low moisture during the end of the crop reproductive phase, late maturing accessions suffer terminal stress leading to low yields as evidenced by the negative correlations between grain yield and days to 50% flowering at Kampi ya Mawe and Ilonga. This agrees with studies by Mukewar and Muley (1974). It is therefore more likely that in areas with short rainfall duration, medium duration varieties will be found.

In eastern Africa, pigeonpea is grown in three major production systems namely semi-arid intermediate season (100-125 days), intermediate season (125-150 days) and sub-humid lowlands hence the need to identify suitable varieties for specific production systems (Silim et al., 1995). The broad variability in plant heights, days to flower, number of primary and secondary branches and racemes per plant evident in these accessions can be utilized to select materials to fit in the different cropping systems in eastern Africa where the crop is mainly intercropped and also help minimize effects of seasonal constraints (Byth *et al.*, 1981) and improve productivity. The recently released variety ICEAP 00040 that has found a niche in both medium and high altitude areas in the eastern Africa region attests to the potential in the local landraces as it is a selection from a local landrace in Kenya. In Tanzania where the breeding program aims at identifying varieties with bold white/cream seeds in each maturity group (Mligo, 1995), opportunities to achieve this exist in the diversity revealed in the 123 accessions with further evaluation and/or hybridization and selection.

5.2.2 Heritabilities

According to Ortiz (1985), the most useful quantitative traits descriptors should have high broad sense heritability and exhibit high repeatability. A low repeatability is an indication of high genotype by environment interaction effects on the trait observed in different environments. Thus the heritability estimates help in selection as they isolate the variability due to genotype from the phenotypic variance. Earlier studies in pigeonpea by Saxena and Sharma (1990) classified heritability ranges as low (<0.5), medium (0.5-0.75) and high (>0.75). Based on this classification low heritabilities were observed in grain yield and seeds per pod, medium heritabilities in days to maturity, number of primary branches and 100 seed mass and high heritabilities in days to flowering and plant heights. Due to the heterogeneity of pigeonpea resulting from out-crossing and the test site differences, these results are only limited to the evaluated germplasm and test site environments. Saxena and Sharma (1990) also cited varying degrees of heritabilities reported in different pigeonpea qualitative traits by previous researchers: grain yield was reported to have low, medium and high heritabilities by 8, 4 and 2 scholars respectively, days to flowering had 7, and 5 reporting medium and high; days to maturity had 1 low, 1 medium and 2 high; plant heights had 4 low, 3 medium and 5 high. Dahiya and Brar (1977), Rubaihayo and Onim (1975) and Raju and Chandra (1972) also reported similar varying heritabilities in these traits. Similar trends were recorded on pooled means across 2 sites (Kampi ya Mawe and Kabete) in this study.

Results reported in this study hence fit into the hereditary patterns of pigeonpea quantitative traits observed by other researchers. Because traits with high heritabilities are the most reliable as germplasm descriptors (Abu-Alrub *et al.*, 2004), plant heights, days to flower, days to maturity, racemes per plant and 100 seed mass plus the polymorphic qualitative traits (base flower colour, flowering pattern, pod colour, pod form, streak pattern, second seed colour, seed colour pattern and seed shape) could be used for pigeonpea germplasm classification as results from this study show.

5.2.3 Principal Components and Clustering

Previous research in the use of multivariate analysers for agro-morphological diversity in pigeonpea is limited hence comparison with findings in this study was limited to a few references within pigeonpea but similar studies in other crops were found relevant. The PCA performed revealed similar important traits to explain variability both at individual and across the 3 experimental sites and the bi-plots did scatter accessions within their respective areas. Based on differential traits loadings on first and second PCs, the first PC delineated accessions that are tall, late flowering, have long pod bearing lengths, high number of pods per plant, and high number of both primary and secondary branches. Grain yields loadings were location dependent. The second PC differentiated accessions based on low pod and grain yield, low seeds per pod, long pod bearing lengths, short pod lengths and long pod bearing lengths. Accessions from the northern highlands had a wider spread in the PCA bi-plots than those from the 3 other regions, an indication of wider variability within the the northern highlands material and less variability within collections from Coast, Eastern and southern region. Cluster analysis separated the genetic diversity expressed by phenotypic variability in this collection into 6 groups. However, the delineation did distinctly identify two regions of genetic diversity separated into Northern highlands as one group and Coastal, Eastern and Southern combined (closely related) as another group. Rojas *et al.*, (2000) while studying diversity in quinoa in Bolivia was able to place the seven clusters identified into 3 genetic diversity areas based on altitude.

Climatic and ecotypic differences at a site play an important role in developing and sustaining genetic variability within a population (Bennet, 1999). This best explains the two region classification in this study. The climatic diversity in the 3 regions of Coast, Eastern and Southern, are not wide enough to strongly separate pigeonpea varieties grown. It is also possible that years of farmer selection for adaptation to unfavourable weather (low moisture) could have reduced the diversity in the coastal, eastern and Southern regions relative to the northern highlands where moisture is not as limiting. However, as indicated earlier in this study, pigeonpea is sensitive to temperature which limits its adaptation to diverse altitudes with a definite separation between high and low altitude varieties (Byth *et al.*, 1981; Whiteman, *et al.*, 1985; Silim and Omanga, 2001 and Silim *et al.*, 2006) hence the separate clustering of the northern highlands collections.

Accessions with similar agronomic traits were grouped together irrespective of collection region (Accessions 21, 24, 25, 41, 43, 54, 64, 67, and 71 from lower altitudes together with highlands collections) a finding also reported by Ortiz (1999) in quinoa diversity studies in Peru. The cross region clustering could also be as a result of seed exchanges between farmers either through relatives, markets and/or relief food/seed. Agro-ecological/topographic conditions in a given location usually determine farmers' selection strategies. As shown in this study, farmers' selection for desirable agronomic traits is a major determinant in shaping the dynamics of the crop's population hence conservation strategies should strive to sustain this dynamic process.

CHAPTER 6

6.0 SUMMARY AND RECOMMENDATIONS

6.1 Summary

The aim of this study was to determine genetic diversity in the 123 pigeonpea accessions collected in four regions of Tanzania and evaluate their response to variability in pigeonpea production environments. The genotypes were characterized and evaluated at 3 sites in Kenya and Tanzania for 16 qualitative and 14 quantitative traits. Information from the study revealed that:

- Generally, relatively low variability was observed in qualitative traits. In the northern highland areas where commercialization and uptake of new pigeonpea varieties has taken place, there is evidence of diversity loss as reflected in the very low diversity in qualitative traits relative to the other three regions.
- There exists high polymorphism in quantitative traits in this germplasm. High diversity in quantitative traits exits within the highland materials whereas materials from Coastal, Eastern and Southern plains all seem to be closely related within and between the regions. The diversity grouping in this study has helped establish the possible heterotic groups which may be used in intercrossing to maximize hybrid vigor and generate varieties adapted to different pigeonpea growing environments with consumer acceptability. Differential reaction of the accessions to different environments revealed in this study for agronomic traits will be useful in designing pigeonpea breeding programs and selecting genotypes for cultivation in suitable agro-ecologies.
- The high heritabilities obtained for days to flower, days to maturity, plant heights, raceme number and 100 seed mass is an indication of possibility of improvement through selection using these traits.

- Pods per plant, racemes per plant and both primary and secondary branches per plant can be used to select for grain yield (though not absolutely) due to the high positive correlations recorded.
- The major agronomic traits delineating this pigeonpea germplasm were plant heights, maturity duration, primary and secondary branches, pod bearing lengths, number of racemes per plant and pods per plant.
- Although six clusters were identified in the germplasm, 2 distinct genetic groups stood out comprising of the lowland and mid-altitude material in one group and the high altitude material in the other group.
- Accessions with similar agronomic traits were grouped together irrespective of collection region. The study also revealed that although characterizing germplasm in areas that are not similar to areas of collection may not reveal agronomic potential of the germplasm, clustering into diversity groups did not change from location to the other. Since it is important to carry out diversity studies that will be useful for agronomic purposes, the breeder should hence take cognizance of the limits in agronomic revelations in germplasm in a given environment.

6.2 Recommendations for further research

- As a further verification/confirmation of the heterotic groups identified, there is need for molecular characterization to confirm relatedness or otherwise of these accessions
- There is need to identify collection gaps and carry out targeted collections. And as much as this grouping based on reproductive and morphological traits can form the basis of forming a core collection of this germplasm representing the variability groups identified, there is need to extend collection and characterization to all other pigeonpea areas in

Tanzania (and eastern and southern Africa) to capture the actual diversity and especially now that new improved pigeonpea types are getting adopted by farmers. However, based on observed relationships between agronomic performance and environmental factors, accurate and complete records of passport information with georefernces (including temperature and rainfall) should be taken to derive maximum value from the collected germplasm.

- The broad variability in plant heights, days to flower, number of primary and secondary branches and racemes per plant evident in these germplasm can be utilized to select materials to fit in the different cropping systems in eastern Africa where the crop is mainly intercropped and also help minimize effects of seasonal constraints and improve productivity.
- There is need to increase accessibility to seeds of local pigeonpea varieties especially in areas of pigeonpea commercial production to sustain conservation of diverse useful genetic materials for food security.

References

Abu-Alrub, I., Christiansen, J.L., Madsen, S., Sevilla, R., and Ortiz, R. 2004. Assessing tassel, kernel and ear variation in Peruvian highland maize. Plant Genetic Resources Newsletter no. 137, March, 2004. pp 34-41.

Ae, N., Arihara, J., Okada, K. and Johansen, C. 1990. Phosphorus uptake by pigeonpea and its role in cropping systems of the Indian sub-continent. Science 248: 477-480.

Agong, S.G., Schittenhelm, S., Friedt, W. 2001. Genotypic variation of Kenyan tomato (Lycopersicon esculentum L.). The Journal of Food Technology in Africa, Vol. 6, No. 1, Jan-Mar, 2001, 13-17.

Akinola, J.O. and Whiteman, P.C. 1975. Agronomic studies on pigeonpea (*Cajanus cajan* (L.) Millsp.). field responses to sowing time. Australian Journal of Agricultural Research 26, 43-56.

Angus, J.F., Cunningham, R.B., Moncur, M.W. and MacKenzie, D.H. 1981. Phasic development in field crops I. Thermal response in the seedling phase. Field Crops Research 3, 365-378.

Baldev, B. 1988. Cropping patterns. Pages 513-557 *In* Baldev, B. Ramanujam, S. and Jain, H.K. (Eds) Pulse Crops. New Delhi, India. Oxford and IBH Publishing Co. Pvt. Ltd.

Bekele, E. 1984. Analysis of regional patterns of phenotypic diversity in the Ethiopian tetraploid and hexaploid wheats. *Hereditas* 100, 131-154.

Bennet, S.J. 1999. Ecotypic variation between and within two populations of Trifolium tomentosum (wooly clover) from Syria and western Australia. Its success as a colonizing species. Australian Journal of Agric. Research, 1999, 50:1443-1450.

Beohar, A.R.L. and Nigam, P.K. 1972. Correlation studies in arhar, *Cajanus cajan* (L.) Millsp. JNKVV Research Journal 6, 58.

Bramel, P.J., Kiran, S., Reddy, L.J., Ford-Lloyd, B. And Chandra, S. 2004. Degree and distribution of pigeonpea landraces morphological diversity in traditional cropping systems in Andhra Pradesh. Pages 1-43 *In* Bramel, P. (Ed) Assessing the risk of losses in biodiversity in traditional cropping systems. A case study of pigeonpea in Andhra Pradesh. ICRISAT, A.P. India.

Brown, A.H.D. and Weir, B.S. 1983. Measuring genetic variability in plant populations. Pages 219-238 *In* Tanksley, A. and Oiton T.J. (eds). Isozymes in plant genetic and breeding. Part A. Elsevier, Amsterdam.

Byth, D.E., Wallis, E.S. and Saxena, K.B. 1981. Adaptation and breeding strategies for pigeonpea. Pages 450-465 *In* Proceedings of the International Workshop on Pigeonpea, Vol 1, 15-19 Dec 1980, ICRISAT Centre, India. Patancheru, A.P., India: ICRISAT.

Chauhan, Y.S. 1987. Screening for tolerance to salinity and waterlogging: case studies with pigeonpea and chickpea. Pages 93-10 *In* Adaptation of Chickpea and Pigeonpea to Abiotic Stresses. Proceedings of the Consultants' Workshop, 19-21 Dec 1984, ICRISAT Centre, India. Patancheru, A.P., India: ICRISAT.

Chauhan, Y.S., Venkataratram, N. And Sheldrake, A.R. 1987. Factors affecting growth and yield of short duration pigeonpea and its potential for multiple harvest. Journal of Agricultural Science, Cambridge 109: 519-529.

Chong, K., Wynne, J.C., Elkan, G.H. and Schneeweis, T.J. 1987. Effects of soil acidity and aluminum content on Rhizobium inoculation, growth and nitrogen fixation of peanuts and other grain legumes. Tropical Agriculture (Trinidad) 64, 97-104.

Cowie, A.L., Rayment, G.E. and Chand, V. 1987. Responses of pigeonpea to lime on an Oxisol in Fiji. In: Wallis, E.S. and Byth, D.E. (eds.), Food Legume Improvement for Asian Farming Systems: Proceedings of an International Workshop held in Khon Kaen, Thailand, 1-5 Sept 1986. ACIAR Proceedings no. 18. ACIAR, Canberra, pp. 258-259.

Cui, Z., Carter, T.E., Burton, J.W. and Wells, R. 2001. Phenotypic diversity of modern Chinese and North American soybean cultivars. Crop Science 41:1954-1967.

Dahiya , B.S. and Brar, J.S. 1977. Diallel analysis of genetic variation in pigeonpea Cajanus cajan (L.) Millsp.. Experimental Agriculture 13(2):193-200.

Dasappa and Mahadevappa, M. 1970. Investigations on grain yield and related characters of some tur varieties. Mysore Journal of Agricultural Science 4, 212-215.

Edwards, D.G. 1981. Development of research on pigeonpea nutrition. Pages 205-211 *In* Proceedings of the International Workshop on Pigeonpeas, vol. 1, 15-19 Dec 1980, ICRISAT Centre, India. Patancheru, A.P., India: ICRISAT.

Eticha, F., Bekele, E., Belay, G. And Borner, A. 2005. Phenotypic diversity in tetraploid wheats collected from Bale and Wello regions of Ethiopia. Plant Genetic Resources 3(1); 35-43.

Fowler, J. and Cohen, L. 1990. Practical Statistics for Field Biology. John Wiley and Sons Ltd, West Sussex, England. pp. 130-141.

Fundora Mayor, Z., Hernandez, M, Lopez, R., Fernandez, L., Sanchez, A., Lopez, J. and Ravelo, I. 2004. Analysis of the variability in collected peanut (*Arachis hypogea* L.) cultivars for the establishment of core collections. Plant genetic Resources Newsletter, 2004, No. 137:9-13.

Goodman, M. and Paterniani, E. 1969. The races of maize III. Choice of appropriate characters for racial classification. Economic Botany 23: 265-273.

Goli, A.E., Begmann, F. and Ng, N.Q. 1997. Characterization and evaluation of IITA bambara groundnut collection. Bambara groundnut *Vigna subterranea* (L) Verdc. Promoting the conservation and use of under-utilised and neglected crops. Pages 53-58 *In* Heller, J., Begmann, F. and Mushonga, J. (eds.). Proceedings of the workshop on conservation and improvement of bambara groundnut (*Vigna subterranea* (L.) 14-16, Sep. 1995, Harare, Zimbabwe. Institute of Plant Genetics and Crop Research.

Gower, J.C. 1985. Measures of taxonomic distance and their analysis. Pages 395-405 *In* Kotz S., Johnson N.L. (eds). Encyclopedia of Statistical Sciences, Vol. 5. John Wiley and Sons, New York.

Gupta, S.C., Saxena, K.B. and Sharma, D. 1981. Inheritance of days to flower and seed size in pigeonpea. Pages 61-66 *In* Proceedings of the International Workshop on Pigeonpea, volume 2, 15-19 Dec 1980, ICRISAT Centre, India. Patancheru, A.P., India: ICRISAT.

Gupta, O.M., Katasthana, S.R. and Khare, M.N. 1988. Strain variation in fusarium udum in Madhya Pradesh, India. International Pugeonpea Newsletter No. 7, 22-25.

Hair, J.F., Anderson, R.E., Tatham, R.L., Black, W.C. 1995. Multivariate data analysis. Fourth Edition. New Jersey. Prentice Hall International.

Haryanto, T.A.D. 2002. Procedures for estimating values, genetic correlations and combining abilities of several agronomic characters.www.dl.dion.ne.jp/~tmhk/yosida. Internet.

Hodgkin, T. 1997. Some current issues in conservation of plant genetic resources. Pages 3-10 *In* Ayad, W.G., Hodgkin, T., Jaradat, A. and Rao, V.R. (eds.). Molecular genetic techniques for plant genetic resources. Report of an IPGRI workshop 9-11 October 1995, Rome, Italy.

IBPGR/ICRISAT, 1993. Descriptors for pigeonpea (*Cajanus cajan* (L) Millsp). (International Crops Reseaerch Institute for the Semi-Arid Tropics (ICRISAT) 1975. Annual Report 1974-1975. Patancheru, A.P. India. ICRISAT. p.40.

ICRISAT (International Crops Reseaerch Institute for the Semi-Arid Tropics). 1980. Annual Report 1978-1979. . Patancheru, A.P. India. ICRISAT. p.95.

ICRISAT (International Crops Reseaerch Institute for the Semi-Arid Tropics). 1982. Annual Report. Patancheru, A.P. India. ICRISAT. p.140.

ICRISAT (International Crops Reseaerch Institute for the Semi-Arid Tropics). 2003. Pages 1-14. *in* Raising income of poor farmers: Enhancing pigeonpea productivity and profitability in eastern

Africa. Annual report project report, submitted to DANIDA. Patancheru, A.P. 302 524, India. ICRISAT.

Jadhav, T.K. and Moniz, L. 1972. Cross inoculation studies with Rhizobia of cultivated and wild tur and Sunhemp. Research Journal of Mahatma Gandhi Phule Agricultural University 3(1-2), 64-66.

Jain, S.K., Qualset, C.O., Bhatt, G.M. and Wu, K.K. 1975. Geographic patterns of phenotypic diversity in a world collection of durum wheats. Crop Science 15:700-704.

Jaradat, A.A., Shahid, M., and Al-Maksri, A.Y. 2004. Genetic diversity in the Batini barley landrace from Oman. Spike and seed quantitative and qualitative traits. Crop Science 44:304-315.

Joshi, P.K., Parthasarathy Rao, P., Gowda, C.L.L, Jones, R.B., Silim, S.N., Saxena, K.B., and Jagdish Kumar. 2001. The world chickpea and pigeonpea economies: facts, trends, and outlook. Patancheru 502 324, Andhra Pradesh, India. International Crops Research Institute for the Semi-Arid Tropics. pp 31-62. ISBN 92-9066-443-6.

Kaemer, D., Weising, K., Beyermann, B., Borner, T., Epplen, J.T. and Kahl, G. 1995. Oligonucleotide fingerprinting of tomato DNA. Plant Breed. 114:12-17.

Kaiser, H.F. 1960. The application of electronic computers to factor analysis. Educ. Psychol. Meas. 20:141-151.

Kannaiyan, J., Nene, Y.L., Reddy, M.V., Ryan, J.G., and Raju, T.N. 1984. Prevalence of pigeonpea diseases and associated crop losses in Asia, Africa, and the Americas. Tropical pest management 30 (1): 62-71.

Kannaiyan, J., and Haciwa, H.C. 1990. Diseases of pigeonpea in Zambia. International Pigeonpea Newsletter 12: 22-23.

Kebebew, F., Tsehaye, Y. and McNeilly, T. 2001. Diversity of durum wheat (*Triticum durum* Desf.) at in situ conservation sites in North Shewa and Bale, Ethiopia. Journal of Agricultural Science, Cambridge (2001), 136, 383-392.

Khan, T.N. and Rachie, K.O. 1972. Preliminary evaluation and utilization of pigeonpea germplasm in Uganda. East African Agricultural and Forestry Journal 38, 78-82.

Kimani, P.M. 2001. Pigeonpea. Status and potential in eastern and southern Africa. Pages 21-32 *In* Silim, S.N., Mergeai, G. and Kimani P.M. (eds.). Status and potential of pigeonpea in eastern and southern Africa. Proceedings of a regional workshop Nairobi, Kenya, 12-15 Sep 2000. ICRISAT, Patancheru, India.

Klug, W.S. and Cummings, M.R. 1994. Concepts of Genetics, 4th Edition, USA. Mcmillan College Publishing Company.

Kumar Rao, J.V.D.K. and Dart, P.J. 1979. Biology of nodulation of pigeonpea *Cajanus cajan (*L.) Millsp. pp. 80-82 *In* Proceedings of the sixth Australian legume nodulation conference, 21-24 August 1979, Perth, Australia. University of Western Australia, Perth , Australia.

Kumar Rao, J.V.D.K. and Dart, P.J. 1987. Nodulation, nitrogen fixation and nitrogen uptake in pigeonpea (Cajanus cajan (L.) Millsp.) of different maturity groups. Plant and Soil 99, 255-255.

Kumar Rao, J.V.D.K. 1990. Nitrogen fixation. Pages 233-256 *In* Nene, Y.L., Hall, S.D. and Sheila, V.K., (eds.). The Pigeonpea. Wallingford, UK: CAB International.

Lateef, S.S. 1991. Insect Pests of Pigeonpea and their Management. Pages 53-53 *In* Singh, L., Silim S.N., Ariyanayagam, R.P., and Reddy, M.V. (Eds). Proceedings of the First Eastern and Southern Africa Regional Legumes (Pigeonpea) workshop, 25-27 Jun 1990, Nairobi, Kenya. Eastern African Regional Cereals and Legumes (EARCAL) Program, ICRISAT.

Lawn, R.J. and Troedson, R.J. 1990. Physiology of yield formation pgs 179-208 *in* (Nene. Y.L., Hall, S.D. and Sheila, V.K. (eds.). The Pigeonpea. Wallingford, UK: CAB International.

Lenne, J., Weltzien, R. and Stenhouse, J. 1997. *In* Sperling, L. and Loevinsohn, M.E. (eds). A role for ICRISAT Enhancing and maintaining genetic resources on-farm. IDRC.

Maggs-Kolling, G.L., Madsen, S. And Christiansen, J.L. 2000. A phenetic analysis of morphological variation in *Citrullus lanatus* in Namibia. Genetic Resources and Crop Evolution 2000, 47:385-393.

Maingu, Z.E. and Mligo, J.K.1991. Pigeonpea production systems and research in Tanzania. Pages 83-90 *In* Singh, L., Silim S.N., Ariyanayagam, R.P., and Reddy, M.V. (Eds). Proceedings of the First Eastern and Southern Africa Regional Legumes (Pigeonpea) workshop, 25-27 Jun 1990, Nairobi, Kenya. Eastern African Regional Cereals and Legumes (EARCAL) Program, ICRISAT.

Mbwaga, A.M. 1998. Grain legume pathology in Tanzania, 1987/88 cropping season. Pages 66-68 *in* National Grain Legume Progress Report. Arusha, Tanzania: Ministry of Agriculture.

Mcpherson, H.G., Warrington, I.J. and Turnbull, H.L. 1985. The effects of temperature and daylength on the rate of development of pigeonpea. Annals of Botany 56, 597-611.

Mead, R., Curnow, R.N., and Hasted, A.M. 2002. Statistical Methods in Agriculture and Experimental Biology. 3rd Edition. Chapman and Hall/CRC. pp. 406-418.

Mengesha, M.H. 1984. International germplasm collection, conservation and exchange at ICRISAT. Crop Science of America, 677 South Segoe Road, Madison, WI. 53711.

Minja, E.M. 1997. Insect pests of pigeonpea in Kenya, Malawi, Tanzania and Uganda; and grain yield losses in Kenya – A consultant's report. In Improvement of pigeonpea in Eastern Africa. Submitted to the African Dev. Bank. ICRISAT, SEA, Bulawayo, Zimbabwe.

Mligo, J.K. and Myaka, F.A. 1994. Progress on pigeonpea research in Tanzania. Pages 51-58 *In* Silim, S.N., King, S.B. and Tuwafe, S. (Eds). Improvement of Pigeonpea in eastern and southern Africa. Annual Research Planning Meeting 21-23 Sept. 1994, Nairobi, Kenya. ICRISAT.

Mligo, J. 1995. Pigeonpea breeding research in Tanzania. *In* Silim, S.N., King, S.B. and Tuwafe, S. (Eds). Improvement of Pigeonpea in eastern and southern Africa. Annual Research Planning Meeting 21-23 Sept. 1994, Nairobi, Kenya. ICRISAT.

Mohammadi, S.A. and Prasanna, B.M. 2003. Analysis of genetic diversity in crop plants-Salient statistical tools and considerations. Crop Science 43: 1235-1248.

Morton, J.F. 1976. The Pigeonpea (*Cajanus cajan Millsp.*), a high protein tropical bush legume. HortScience 11(1), 11-19.

Morton, J.F., Smith, R.E., Lugo-Lopez, M.A. and Abrams, R. 1982. Pigeonpeas (Cajanus cajan Millsp.): A Valuable Crop of the Tropics. Special Publication of the College of Agricultural Sciences, Department of Agronomy and Soils, University of Puereto Rico, Mayaguez, Pureto Rico, 123 pp.

Mphuru, A.N. 1978. Occurrence, host plants and relative importance of *Callosobruchus* species in Tanzania. Report of surveys, Tanzania.

Mukewar, A.M. and Muley, B.P. 1974. Correlation studies of some yield components in *fur* (Cajanus cajan (L.) Millsp) (Abstract 771). In: Dahiya, B.S. 1980. An annotated bibliography of pigeonpea 1900-1977. Patancheru, India. ICRISAT.

Murthi, A.N. and van der Maesen, L.J.G. 1979. Leaf variants in pigeonpea (Cajanus cajan (L.) Millsp.). Tropical Agriculture (Trinidad) 56, 81-83.

Nene, Y.L. and Sheila, V.K. 1990. Pigeonpea: Geography and Importance. Pages 1-14 *In* Nene, Y.L., Hall, S.D. and Sheila, V.K (eds). The Pigeonpea. Wallingford, UK: CAB International.

Nene, Y.L. 1991. Pigeonpea Research: Future Strategies in Africa. Pages 1-4 *In* Singh, L., Silim S.N., Ariyanayagam, R.P., and Reddy, M.V. (Eds). Proceedings of the First Eastern and Southern Africa Regional Legumes (Pigeonpea) workshop, 25-27 Jun 1990, Nairobi, Kenya. Eastern African Regional Cereals and Legumes (EARCAL) Program, ICRISAT.

Nevado M and Ortiz R (1985) Pruebas de hipotesis en series de ensyos, Agrociencia 1:22-37.

Ntundu, W.H. 2002. Genetic diversity of bambara groundnut (Vigna subterranean (L.) Verdc) in Tanzania. PhD thesis, The Royal Veterinary and Agricultural University Copenhagen, Denmark. 149 pp.

Odeny, D.A. 2001. Inheritance of resistance to fusarium wilt in pigeonpea. Pages 43-47 *In* Status and potential of pigeonpea in eastern and southern Africa. Proceedings of a Regional Workshop. Nairobi, Kenya, 12-15 Sep 2000. ICRISAT, Patancheru, India.

Ogunbodede, B.A. 1997. Multivariate analysis of genetic diversity in Kenaf, *Hibiscus cannabinus* (L.). African Crop Science Journal, Vol. 5. No. 2, pp. 127-133.

Okeyo-Owour, J.B. 1978. Insect pod borers of pigeonpea, Cajanus cajan (L.) Millsp., and their influence on developing pods and final seed yield in Kenya. MSc. Thesis, University of Nairobi, Kenya. 150 pp.

Omanga, P.A., Silim, S.N., Singh, L. And Kimani, P.M. 1995. From multi-location testing and on-farm trials to growing pigeonpea on farmers' fields. Pages 23-29 *In* Silim, S.N., King, S.B. and Tuwafe, S. (Eds). Improvement of pigeonpea in Eastern and Southern Africa. Annual Research Planning Meeting, 21-23 Sept. 1994, Nairobi, Kenya. ICRISAT.

Ong, C.K. and Monteith, J.L. 1985. Response of pearl millet to light and temperature. Field Crops Research 11: 141-160.

Onim, J.F.M. and Rubaihayo, P.R. 1976. Screening pigeonpea for resistance to *Mycovellosiellsa cajani. SABRAO Journal* 8, 121-125.

Onim, J.F.M. 1980. Foliar fungicides for the control of *Mycovellosiella cajani* causing the leaf spot of pigeonpea. Indian Journal of Agricultural Sciences 50, 615-619.

Onim, J.F.M. 1981. Pigeonpea improvement in Kenya. Pages 427-436 *In* Proceedings of the International Workshop on Pigeonpea, 15-19 Dec 1980, ICRISAT Centre, India. Vol. 1. Patancheru , A.P. 602 324, India: ICRISAT.

Ortiz, R. 1997. Morphological variation in Musa germplasm. Genetic Resources and Crop Evolution 44:393-404.

Ortiz, R. and Sevilla, R. 1997. Quantitative descriptors for classification and characterization of highland Peruvian maize. Plant Genetic Resources Newsletter, 1997, No. 110:49-52.

Ortiz, R., Madsen, S. and Vuylsteke, D. 1998. Classification of African plantain landraces and banana cultivars using a phenotypic distance index of quantitative descriptors. Theoretical and Applied Genetics 96: 904-911.

Ortiz, R. 1999. Genetic diversity of cultivated crops and *In Situ* conservation of genetic resources. Botanica Lithuanica, 1999. Suppl.. 2:15-30.

Ortiz, R. 2000. The state of the use of potato genetic diversity. Pages 181-200 *In* Cooper, H.D., Spillane, C. and Hodgkin, T. (eds). Broadening the general bases of crop production. Food and Agriculture Organization of the United Nations. IPGRI, Rome, Italy. CAB International.

Pandey, R.K. and Singh, V.B. 1981. Influence of source and sink on flower drop and seed yield of pigeonpea. Indian Journal of Agricultural Sciences 51, 185-188.

Pathak, G.N. 1970. Red gram. In: Pulse Crops of India. Indian Council of Agricultural Research, New Delhi, India, pp. 14-53.

Raju, D.R.G. and Chandra, H.C.S. 1972. Studies on variability in tur. Andhra Agri. J. 19(9-6): 155-156.

Rao, M.R. and Willey, R.W. 1981. Stability of performance of a pigeonpea/sorghum intercrop system. Pages 306-317 *In* Proceedings of the International Workshop on Intercropping, 10-13 January 1979, ICRISAT Centre, India. Patancheru, A.P. India: ICRISAT.

Rao, N.K. and Bramel, P.J. 2000. Manual of Genebank operations and procedures. Technical manual No. 6. ICRISAT, A.P. 502 324, India. International Crops Research Institute for Semi-Arid Tropics.

Reddy, L.J. 1990. Pigeonpea: Morphology. Pages 47-87 *in* Nene. Y.L., Hall, S.D. and Sheila, V.K. (eds.). The Pigeonpea. Wallingford, UK: CAB International.

Reddy, M.V. 1991. Disease Problems of Pigeonpea in Eastern Africa. Pages 60-64 *In* Singh, L., Silim S.N., Ariyanayagam, R.P., and Reddy, M.V. (Eds). Proceedings of the First Eastern and Southern Africa Regional Legumes (Pigeonpea) workshop, 25-27 Jun 1990, Nairobi, Kenya (Eastern African Regional Cereals and Legumes (EARCAL) Program, ICRISAT.

Reddy, M.V., and Raju, T.N. 1993. Pathogenic variability in pigeonpea wilt pathogen Fusarium udum. Pages 32-34 *In* Muralidharan, K., and Reddy, C.S. (eds). Plant disease problems in central India: Proceedings of the symposium, Central zone. Hyderabad, India: Indian Phytopathological Society and Directorate of Rice Research.

Reddy, N., Rao, K. and Ahmed, I. 2004. Geographical patterns of diversity in pearl millet germplasm from Yemen. Genetic Resources and Crop Evolution 51:513-517.

Reed, W., Lateef, S.S., and Sithanatham, S. 1980. Pest management in low input pigeonpea. Pages 99-105 *in* Proceedings of the International workshop on Pigeonpea, vol. 1, 15-19 Dec 1980, ICRISAT, Hyderabad, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Reed, W. and Lateef, S.S. 1990. Pigeonpea: Pest Management. Pages 349-374 *In* Nene. Y.L., Hall, S.D. and Sheila, V.K., (eds). The Pigeonpea. Wallingford, UK: CAB International.

Remanandan, R.P., Sastry, D.V.S.S.R., and Mengesha, M.H. 1988. ICRISAT Pigeonpea Germplasm Catalog. Evaluation and Analysis. Patancheru, A.P., India: ICRISAT, 90 pp.

Remanandan, P. 1990. Pigeonpea: Genetic Resources. Pages 89-115 *In* Nene. Y.L., Hall, S.D. and Sheila, V.K. (eds). The Pigeonpea. Wallingford, UK: CAB International.

Remanandan, P., Omanga, P.G.A., Shakoor, A., Mengesha, M.H., and Sastry, D.V.S.S.R. 1991. Regional Pigeonpea Germplasm Evaluation in Kenya. Pages 45-52 *In* Proceedings of the First Eastern and Southern Africa Regional Legumes (Pigeonpea) workshop, 25-27 Jun 1990, Nairobi,

Rick C.M. and Holle, M. 1990. Andean Lycopersicon esculentum var. cerasiformie. Genetic variation and its evolutionary significance. Econ. Bot. 44:69-78.

Rojas, W., Barriga, P., Figueroa, H. 2000. Multivariate analysis of the genetic diversity of Bolivian quinoa germplasm. Plant Genetic Resources Newsletter, No. 122: 16-23.

Rubaihayo, P.R. and Onim, J.F.M. 1975. A study of some characters of pigeonpea. Sabrao J. 7(2): 183-187.

Saxena, K.B. and Sharma, D. 1990. Pigeonpea: Genetics. Pages 137-157 *In* Nene. Y.L., Hall, S.D. and Sheila, V.K., (eds). The Pigeonpea. Wallingford, UK: CAB International.

Sehgal, C.B. and Gandhi, V. (1986). Histology and histochemistry of pericarp of grain legumes: *Cajanus cajan, Vigna mungo* and *Vigna radiaae*. Cytologia 51, 333-339.

Sen, A.N. 1956. Nitrogen economy of soil under rabar (Cajanus cajan). Journal of Indian Society of Soil science 6, 171-176.

Sharma, D., Reddy, L.J., Green, J.M. and Jain, K.C. 1981. Iinternational adaptation of pigeonpeas. Pages 71-81 *In* Proceedings of the International Workshop on Pigeonpeas, vol 1, 15-19 Dec 1980, ICRISAT Centre, India. Patancheru, A.P., India: ICRISAT.

Sharma, D., Reddy, L.J., Green, J.M. and Jain, K.C. 1981. International adaptation of pigeonpeas. Pages 71-81 *In* Proceedings of the International Workshop on Pigeonpeas, volume 1, 15-19 December 1980, ICRISAT, Centre, India. Patancheru, A.P. India: ICRISAT.

Sharma, H.K. 1981. Genetic analysis of plant height in pigeonpea. Pages 55-59 *In* Proceedings of the International Workshop on Pigeonpea, volume 2, 15-19 December 1980, ICRISAT Centre, India. Patancheru, A.P. India: ICRISAT.

Sheldrake, A.R. and Narayanan, A. 1979. Growth, development and nutrient uptake in pigeonpeas (*Cajanus cajan*). Journal of Agricultural Science, Cambridge 92, 513-526.

Shiferaw, B., Silim, S.N., Muricho, G., Audi, P., Mligo, J., Lyimo, S., Liangzhi, Y. and Christiansen, J.L. 2005. Assessment of the adoption and impact of improved pigeonpea varieties in Tanzania. Working paper series no. 21. Patacheru 502 324, A.P. India. ICRISAT.

Silim, S.N., Omanga, P.A., Johansen, C., Singh, L. and Kimani, P.M. 1995. Use of the Kenya transect for selecting and targeting adapted cultivars to appropriate production systems. Pages 44-54 *In* Silim, S.N., King, S.B., and Tuwafe, S. (eds). Proceedings of Improvement of pigeonpea in Eastern and Southern Africa-Annual Research Planning Meeting 1994, 21-23 Sep 1994, Nairobi, Kenya. Patancheru 502 324, A.P., India. ICRISAT. 220 pp. ISBN 92-9066-316-2.

Silim, S.N. and Omanga, P.A. 2001. The response of short duration pigeonpea lines to variation in temperature under field conditions in Kenya. Field Crops Research 72: 97-108.

Silim, S.N., Bramel, P.J., Akonaay, H.B., Mligo, J.K. and Christiansen, J.L. 2005. Cropping systems, uses, and primary *in situ* characterization of Tanzanian pigeonpea (Cajanus cajan (L) Millsp.) landraces. Genetic Resources and Crop Evolution 52: 645-654.

Silim, S.N., Coe, R., Omanga, P.A. and Gwata, E.T. 2006. The response of pigeonpea genotypes of different types to variation in temperature and photoperiod under field conditions in Kenya. Journal of Food, Agriculture and Environment, Vol. 4 (1): 209-214.

Silim-Nahdy, M., and M. 1994. Pigeonpea storage pests in Uganda and sun-drying for disinfection. Pages 74-80 *In* Silim, S.N., King, S.B., and Tuwafe, S. (eds.). Proceedings of Improvement of pigeonpea in Eastern and Southern Africa-Annual Research Planning Meeting 1994, 21-23 Sep 1994, Nairobi, Kenya. Patancheru 502 324, A.P., India. ICRISAT.

Silim-Nahdy, M. 1995. Non-chemical methods of pigeonpea storage pest management. Pages 90-94 *In* Silim, S.N., King, S.B., and Tuwafe, S. (eds.). Proceedings of Improvement of pigeonpea in Eastern and Southern Africa-Annual Research Planning Meeting 1994, 21-23 Sep 1994, Nairobi, Kenya. Patancheru 502 324, A.P., India. ICRISAT.

Silim,-Nahdy, M., Silim, S.N., and Ellis, R.H. 1999. Some aspects of pod characteristics predisposing pigeonpea (Cajanus cajan (L.) Millsp.) to infestation by *Callosobruchus chinensis* (L.). Journal of stored products research, 35:47-55.

Singh, L. 1991. Overview of Pigeonpea Improvement Research: Objectives, Achievements and Looking Ahead in the African Context. Pages 5-16 *In* Singh, L., Silim S.N., Ariyanayagam, R.P., and Reddy, M.V. (eds.) Proceedings of the First Eastern and Southern Africa Regional Legumes (Pigeonpea) workshop, 25-27 Jun 1990, Nairobi, Kenya. Eastern African Regional Cereals and Legumes (EARCAL) Program, ICRISAT.

Sinha, S.K. 1981. Water availability and grain yield in pigeonpea. Pages 283-288 *In* Proceedings of the International Workshop on Pigeonpeas, vol. 1, 15-19 Dec 1980, ICRISAT Centre, India. Patancheru, A.P., India: ICRISAT.

Sivakumar, M.V.K. and Virmani, S.M. 1980. Growth and resource use of maize, pigeonpea and maize/pigeonpea intercrop in an operational research watershed. Experimental Agriculture 16, 377-386.

Smith, S.E., Al-Dos, and Warburton, M. 1991. Morphological and agronomic variation in North African and Arabian alfalfas. Crop Science 31:1159-1163.

Songa, W., and King, S.B. 1994. Pigeonpea pathology research in Kenya. Pages 45-50 94 *In* Silim, S.N., Tuwafe, S., and Laxman Singh, (eds). Pigeonpea improvement in Eastern and Southern Africa: Annual Research Planning Meeting 1993, 25-27 Oct 1993, Bulawayo, Zimbabwe. Patancheru 502 324, Andhra Pradesh, India: ICRISAT.

Songa, W.A., King, S.B. and Omanga, P.A. 1995. Pigeonpea pathology research in Kenya. Pages 30-37 *In* Silim, S.N., King, S.B., and Tuwafe, S. (eds.). Pigeonpea improvement in Eastern and

Southern Africa: Annual Research Planning Meeting 1994, 21-23 Sep 1994, Nairobi, Kenya. Patancheru 502 324, A.P., India. ICRISAT. 220 pp.

Spark, D.N. 1973. Euclidean cluster analysis. Algorithm As. 58. Applied Statistics 22:126-130.

Summerfield, R.J. and Roberts, E.H. 1985. *Cajanus cajan*. Pages 83-91 *In* Halevy, A.H. (eds), CRC Handbook of Flowering, vol 1. CRC Press Inc., Boca Raton, Florida.

Thirathon, A., Byth, D.E., Fischer, K.S. and Whiteman, P.C. 1987. Effect on sink development of changes in assimilate supply during different growth stages of short-season pigeonpea. Page 252 *In* Wallis, E.S. and Byth, D.E. (eds.), Food Legume Improvement for Asian Farming Systems: Proceedings of an International Workshop held in Khon Kaen, Thailand, 1-5 Sept 1986. ACIAR Proceedings no. 18. ACIAR, Canberra.

Thomas, T.A. and Mathur, P.N. 1991. Germplasm evaluation and utilization *In* Paroda, R.S. and Arora .R.K. (eds). Plant Genetic Resources Conservation and Management Concepts and Approaches.. International Board for Plant Genetic Resources Regional Office for South and Southeast Asia New Delhi.

Thompson, J.A., Kamar Rao, J.V.D.K and Dart, P.J. 1981. Measurement of inoculation response in pigeonpea. Pages 249-253 *In* Proceedings of the International Workshop on Pigeonpea , vol. 1, 15-19 Dec 1980, ICRISAT Centre, India. Patancheru, A.P., India: ICRISAT.

Truedson, R.J. 1987. Effect of plant density on pigeonpea (Cajanus cajan (L.) Millsp.) in sub-humid environments. Page 222 *In* Proceedings of the Fourth Australian Agronomy Conference. Australian Society of Agronomy, Melbourne.

Troedson, R.J., Wallis, E.S. and Singh, L. 1990. Pigeonpea Adaptation. Pages 159-177 *In* Nene, Y.L., Hall, S.D. and Sheila, V.K., (eds.). The Pigeonpea. Wallingford, UK: CAB International.

Turnbull, L.V. 1986. The role of photoperiod and temperature in early vegetative growth and floral development in selected lines of pigeonpea (Cajanus cajan (L.) Millsp.). PhD thesis, University of Queensland, Australia, 309 pp.

Upadhyaya, H.D. and Ortiz, R. 2001. A mini core subset for capturing diversity and promoting utilization of chickpea genetic resources in crop improvement. PhD Course on Data analysis in biodiversity. Course literature, 15 Jan – 2 Feb 2001. The Royal Veterinary and Agriculture University (KVL), Department of Agric. Sciences, Frederiksberg, Copenhagen, Denmark.

Upadhyaya, H.D., Pundir, R.P.S., Gowda, C.L.L., Reddy, K.N. and Singh, S. 2005. Geographical patterns of diversity for qualitative and quantitative traits in the pigeonpea germplasm collection. Plant Genetic Resources 3(3); 331-352.

van de Maesen, L.J.G. 1986. *Cajanus DC. And Atylosia W. & a. (Leguminosae). Agricultural University Wageningen Papers 85-4 (1995).* Agricultural University, Wageningen, the Netherlands, 225 pp.

van de Maesen, L.J.G. 1990. Pigeonpea: Origin, History, Evolution and Taxonomy. Pages 15-46 *In* Nene. Y.L., Hall, S.D. and Sheila, V.K., (eds.). The Pigeonpea. Wallingford, UK: CAB International.

Whiteman, P.C., Byth, D.E. and Wallis, E.S. 1985. Pigeonpea (*Cajanus cajan* (L.) millsp.). Pages 658-698 *In* Summerfield, R.J. and Roberts, E.H. (eds.), Grain Legume Crops. Collins Professional and Technical Books, London.

Williams, I.H. 1977. Behavior of insects foraging on pigeonpea (*Cajanus cajan* (L.) Millsp.) in India. Tropical Agriculture (Trinidad) 54, 353-363.

Yang, R.C. Jana, S. and Clarke, J.M. 1991. Phenotypic diversity and association of some potentially drought responsive characters in durum wheat. Crop Science 31:1484-1491.

Appendices

Appendix 1. Accessions, collection sites and GPS information

Accession Number	Region	State	District	Village	Precise location	Altitude (M)	Latitude Deg	Latitude min	Latitude sec	Longitude Deg	Longitude min	Longitude sec
ACCESSION NO. 1	COAST	Dar es salaam	Temeke	Somangila	Kizitohuonjwa	29	6	59	44	39	32	
ACCESSION NO. 2	COAST	Dar es salaam	Temeke	Somangila	Kizitohuonjwa	19	6	59	38	39	32	
ACCESSION NO. 3	COAST	Dar es salaam	Temeke	Somangila	Mwongozo	23	6	53	7	39	25	7
ACCESSION NO. 4	COAST	Dar es salaam	Temeke	Somangila	Geza	11	6	52	6	39	24	8
ACCESSION NO. 5	COAST	Dar es salaam	Temeke	Somangila	Geza	13	6	52	5	39	24	9
ACCESSION NO. 6	COAST	Dar es salaam	Temeke	Mji mwema	Mji mwema	13	6	51	8	39	21	6
ACCESSION NO. 7	COAST	Dar es salaam	Temeke	Kibanda	Mizibini	10	6	52	9	39	20	52
ACCESSION NO. 8	COAST	Dar es salaam	Temeke		Mikwambe	35	6	54	59	39	20	33
ACCESSION NO. 9	COAST	Dar es salaam		Kiluvya	Kiluvya B	115	6	47	5	39	1	2
ACCESSION NO. 10	COAST	Coast	Kibaha	Mchandege	Twende pamoja	137	6	49	9	38	57	4
ACCESSION NO. 11	COAST	Coast	Kibaha		Tanita	155	6	45	2	38	55	2
ACCESSION NO. 12	COAST	Coast	Kibaha	Mwenda pole	Myembe saba	150	6	44	38	38	53	4
ACCESSION NO. 13	COAST	Coast	Kibaha	Vesiga	Vesiga	95	6	43	45	38	48	2
ACCESSION NO. 14	COAST	Coast	Bwagamoyo	Vigwaza	Vigwaza	58	6	40	6	38	52	7
ACCESSION NO. 15	COAST	Coast	Bwagamoyo	Vigwaza	Vigwaza	55	6	40	9	38	37	1
ACCESSION NO. 16	COAST	Coast	Bwagamoyo	Chalinze	pingo	174	6	38	7	38	24	6
ACCESSION NO. 17	COAST	Coast	Bwagamoyo	Chalinze	Msolwa	230	6	37	6	38	16	4
ACCESSION NO. 18	COAST	Coast	Bwagamoyo	Ubena	Ubena Zomozi	262	6	38	3	38	11	8
ACCESSION NO. 19	COAST	Coast	Morogoro Urban	Mazimbo	Mindu	517	6	52	3	37	36	1
ACCESSION NO. 20	EASTERN	Morogoro	Morogoro Rural	Mlali	Manza	661	7	0	56	37	31	22
ACCESSION NO. 21	EASTERN	Morogoro	Morogoro Rural	Mlali	Manza	661	7	0	6	37	31	21
ACCESSION NO. 22	EASTERN	Morogoro	Morogoro Rural	Melela	Kibaani	518	6	54	6	37	27	2
ACCESSION NO. 23	EASTERN	Morogoro	Morogoro Rural	Doma	Maharaka	576	7	9	95	37	17	45
ACCESSION NO. 24	EASTERN	Morogoro	Morogoro Rural	Doma	Doma	555	7	7	3	37	15	9
ACCESSION NO. 25	EASTERN	Morogoro	Morogoro Rural	Mikesi	Mikesi Mjini	396	6	45	5	37	54	5
ACCESSION NO. 26	EASTERN	Morogoro	Morogoro Rural	Mikesi	Gwatamgembe	323	6	38	4	38	0	5
ACCESSION NO. 27	EASTERN	Morogoro	Morogoro Rural	Mikesi	Gwatamgembe	323	6	38	4	38	0	5
ACCESSION NO. 28	EASTERN	Morogoro	Bwagamoyo	Lugomba	Makombe	320	6	25	3	38	18	46
ACCESSION NO. 29	COAST	Coast	Bwagamoyo	Msata	Mbata	291	6	19	9	38	22	1
ACCESSION NO. 30	COAST	Coast	Bwagamoyo	Miono	Mandera	194	6	13	1	38	24	1
ACCESSION NO. 31	COAST	Coast	Handeni	Kong Kong	Mumbwe	328	5	33	1	38	25	0
ACCESSION NO. 32	COAST	Coast	Handeni	Mkata	Kwekale	421	5	43	1	38	20	2
ACCESSION NO. 33	EASTERN	Tanga	Handeni	Mazingara	Mazingara	431	5	45	0	38	15	8
ACCESSION NO. 34	EASTERN	Tanga	Handeni	Mazingara	Mazingara	431	5	45	0	38	15	8
ACCESSION NO. 35	EASTERN	Tanga	Handeni	Kwakoje	Kwachaga	581	5	38	92	38	9	64
ACCESSION NO. 36	EASTERN	Tanga	Handeni	Kwa Msisi	Pozo	292	5	51	5	38	30	20
ACCESSION NO. 37	EASTERN	Tanga	Handeni	Kwa Msisi	Pozo	292	5	51	5	38	30	2
ACCESSION NO. 38	EASTERN	Tanga	Handeni	Mkata	Manga Mapenduzi	362	5	55	8	38	14	7
ACCESSION NO. 39	SOUTHERN	Mtwara	Mtwara Rural	Nangurue	Nangurue	171	10	28	96	40	1	83

Accession Number	Region	State	District	Village	Precise location	Altitude (M)	Latitude			Longitude		
							Deg	min	sec	Deg	min	sec
ACCESSION NO. 40	SOUTHERN	Mtwara	Newala	Makote	Mahumbika	587	10	54	64	39	20	74
ACCESSION NO. 41	SOUTHERN	Mtwara	Newala	Luchingu	Lekanelo	638	10	55	92	39	18	71
ACCESSION NO. 42	SOUTHERN	Mtwara	Newala	Luchingu	Chitadi	597	10	56	56	39	14	42
ACCESSION NO. 43	SOUTHERN	Mtwara	Newala	Luchingu	Chitadi	597	10	56	56	39	14	42
ACCESSION NO. 44	SOUTHERN	Mtwara	Newala	Mnekachi	Nambunga	773	10	52	45	39	14	27
ACCESSION NO. 45	SOUTHERN	Mtwara	Newala	Mnekachi	Nambunga	785	10	52	85	39	14	22
ACCESSION NO. 46	SOUTHERN	Mtwara	Masasi	Namalenga	Chikundi Msanga	522	10	53	52	39	11	89
ACCESSION NO. 47	SOUTHERN	Mtwara	Masasi	Namalenga	Nkangaula	347	10	54	59	39	7	69
ACCESSION NO. 48	SOUTHERN	Mtwara	Masasi	Chungutwa	Chungutwa	261	10	53	67	38	59	53
ACCESSION NO. 49	SOUTHERN	Mtwara	Masasi	Chungutwa	Chungutwa	273	10	53	69	38	59	44
ACCESSION NO. 50	SOUTHERN	Mtwara	Masasi	Lisekese	Songambele	399	10	46	44	38	45	13
ACCESSION NO. 51	SOUTHERN	Mtwara	Masasi	Makulani	Mkarakati	407	10	48	23	38	42	28
ACCESSION NO. 52	SOUTHERN	Mtwara	Masasi	Mikangaula	Nahimba	305	10	52	59	38	35	37
ACCESSION NO. 53	SOUTHERN	Mtwara	Masasi	Nagomba	Nagomba	285	10	54	9	38	31	51
ACCESSION NO. 54	SOUTHERN	Mtwara	Masasi	Nagomba	Nagomba	285	10	54	9	38	31	51
ACCESSION NO. 55	SOUTHERN	Mtwara	Masasi	Lisekese	Mogogongo	404	10	42	29	38	47	61
ACCESSION NO. 56	SOUTHERN	Mtwara	Masasi	Sekesa	Temeke	386	10	40	4	38	48	21
ACCESSION NO. 57	SOUTHERN	Mtwara	Masasi	Lukuledi	Lukuledi	320	10	34	67	38	48	61
ACCESSION NO. 58	SOUTHERN	Lindi	Nachingwea	Naipanga	Nkongwe	359	10	31	5	38	48	99
ACCESSION NO. 59	SOUTHERN	Lindi	Nachingwea			382	10	25	63	38	48	48
ACCESSION NO. 60	SOUTHERN	Lindi	Nachingwea	Nambambo Mjini	Tunduru ya leo	396	10	23	1	38	45	58
ACCESSION NO. 61	SOUTHERN	Lindi	Nachingwea	Nangoematangini	Nangoe	434	10	19	89	38	44	71
ACCESSION NO. 62	SOUTHERN	Lindi	Nachingwea	Luponda	Namanga	519	10	16	81	38	43	9
ACCESSION NO. 63	SOUTHERN	Lindi	Nachingwea	Luponda	Nadanga	446	10	14	33	38	40	78
ACCESSION NO. 64	SOUTHERN	Lindi	Nachingwea	Luponda	Nadanga	440	10	14	60	38	41	5
ACCESSION NO. 65	SOUTHERN	Lindi	Nachingwea	Mneromyembeni	Myembeni	388	10	13	69	38	38	74
ACCESSION NO. 66	SOUTHERN	Lindi	Nachingwea	Mnero	Mpute	356	10	12	34	38	35	79
ACCESSION NO. 67	SOUTHERN	Lindi	Nachingwea	Mnero	Mpute	356	10	12	34	38	35	79
ACCESSION NO. 68	SOUTHERN	Lindi	Nachingwea	Namikango	Namikango	336	10	11	72	38	33	79
ACCESSION NO. 69	SOUTHERN	Lindi	Nachingwea	Namikango	Namikango	336	10	11	72	38	33	79
ACCESSION NO. 70	SOUTHERN	Lindi	Nachingwea	Liupota	Libeya	458	10	17	95	38	45	32
ACCESSION NO. 71	SOUTHERN	Lindi	Nachingwea	Liupota	Libeya	458	10	17	95	38	45	32
ACCESSION NO. 72	SOUTHERN	Lindi	Nachingwea	Liupota	Libeya	458	10	17	95	38	45	32
ACCESSION NO. 73	SOUTHERN	Lindi	Nachingwea	Malambo	Litura	405	10	12	45	38	46	88
ACCESSION NO. 74	SOUTHERN	Lindi	Ruangwa	Makanjiro	Makanjiro	324	10	7	31	38	52	3
ACCESSION NO. 75	SOUTHERN	Lindi	Ruangwa	Mbekenyela	Nachulanga	374	10	1	11	38	56	78
ACCESSION NO. 76	SOUTHERN	Lindi	Ruangwa	Namichiga	Namichiga	317	9	54	47	39	0	93
ACCESSION NO. 77	SOUTHERN	Lindi		Mandawa	Mandawa Shambani	361	9	55	61	39	7	83
ACCESSION NO. 78	SOUTHERN	Lindi	Lindi Rural	Milola	Milola Magharibi	343	9	56	42	39	18	95
ACCESSION NO. 79	SOUTHERN	Lindi	Lindi Rural	Kinyope	Kinyope	216	9	58	89	39	23	70
ACCESSION NO. 80	SOUTHERN	Lindi	Lindi Rural	Lutamba	Lutamba	168	10	2	78	39	28	9
ACCESSION NO. 81	SOUTHERN	Lindi	Lindi Town	Rasibura	Mongo	79	9	56	5	39	43	49
ACCESSION NO. 82	SOUTHERN	Lindi	Lindi Rural	Mbaja	Masasi ya Leo	92	9	50	48	39	43	88

	Region	State	District	Village	Precise location	Altitude (M)	Latitude			Longitude		
Accession Number							Deg	min	sec	Deg	min	sec
ACCESSION NO. 83	SOUTHERN	Lindi	Lindi Rural	Mbaja	Mtomkavu	60	9	47	4	39	43	67
ACCESSION NO. 84	SOUTHERN	Lindi	Lindi Rural	Mchinga	Mihambwe	26	9	43	87	39	38	6
ACCESSION NO. 85	SOUTHERN	Lindi	Lindi Rural	Mchinga	Mikalawaje	65	9	44	4	39	36	18
ACCESSION NO. 86	SOUTHERN	Lindi	Lindi Rural	Mchinga	Nangumbu	88	9	41	99	39	33	51
ACCESSION NO. 87	SOUTHERN	Lindi	Lindi Rural	Kitomanga	Mtipule	136	9	39	56	39	32	26
ACCESSION NO. 88	SOUTHERN	Lindi	Kilwa	Mandawa	Mandawa	156	9	23	77	39	26	2
ACCESSION NO. 89	SOUTHERN	Lindi	Kilwa	Kilajilanji	Mtandi	103	9	29	28	38	28	15
ACCESSION NO. 90	SOUTHERN	Lindi	Kilwa	Rasbula	Rasbula	43	9	57	61	39	42	50
ACCESSION NO. 91	SOUTHERN	Lindi	Lindi Town	Jamhuri Lindi	Gurumahambe	47	10	0	87	39	38	75
ACCESSION NO. 92	SOUTHERN	Lindi	Lindi Town	Jamhuri Lindi	Gurumahambe	47	10	0	87	39	38	75
ACCESSION NO. 93	SOUTHERN	Lindi	Lindi Rural	Sudi	Njonjo	156	10	12	67	39	50	68
ACCESSION NO. 94	NORTHERN	Arusha	Babati	Singe	Singe	1390	4	15	39	35	45	16
ACCESSION NO. 95	NORTHERN	Arusha	Babati	Singe	Singe	1430	4	16	2	35	46	13
ACCESSION NO. 96	NORTHERN	Arusha	Babati	Singe	Himiti	1387	4	18	58	35	44	74
ACCESSION NO. 97	NORTHERN	Arusha	Babati	Singe	Himiti	1387	4	18	58	35	44	74
ACCESSION NO. 98	NORTHERN	Arusha	Babati	Mamire	Mamire	1252	4	9	47	35	50	67
ACCESSION NO. 99	NORTHERN	Arusha	Babati	Mamire	Mwekani	1213	4	7	20	35	51	23
ACCESSION NO. 100	NORTHERN	Arusha	Babati	Mamire	Mwekanse	1199	4	8	13	35	52	35
ACCESSION NO. 101	NORTHERN	Arusha	Babati	Gidas	Bayai	1641	4	23	14	35	45	86
ACCESSION NO. 102	NORTHERN	Arusha	Kondoa	Bereko	puki	1548	4	26	18	35	44	81
ACCESSION NO. 103	NORTHERN	Dodoma	Kondoa	Bereko	Massawi	1553	4	31	48	35	45	13
ACCESSION NO. 104	NORTHERN	Dodoma	Kondoa	Sowera	Humai	1580	4	39	16	35	47	65
ACCESSION NO. 105	NORTHERN	Dodoma	Kondoa	Kolo	Bolisa	1455	4	50	10	35	48	53
ACCESSION NO. 106	NORTHERN	Dodoma	Kondoa	Kolo	Chawinwi	1457	4	50	40	35	48	53
ACCESSION NO. 107	NORTHERN	Dodoma	Kondoa	Kalamba	Baura	1688	4	48	25	35	53	47
ACCESSION NO. 108	NORTHERN	Dodoma	Kondoa	Kalamba	Baura	1688	4	48	26	35	53	47
ACCESSION NO. 109	NORTHERN	Dodoma	Babati	Hauhi	Haubi	1677	4	48	25	35	56	93
ACCESSION NO. 110	NORTHERN	Dodoma	Kondoa	Haubi	Haubi	1667	4	48	47	35	58	1
ACCESSION NO. 111	NORTHERN	Dodoma	Kondoa	Hauhi	Mercka	1682	4	47	7	35	57	40
ACCESSION NO. 112	NORTHERN	Dodoma	Kondoa	Hauhi	Mercka	1682	4	47	7	35	57	
ACCESSION NO. 113	NORTHERN	Dodoma	Kondoa	Kolo	Hembe	1480	4	44	54	35	50	10
ACCESSION NO. 114	NORTHERN	Arusha	Hanang	Endegaki	Endagao	1597	4	24	15	35	32	33
ACCESSION NO. 115	NORTHERN	Arusha	Hanang	Maskaroda	Maskaroda	1565	4	21	88	35	33	35
ACCESSION NO. 116	NORTHERN	Arusha	Babati	Daroda	Daroda Kati	1610	4	13	48	35	35	51
ACCESSION NO. 117	NORTHERN	Arusha	Babati	Sigino	Wangbai	5590	4	12	3	35	39	69
ACCESSION NO. 118	NORTHERN	Arusha	Babati	Babati Mjini	Maisaka	1315	4	11	68	35	45	8
ACCESSION NO. 119	NORTHERN	Arusha	Karatu	Endamararck	Basodawish	1416	3	26	17	35	40	60
ACCESSION NO. 120	NORTHERN	Arusha	Karatu	Endamararck	Endamararck	1413	3	28	77	35	39	64
ACCESSION NO. 121	NORTHERN	Arusha	Karatu	Endamararck	Endamararck	1401	3	29	72	35	40	7
ACCESSION NO. 122	NORTHERN	Arusha	Karatu	Endamararck	Getamok	1433	3	30	75	35	42	78
ACCESSION NO. 123	NORTHERN	Arusha	Karatu	Rhotia	Rhotia	1595	3	18	85	35	44	48

Appendix 2. Monthly rainfall and mean monthly temperatures during the cropping Seasons

a) Kabete

Month	Rainfall (mm)	Temperature (°C)	
		Mean Min	Mean Max
November	108.9	14.5	22.8
December	58.1	14.4	23.8
January	77.8	13.8	25.4
February	45.7	14.0	26.3
March	104.7	15.0	25.8
April	210.2	14.9	24.3
May	254.3	14.6	22.9
June	27.2	12.8	20.9
July	26.8	11.3	20.1
August	8.5	11.5	21.0
September	28.2	11.8	23.2
Seasonal total/ mean	**950.4**	**13.5**	**23.3**

b) Kampi ya Mawe

Month	Rainfall (mm)	Temperature (°C)	
		Mean Min	Mean Max
November	161.9	N/A	N/A
December	117.6	N/A	N/A
January	21.5	N/A	N/A
February	22.0	21.4	29.3
March	48.0	20.0	31.2
April	68.0	19.6	28.9
May	51.0	18.5	28.6
June	0.0	16.2	27.0
July	0.0	14.2	25.3
August	0.0	14.3	25.8
September	0.0	15.3	28.9
Seasonal total/ mean	**490.0**	**17.4**	**28.1**

c) Ilonga

Month	Rainfall (mm)	Temperature (°C)	
		Mean Min	Mean Max
February	61.8	21.6	31.1
March	328.3	21.9	31.0
April	327.3	21.3	28.3
May	30.2	19.2	28.7
June	0.0	16.0	27.4
July	1.2	17.4	27.9
August	15.0	18.4	28.2
September	31.1	19.4	29.3
October	40.4	20.2	31.2
Seasonal total/ mean	**835.3**	**19.5**	**29.2**

Appendix 3. Mean performance for 15 quantitative traits recorded on 123 Tanzanian pigeonpea accessions and 21 checks at Kabete, Kenya.

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	Primary branches	Secondary branches	Raceme number	Pod bearing length (cm)	pod length (cm)	Pod width (cm)	Pods/ plant	Pod yield ton/ha	Seeds/pod	Grain yield ton/ha	100 seed mass (g)	thresh%
1	109	147	142.0	12	11	151	64.9	9.2	1.2	139	1.822	6	0.799	12.4	43.4
2	98	151	104.4	10	14	118	52.9	8.1	1.1	156	3.318	6	1.840	14.1	55.2
3	107	149	91.2	10	21	141	50.9	8.6	1.2	262	4.075	6	2.091	14.0	50.4
4	90	149	95.1	9	10	120	47.7	8.3	1.1	129	2.435	6	1.358	13.8	54.6
5	99	151	97.3	11	12	127	45.0	9.7	1.2	166	3.708	6	2.100	14.0	56.6
6	93	148	92.4	9	13	147	44.1	9.0	1.2	155	3.451	6	2.099	13.2	61.4
7	92	151	110.4	7	12	115	51.0	8.6	1.1	134	3.368	6	1.984	15.8	58.7
8	88	151	97.8	8	14	239	56.5	8.7	1.1	133	2.786	6	1.529	13.4	54.6
9	94	150	117.5	10	9	273	54.8	7.5	1.1	162	0.885	6	0.526	13.6	55.9
10	95	148	115.7	11	16	122	48.1	9.0	1.2	138	3.242	6	1.846	15.0	57.0
11	85	156	110.3	10	18	181	55.1	8.9	1.0	163	3.699	6	2.073	15.1	55.9
12	89	157	96.8	9	22	134	45.6	9.1	1.1	135	0.981	6	0.632	14.8	64.0
13	94	160	136.3	9	12	162	75.0	8.9	1.1	181	1.336	6	0.828	15.1	62.0
14	96	150	100.8	7	21	114	47.2	9.9	1.1	140	3.557	6	2.025	15.2	57.4
15	138	147	203.9	13	14	369	72.5	9.2	1.2	152	3.935	6	1.972	12.1	50.0
16	107	142	183.1	8	21	214	57.6	8.3	1.2	173	2.371	6	1.732	16.2	61.5
17	92	150	85.0	7	12	70	38.3	8.7	1.1	104	1.984	6	1.175	14.3	60.1
18	93	151	103.2	9	14	128	45.4	8.5	1.0	134	2.530	6	1.634	15.2	64.5
19	99	149	113.6	7	17	81	53.2	9.1	1.1	145	3.483	6	2.104	14.3	60.4
20	107	148	137.5	11	16	125	63.6	8.5	1.1	168	4.138	6	2.463	17.2	59.4
21	97	160	126.6	12	19	154	57.0	8.8	1.2	214	5.252	6	3.145	15.3	59.8
22	94	151	107.9	9	11	101	53.2	9.0	1.2	152	3.572	6	2.194	15.9	61.5
23	102	152	125.8	10	13	171	53.3	7.8	1.1	203	4.830	6	2.693	13.9	55.7
24	122	148	153.3	15	21	198	66.5	10.6	1.1	192	4.412	6	2.417	15.5	54.5
25	101	164	113.2	12	28	95	47.6	9.1	1.1	278	2.673	5	1.693	19.5	64.0
26	101	151	113.6	11	13	104	53.2	10.5	1.2	149	4.156	6	2.531	18.3	61.0
27	95	151	108.9	10	12	136	55.4	8.1	1.1	161	1.638	6	1.042	14.1	63.4
28	95	149	95.1	8	13	91	45.5	9.2	1.1	130	2.467	5	1.421	15.3	57.5
29	96	155	109.7	10	12	104	51.9	8.9	1.0	149	1.964	6	1.187	18.1	60.3

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	Primary branches	Secondary branches	Raceme number	Pod bearing length (cm)	pod length (cm)	Pod width (cm)	Pods/ plant	Pod yield ton/ha	Seeds/pod	Grain yield ton/ha	100 seed mass (g)	thresh%
30	94	153	129.6	11	12	150	49.8	10.7	1.1	177	4.766	6	2.780	18.2	58.4
31	101	153	104.4	11	8	76	44.2	8.3	1.0	156	2.823	6	1.002	12.0	52.3
32	95	150	105.0	8	11	124	46.0	7.7	1.5	143	3.049	6	1.859	14.5	61.5
33	97	155	109.1	9	16	103	52.4	8.4	1.1	179	3.692	6	2.145	13.3	58.1
34	97	151	95.9	10	8	139	42.8	8.1	1.0	129	3.321	6	2.230	13.3	67.1
35	104	158	108.6	10	12	99	51.0	8.8	1.1	185	4.544	6	2.596	13.7	57.0
36	97	155	100.8	10	6	93	41.4	9.8	1.0	136	3.046	6	1.853	18.1	61.5
37	93	153	101.4	8	13	132	49.2	8.1	1.1	166	3.622	6	2.341	14.8	64.7
38	96	149	103.6	8	8	136	46.3	9.5	1.1	119	3.242	6	1.998	18.3	61.1
39	94	149	107.1	8	14	94	53.5	9.3	1.0	155	3.515	6	2.094	16.0	59.7
40	97	144	157.9	12	10	133	69.4	9.6	1.1	172	2.321	6	1.332	15.1	56.4
41	91	151	109.3	9	14	221	52.4	8.6	1.0	194	1.623	5	0.713	17.9	61.6
42	91	152	117.6	7	11	93	54.6	8.6	1.2	128	3.336	6	2.074	16.8	62.2
43	114	153	127.0	16	19	73	53.8	9.9	1.1	265	0.990	6	1.627	19.8	69.2
44	94	148	106.8	9	5	109	48.0	8.2	1.0	132	3.401	6	1.951	15.5	57.9
45	84	150	102.0	11	10	126	51.8	8.9	1.2	152	2.738	6	1.682	16.7	61.4
46	81	148	102.3	8	9	136	45.3	8.3	1.1	130	3.166	6	2.000	15.7	63.2
47	93	150	94.6	7	10	100	40.9	8.9	1.1	148	2.929	6	1.657	15.2	58.1
48	90	156	98.8	11	9	130	51.0	8.4	1.0	146	3.350	6	2.124	16.3	63.2
49	92	150	84.0	9	8	98	43.0	8.6	1.1	110	2.730	6	1.604	14.9	58.8
50	91	149	100.9	6	10	116	47.8	8.3	1.3	129	2.097	6	1.297	15.8	62.2
51	92	151	92.0	7	14	77	39.2	9.1	1.1	107	2.115	6	1.301	16.7	61.5
52	89	153	89.0	9	9	95	50.3	8.6	1.2	101	2.142	6	1.199	17.3	56.7
53	94	151	93.2	8	22	98	43.6	9.0	1.2	121	2.579	6	1.652	15.5	63.9
54	91	150	91.5	9	15	175	48.2	7.9	1.2	177	1.902	5	1.449	16.9	51.3
55	89	150	100.9	10	12	82	49.1	8.3	1.3	130	0.637	6	0.891	15.8	56.4
56	90	146	101.2	8	13	123	47.8	8.9	1.2	129	3.057	6	1.778	17.5	58.1
57	89	155	99.3	10	13	89	48.4	8.5	1.2	127	3.000	6	1.799	17.1	60.3
58	86	150	100.2	7	14	109	46.3	8.0	1.1	131	3.193	5	1.830	14.3	58.2
59	93	143	116.4	9	11	100	53.1	8.1	1.0	208	3.585	6	3.054	13.5	60.1

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	Primary branches	Secondary branches	Raceme number
60	95	155	93.9	9	11	96
61	86	151	98.6	10	23	110
62	98	151	114.6	8	14	146
63	96	149	115.5	12	12	121
64	115	148	117.4	10	17	129
65	88	153	101.0	13	12	170
66	86	145	103.7	8	12	143
67	122	-	115.5	16	15	128
68	93	152	108.0	11	16	189
69	99	154	112.7	13	11	77
70	99	150	94.7	8	10	86
71	97	151	101.0	7	11	95
72	94	152	91.7	12	14	108
73	91	152	95.8	8	2	113
74	97	152	104.4	7	11	86
75	105	151	120.2	9	10	216
76	95	148	97.2	10	6	86
77	88	139	107.2	10	5	138
78	92	152	108.3	7	8	130
79	89	150	100.5	7	4	110
80	92	150	128.3	7	9	207
81	86	153	93.3	10	4	101
82	91	153	101.9	6	9	118
83	90	150	108.2	7	4	108
84	94	158	87.0	9	20	97
85	91	154	105.9	9	6	136
86	94	147	93.4	8	8	123
87	87	144	96.4	10	12	101
88	85	139	87.9	9	5	162
89	99	159	110.2	9	13	107

Pod bearing length (cm)	pod length (cm)	Pod width (cm)	Pods/ plant	Pod yield ton/ha	Seeds/pod	Grain yield ton/ha	100 seed mass (g)	thresh%
41.7	8.2	1.1	107	2.315	5	1.480	16.4	63.7
46.9	8.6	1.1	142	2.929	6	1.875	15.7	65.4
54.8	8.6	1.0	205	2.983	6	1.687	16.6	58.8
51.5	8.6	1.1	161	3.891	6	2.398	15.3	61.7
49.8	9.8	1.2	227	3.791	6	2.147	19.8	55.4
48.4	8.8	1.1	94	0.625	6	0.366	16.0	62.5
58.5	8.7	1.1	141	3.289	6	2.218	13.8	67.5
48.8	9.8	1.2	276	4.510	6	2.757	19.5	60.6
48.0	8.8	1.1	136	1.054	6	1.213	15.0	55.3
54.0	9.3	1.1	176	4.561	6	2.101	17.8	46.5
39.7	8.5	1.2	108	2.077	6	1.152	17.7	55.4
39.4	7.3	1.1	146	3.289	5	2.110	19.8	64.5
41.1	8.6	1.0	100	2.381	6	1.541	16.7	64.4
47.8	9.1	1.3	102	2.725	6	1.623	18.9	59.7
45.3	10.6	1.1	187	4.282	5	2.535	17.7	59.3
61.5	8.6	1.2	80	0.678	5	0.397	16.3	58.1
45.2	7.7	1.1	115	1.922	5	1.118	14.6	54.5
57.6	8.1	1.1	143	2.651	6	1.715	15.2	64.1
50.6	9.2	1.1	159	4.171	6	2.609	16.8	62.1
51.6	9.6	1.1	130	2.965	6	1.697	17.0	58.5
52.4	8.8	1.1	145	1.232	6	0.704	15.0	59.4
39.8	8.2	1.3	115	3.899	5	1.833	15.9	62.4
45.8	9.9	1.1	155	3.767	6	2.144	16.3	58.0
62.0	9.2	1.2	138	0.669	6	0.397	15.9	60.0
47.8	8.0	1.0	195	0.915	5	0.508	14.9	55.7
47.1	8.7	1.2	150	2.856	6	1.806	16.3	63.0
42.9	8.4	1.1	143	2.966	6	1.750	13.8	59.2
43.1	8.1	1.1	137	2.230	6	1.429	15.3	63.5
41.6	9.6	1.1	125	2.897	6	1.179	16.4	54.9
49.4	10.3	1.1	158	3.330	6	2.033	15.1	60.9

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	Primary branches	Secondary branches	Raceme number	Pod bearing length (cm)	pod length (cm)
90	94	150	98.0	9	6	99	46.3	9.3
91	87	150	99.7	10	7	167	50.3	8.9
92	95	150	96.4	6	11	88	46.5	9.1
93	98	151	105.5	12	11	122	50.1	8.9
94	120	149	199.8	13	18	219	58.3	8.7
95	102	150	99.5	8	14	70	39.0	9.1
96	104	148	147.8	9	11	161	70.0	8.5
97	110	165	145.6	13	19	149	72.5	7.4
98	115	153	175.5	8	18	217	69.5	7.9
99	128	-	168.4	13	24	219	76.0	8.7
100	120	149	167.0	14	23	213	82.8	8.8
102	96	-	94.2	8	5	57	43.2	9.1
103	142	-	182.7	10	24	249	71.4	9.2
104	102	-	89.7	9	6	58	36.6	9.3
105	93	148	253.8	12	18	327	72.5	8.6
106	129	-	179.3	7	24	219	80.0	9.0
107	114	149	165.3	9	20	193	62.8	8.2
108	127	144	162.1	13	22	432	63.7	8.4
109	138	252	187.7	11	23	287	85.5	9.0
110	128	176	171.4	17	25	333	61.6	7.4
111	143	252	187.8	13	17	352	73.5	7.9
112	139	-	194.8	8	16	467	79.9	8.9
113	100	156	130.9	9	19	168	63.1	7.8
114	149	245	197.9	12	20	414	79.9	9.6
115	134	147	167.8	9	20	196	69.9	8.2
116	107	155	137.3	9	19	150	60.5	8.5
117	144	-	189.9	14	30	326	80.1	8.9
118	126	-	166.5	11	21	219	77.7	9.0
119	83	131	109.9	12	13	227	47.8	8.0
120	108	164	158.4	15	20	173	60.3	7.6

Pod width (cm)	Pods/ plant	Pod yield ton/ha	Seeds/pod	Grain yield ton/ha	100 seed mass (g)	thresh%
1.1	133	2.732	6	1.655	16.5	60.7
1.1	144	3.545	6	2.373	14.6	66.8
1.0	132	2.142	6	1.317	14.3	63.1
1.1	138	3.137	6	1.927	16.6	61.2
1.2	254	5.643	6	3.293	15.7	57.6
1.1	127	3.312	6	1.979	14.1	59.6
1.2	245	4.774	6	2.890	15.2	60.6
1.1	163	4.407	5	2.789	16.8	63.9
1.1	286	6.346	6	3.125	14.3	49.6
1.1	229	6.600	6	3.789	15.2	58.1
1.2	217	4.794	6	2.605	13.9	54.8
1.3	76	2.179	6	1.344	18.8	61.8
1.3	195	5.233	6	3.020	18.4	57.8
1.3	91	2.176	6	1.137	19.2	51.9
1.2	104	2.560	6	0.832	16.8	34.5
1.2	237	7.188	6	4.027	17.3	56.8
1.1	271	6.713	6	4.106	17.0	60.6
1.1	239	4.218	6	2.506	14.9	59.9
1.2	276	7.877	6	4.151	13.4	52.8
1.1	360	8.431	6	3.842	15.8	57.3
1.2	174	4.152	6	2.456	14.4	59.1
1.2	267	5.793	6	3.346	17.6	58.5
1.1	180	3.994	5	2.173	14.1	53.9
1.3	242	6.145	6	3.541	16.5	57.7
1.2	222	5.550	5	3.171	16.4	56.9
1.2	161	4.019	6	2.399	19.9	60.0
1.3	287	6.023	6	3.436	17.4	57.7
1.2	217	5.000	6	2.364	18.0	58.0
1.1	116	3.070	5	1.689	15.8	56.3
1.1	167	5.438	6	3.425	15.2	63.4

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	Primary branches	Secondary branches	Raceme number	Pod bearing length (cm)	pod length (cm)	Pod width (cm)	Pods/ plant	Pod yield ton/ha	Seeds/pod	Grain yield ton/ha	100 seed mass (g)	thresh%
122	127	147	169.9	12	19	231	77.9	8.9	1.2	257	6.706	6	3.599	17.4	52.8
123	142	209	184.3	13	26	381	73.9	7.8	1.1	262	6.826	5	3.869	15.0	52.6
Checks															
ICEAP 00020 (L)	104	154	143.7	11	11	124	69.8	7.9	1.2	173	4.110	5	2.603	18.5	63.4
ICEAP 00040 (L)	96	151	132.8	9	8	85	60.7	8.0	1.1	141	2.851	6	1.859	20.0	65.0
ICEAP 00053 (L)	110	158	146.3	9	9	135	79.4	7.6	1.1	176	4.426	6	2.692	15.6	60.7
ICEAP 00950 (L)	121	159	195.7	11	57	240	73.2	8.7	1.2	244	2.051	6	2.152	15.7	61.5
ICEAP 13076 (L)	105	-	140.6	9	14	102	74.1	8.2	1.1	183	4.457	5	2.603	17.6	58.2
ICP 9145 (L)	102	156	128.2	12	13	143	59.8	8.3	1.1	231	4.783	6	2.924	15.2	60.4
ICEAP 00926 (L)	107	153	133.8	11	7	129	75.0	7.8	1.2	176	4.492	5	2.673	16.7	59.2
T-7 (M)	102	151	146.4	8	25	345	70.4	7.3	1.0	340	7.289	6	4.067	12.4	55.4
ICEAP 00933 (L)	105	150	140.6	11	11	136	65.4	9.2	1.2	192	4.818	6	3.054	14.1	63.6
ICP 6927 (M)	88	154	104.0	11	14	157	54.4	7.4	1.2	134	1.877	5	1.215	15.4	64.4
ICPL 87051 (M)	88	155	106.7	14	17	184	58.3	7.5	1.1	216	4.607	6	2.906	14.1	63.9
ICEAP 00068 (M)	87	145	102.3	11	10	80	49.1	8.5	1.1	154	2.170	6	1.323	16.6	60.9
ICEAP 00540 (M)	88	152	96.6	8	12	96	46.4	7.9	1.1	116	2.687	5	1.571	15.4	59.4
ICEAP 00550 (M)	84	151	103.2	9	15	97	52.9	7.7	1.1	134	0.973	6	0.604	16.3	61.5
ICEAP 00554 (M)	91	151	108.3	7	10	147	50.2	8.5	1.1	148	2.606	6	1.657	15.2	65.2
ICEAP 00557 (M)	86	151	108.3	8	18	136	56.5	9.4	1.1	166	2.965	6	1.921	16.0	65.0
ICEAP 00911 (M)	87	147	111.3	13	12	183	50.8	7.3	1.1	172	3.801	6	2.220	14.4	58.1
QP 14 (M)	86	151	100.4	8	3	136	47.1	8.0	1.0	136	0.899	6	0.571	17.8	63.6
ICP 12734 (M)	85	155	103.7	10	11	239	50.3	7.5	1.0	199	2.674	6	1.726	14.1	71.8
ICEAP 00790 (M)	117	172	160.7	14	14	337	82.4	8.3	1.1	311	3.369	6	3.975	16.8	73.1
Grand mean	**101**	**154**	**121.6**	**10**	**14**	**155**	**55.2**	**8.7**	**1.1**	**169**	**3.412**	**6**	**2.029**	**15.9**	**59.3**
SE+	**5.483**	**4.818**	**6.188**	**2.210**	**3.471**	**36.500**	**6.146**	**0.663**	**0.109**	**44.740**	**0.909**	**0.336**	**0.625**	**1.101**	**4.823**
CV%	**5.460**	**2.970**	**5.080**	**22.570**	**25.040**	**24.700**	**11.190**	**7.660**	**9.650**	**26.750**	**26.210**	**5.820**	**30.400**	**6.950**	**8.120**
LSD (5%)	**9.178**	**8.98**	**10.59**	**3.762**	**6.104**	**64.61**	**10.63**	**1.12**	**0.182**	**76.63**	**1.575**	**0.562**	**1.065**	**1.884**	**8.47**

L - Long duration; M - Medium duration

Appendix 4. Mean performance for 14 quantitative traits recorded on 123 Tanzanian pigeonpea accessions and 21 checks at Kampi ya Mawe, Kenya.

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	Primary branches	Secondary branches	Raceme number	Pod bearing length (cm)	Pod length (cm)	Pods/plant	Pod yield ton/ha	Seeds/pod	Grain yield ton/ha	100 seed mass (g)	thresh%
1	125	165	101.8	5	3	56	88.8	8.3	38	0.594	6	0.304	11.5	49.0
2	112	151	71.0	5	8	32	44.0	8.4	44	1.007	6	0.548	13.0	53.8
3	114	153	69.7	5	2	33	35.0	8.1	52	0.586	6	0.273	12.0	46.8
4	114	154	86.3	4	4	63	35.5	9.0	60	0.753	6	0.412	12.9	54.8
5	114	154	93.8	6	5	36	46.4	9.3	109	0.938	6	0.474	12.4	50.7
6	104	140	88.6	5	7	43	73.5	9.0	56	0.364	7	0.286	11.0	54.9
7	118	158	89.4	4	3	56	71.0	8.9	54	0.434	6	0.204	13.8	45.2
8	108	148	101.7	4	3	18	76.7	8.2	58	0.509	6	0.217	11.8	43.0
9	119	153	85.6	3	2	26	77.5	9.1	60	0.533	6	0.258	15.8	48.1
10	115	149	105.0	4	3	62	52.6	9.5	39	0.493	6	0.289	13.2	58.5
11	123	164	99.9	5	7	32	83.0	8.7	54	0.634	6	0.277	14.7	43.8
12	108	140	80.2	3	2	13	58.8	8.8	69	0.352	6	0.171	11.7	48.8
13	116	155	108.0	4	3	28	75.5	8.6	67	1.077	6	0.474	13.2	43.3
14	113	148	110.4	4	3	35	78.6	8.7	59	0.813	6	0.390	13.3	47.9
15	135	173	90.2	6	3	53	55.0	8.0	52	0.916	6	0.408	12.5	44.8
16	117	154	100.8	4	7	27	79.2	8.2	74	1.077	6	0.438	14.1	40.7
17	105	147	106.6	4	2	23	43.7	8.4	65	0.431	6	0.210	12.0	47.6
18	105	143	102.0	5	2	42	65.6	8.4	57	0.709	6	0.365	12.9	50.8
19	120	158	162.9	6	7	46	106.2	8.9	73	0.660	6	0.400	15.0	60.4
20	213	265	191.4	11	6	85	166.3	7.7	152	1.398	6	0.578	16.1	41.2
21	170	218	163.8	7	8	38	61.3	8.7	74	0.975	6	0.647	16.9	66.1
22	146	180	131.2	5	5	65	125.0	8.7	74	0.960	6	0.547	15.4	57.0
23	121	155	139.7	5	4	44	74.5	8.8	68	0.633	6	0.327	14.5	51.9
24	167	209	139.2	5	5	47	152.5	10.0	77	0.373	6	0.175	16.2	46.7
25	123	170	147.3	6	6	46	115.0	8.8	71	1.727	5	0.879	18.2	50.9
26	124	170	116.2	4	3	26	37.0	9.3	56	0.514	6	0.278	17.0	54.4
27	117	156	103.8	6	6	30	84.0	8.4	65	0.595	6	0.229	11.0	38.7
28	114	149	103.9	4	14	41	48.8	9.1	28	0.576	6	0.300	12.9	51.9
29	113	153	110.0	5	4	47	88.8	9.7	67	0.788	6	0.409	15.8	52.1

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	Primary branches	Secondary branches	Raceme number
30	117	159	111.8	5	4	33
31	137	175	151.7	5	3	48
32	122	164	132.9	4	4	27
33	117	156	96.2	5	6	73
34	124	162	108.9	4	2	45
35	119	160	142.0	6	4	59
36	103	142	105.3	6	4	32
37	125	153	103.4	4	4	36
38	110	149	115.1	5	4	46
39	114	151	112.2	4	7	29
40	118	160	96.9	4	4	44
41	122	162	120.8	6	6	19
42	116	161	125.8	5	4	26
43	108	147	113.3	5	2	53
44	106	144	102.9	6	4	28
45	114	159	114.3	4	3	15
46	111	146	101.6	5	5	33
47	109	149	90.0	4	3	54
48	107	146	86.4	4	2	33
49	113	152	84.8	4	4	22
50	110	147	99.8	5	4	13
51	110	148	80.9	4	4	24
52	119	157	103.6	5	1	14
53	113	153	117.2	5	4	53
54	112	153	110.6	6	3	53
55	115	155	94.3	4	5	41
56	114	155	99.5	6	2	53
57	119	156	94.8	5	4	26
58	108	152	119.1	5	7	37
59	112	156	102.6	4	5	27

Pod bearing length (cm)	Pod length (cm)	Pods/plant	Pod yield ton/ha	Seeds/pod	Grain yield ton/ha	100 seed mass (g)	thresh%
50.0	9.4	41	0.638	6	0.308	13.1	48.4
83.3	7.2	67	0.913	6	0.430	12.8	47.0
35.0	8.6	31	0.754	6	0.329	14.5	43.6
44.0	8.5	85	0.763	6	0.372	13.7	49.2
51.8	9.0	63	0.880	6	0.383	15.1	43.6
112.8	7.7	67	0.166	6	0.082	13.0	50.4
42.5	9.3	82	0.802	6	0.362	14.3	45.0
41.2	8.3	74	0.806	6	0.407	13.9	49.1
92.8	11.2	72	0.692	6	0.338	13.9	48.9
55.8	9.3	69	0.415	6	0.344	15.3	46.1
89.6	8.5	45	1.287	6	0.617	15.2	47.9
53.8	8.2	63	1.404	6	0.750	15.6	53.8
63.8	8.9	79	0.798	6	0.430	14.8	53.7
73.3	8.8	74	1.028	6	0.522	14.9	50.8
64.9	8.7	68	1.078	6	0.548	14.4	50.8
82.3	9.2	65	0.461	6	0.223	14.0	48.6
66.4	8.3	69	0.420	6	0.177	14.7	42.4
82.7	7.9	56	0.640	6	0.291	12.9	45.8
54.5	8.7	44	1.050	6	0.580	13.1	56.0
41.3	8.6	58	0.389	6	0.199	16.0	47.8
65.2	8.1	67	0.795	6	0.435	15.0	54.3
85.0	7.9	40	0.342	6	0.160	14.2	47.2
42.5	8.7	66	0.378	6	0.205	16.4	54.4
79.8	8.6	97	0.790	6	0.386	15.0	48.6
63.8	7.3	69	0.702	6	0.420	17.7	53.2
47.2	8.6	53	0.954	6	0.385	15.6	41.9
45.2	8.8	91	0.495	6	0.271	13.3	55.4
58.3	8.0	65	0.570	6	0.250	13.8	43.9
42.5	8.6	54	1.133	6	0.626	15.1	55.3
37.0	8.5	64	1.109	6	0.652	14.2	59.2

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	Primary branches	Secondary branches	Raceme number	Pod bearing length (cm)	Pod length (cm)	Pods/plant	Pod yield ton/ha	Seeds/pod	Grain yield ton/ha	100 seed mass (g)	thresh %
60	111	153	133.5	6	4	69	58.3	8.6	83	1.906	6	0.869	14.5	46.0
61	108	148	112.7	6	4	38	47.8	9.1	91	0.803	6	0.384	13.7	47.8
62	120	161	114.6	6	5	38	102.5	8.9	79	1.449	6	0.687	14.4	47.4
63	119	160	106.3	5	3	36	46.9	8.8	67	0.554	6	0.337	14.6	60.6
64	178	219	180.2	6	4	54	95.8	8.4	66	2.824	6	1.328	16.4	47.0
65	117	156	100.9	6	15	33	70.3	8.2	55	0.492	6	0.239	14.2	47.4
66	116	154	107.2	6	25	32	90.2	8.7	30	0.896	6	0.467	14.1	51.8
67	145	183	148.8	6	6	40	117.5	8.9	68	0.618	6	0.303	18.1	49.0
68	112	152	111.0	5	6	52	50.8	8.9	47	0.547	6	0.289	14.0	51.9
69	110	151	113.3	5	8	18	61.6	8.4	55	1.324	6	0.710	16.7	54.0
70	114	158	98.4	4	7	15	65.0	8.8	87	1.024	6	0.510	14.1	50.9
71	126	181	135.1	6	2	44	46.8	6.5	71	0.674	5	0.315	18.2	46.6
72	118	158	111.6	4	7	39	41.3	8.5	91	1.224	6	0.728	14.5	60.4
73	127	162	135.3	5	3	42	78.4	9.2	55	1.195	6	0.693	17.3	58.9
74	113	154	117.4	5	3	38	48.5	9.3	56	0.587	6	0.342	16.7	58.6
75	107	147	127.5	5	3	44	92.0	7.4	33	1.122	6	0.435	13.5	39.5
76	122	164	108.1	5	3	26	61.7	8.3	65	0.827	6	0.420	13.2	51.3
77	109	145	103.5	6	3	36	80.8	8.8	66	0.770	6	0.335	12.7	43.7
78	113	153	116.3	6	3	54	80.5	8.7	66	0.573	6	0.257	14.9	44.9
79	106	144	99.6	4	10	34	37.5	9.4	43	1.333	6	0.598	15.1	45.3
80	105	143	115.2	4	4	30	45.3	8.5	70	0.933	6	0.438	12.1	47.8
81	117	157	110.9	5	8	94	103.6	8.1	73	1.114	6	0.582	15.1	53.2
82	104	144	111.0	6	7	41	81.3	8.5	139	1.333	6	0.651	13.6	48.6
83	108	153	98.2	4	10	36	47.5	11.9	66	0.994	6	0.566	15.8	56.8
84	192	233	162.8	9	2	70	99.0	8.2	45	0.516	6	0.248	15.8	48.1
85	108	151	99.6	5	7	39	41.1	9.1	65	0.731	6	0.387	15.3	52.9
86	117	158	104.9	6	3	44	50.0	8.6	115	0.469	6	0.176	13.5	44.8
87	111	148	85.1	4	3	54	49.1	8.2	46	0.779	6	0.371	13.7	47.7
88	112	152	88.5	- 5	1	37	52.5	9.0	71	0.134	6	0.053	15.0	38.3
89	122	159	146.2	6	5	37	98.1	9.4	73	0.355	6	0.144	15.4	42.3

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	Primary branches	Secondary branches	Raceme number	Pod bearing length (cm)
90	119	161	113.9	5	10	46	57.2
91	115	158	129.3	5	3	88	37.0
92	115	153	107.4	4	2	26	57.5
93	118	160	107.6	4	5	29	53.3
94	235	269	177.6	5	9	22	167.3
95	239	276	163.0	4	16	33	146.9
96	188	218	182.8	7	14	48	78.0
97	203	207	147.2	7	7	15	95.0
98	195	242	158.0	5	8	56	82.7
99	206	245	190.0	19	11	82	110.3
100	251	279	169.2	14	14	67	77.0
101	206	243	170.0	14	3	142	154.0
102	121	173	120.5	7	2	44	93.8
104	121	157	99.5	8	7	20	62.1
105	262	262	125.0	22	10	210	69.0
106	115	153	77.2	5	4	19	52.5
107	216	254	200.2	7	10	56	136.4
108	208	250	182.5	17	32	91	114.3
109	172	234	197.5	7	36		100.0
110	224	263	208.0	5	26	146	125.0
111	228	264	144.5	5	1	47	113.8
113	126	170	126.2	8	8	23	120.0
118	157	197	86.0	6	8	105	74.5
119	216	252	106.7	12	5	56	147.2
120	203	246	158.7	6	17	30	136.0
122	234	270	215.2	12	5	102	107.9
123	235	270	178.3	16	8	38	79.3

Pod length (cm)	Pods/plant	Pod yield ton/ha	Seeds/pod	Grain yield ton/ha	100 seed mass (g)	thresh %
8.8	56	0.773	6	0.349	15.9	45.0
8.7	87	1.412	6	0.678	14.2	48.0
9.2	84	0.559	6	0.266	15.0	46.6
9.1	30	0.552	6	0.253	13.3	45.1
8.0	56	0.266	6	0.098	13.9	36.9
7.7	75	0.217	6	0.092	15.5	43.3
8.0	86	1.518	6	0.586	14.1	38.6
7.9	57	1.028	6	0.529	16.3	51.5
7.2	71	0.296	5	0.123	14.3	41.4
7.7	82	0.731	6	0.358	14.5	48.9
7.1	92	0.231	5	0.148	13.2	64.3
7.1	117	0.391	6	0.241	17.0	61.6
9.3	69	0.687	5	0.318		46.3
8.8		0.053	6	0.024	13.6	45.1
9.5	102	0.389	6			44.9
6.9	59	0.431	6	0.174	13.4	48.5
7.6	27	0.400	6	0.209	18.7	68.3
7.6	31	0.389	5	0.273	18.0	60.0
5.4		0.510	5		16.0	38.4
7.1	59	0.399	6	0.233	16.0	56.7
9.2	61	0.084	6	0.013	14.0	29.0
8.1	52	0.310	5	0.224	13.9	53.4
5.3	64	0.647	6	0.326	16.6	50.4
7.6	55	0.198	6	0.102		51.5
7.8		0.982	5	0.526	15.9	53.5
8.0	83	0.232	6	0.113	14.0	49.1
7.8	99	0.021	5	0.008	16.0	39.3

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	Primary branches	Secondary branches	Raceme number	Pod bearing length (cm)	Pod length (cm)	Pods/plant	Pod yield ton/ha	Seeds/pod	Grain yield ton/ha	100 seed mass (g)	thresh%
Chec ks														
ICEAP 00020	196	227	205.0	14	12	141	119.7	7.9	210	0.714	6	0.578	20.0	87.3
ICEAP 00040	198	233	163.3	32	9	117	149.2	7.9	143	1.781	6	1.192	21.7	67.0
ICEAP 13076	219	247	165.8	12	5	150	115.9	6.9	178	0.266	6	0.188	19.7	75.4
ICP 9145	227	262	110.9	14	6	130	114.0	6.7	68	0.085	5	0.043	16.0	50.6
ICEAP 00926	240	253	186.0	19	23	104	153.2	7.5	124	0.571	6	0.364	18.0	63.9
T-7	165	202	134.7	7	5	61	133.3	6.6	111	0.809	4	0.396	15.0	48.9
ICEAP 00933	201	239	136.9	13	7	104	150.0	5.3	229	0.317	6	0.268	14.7	84.6
ICP 6927	108	150	108.9	8	7	48	99.2	6.8	119	0.304	5	0.264	16.0	85.9
ICP 7035	92	134	84.8	6	4	61	55.8	7.6	44	0.082	5	0.047	18.0	57.8
ICPL 87051	124	163	114.2	8	8	64	85.0	6.3	88	0.061	5	0.024	14.0	38.2
ICEAP 00068	87	135	104.1	11	4	55	81.2	8.2	84	0.592	6	0.252	14.0	42.5
ICEAP 00540	106	152	109.8	6	5	23	69.2	7.5	68	0.773	6	0.452	15.4	58.8
ICEAP 00550	101	148	118.5	9	7	47	85.0	8.0	73	0.687	6	0.422	14.9	61.4
ICEAP 00554	151	138	92.3	8	7	20	73.3	8.8	100	0.454	6	0.277	14.7	61.2
ICEAP 00557	98	146	105.8	10	4	33	71.9	9.0	63	0.173	6	0.111	12.6	57.9
ICEAP 00911	104	154	117.5	19	4	39	86.9	6.7	64	0.242	5	0.142	14.1	58.2
QP 14	193	231	215.0	15	15	19	110.0	6.6	170	0.291	6	0.240	15.0	82.4
ICP 12734	186	225	107.0	7	6	60	130.6	6.9	103	1.108	5	0.570	14.7	51.5
ICEAP 00790	143	185	173.3	14	11	77	162.2	8.2	148	1.419	5	0.653	14.4	46.0
Grand mean	**138**	**176**	**122.5**	**7**	**6**	**49**	**79.9**	**8.3**	**73**	**0.716**	**6**	**0.367**	**14.8**	**51.1**
SE+	**7.398**	**7.303**	**7.597**	**1.444**	**1.839**	**4.843**	**6.248**	**0.667**	**6.770**	**0.170**	**0.322**	**0.084**	**1.633**	**4.128**
CV%	**5.580**	**4.260**	**6.280**	**22.640**	**30.600**	**9.690**	**7.860**	**8.000**	**9.030**	**24.740**	**5.510**	**23.960**	**11.080**	**8.220**
LSD (5%)	**13.71**	**13.61**	**15.14**	**2.63**	**3.76**	**10.10**	**12.71**	**1.20**	**144**	**0.360**	**0.57**	**0.178**	**3.07**	**8.98**

Appendix 5. Mean performance for 14 quantitative traits recorded on 123 Tanzanian pigeonpea accessions and 21 checks at Ilonga, Tanzania.

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	100seed mass	Primary branches	Seeds/pod	Grain yield ton/ha
1	121	187	203.5	10.1	13	6	0.667
2	94	153	145.0	10.8	14	6	1.467
3	101	154	152.0	10.6	12	6	1.600
4	94	151	189.5	13.3	8	6	1.667
5	94	149	158.0	12.5	13	6	2.000
6	96	150	158.0	10.5	10	6	1.600
7	95	157	194.5	10.9	10	6	1.733
8	97	154	154.5	10.5	9	6	1.300
9	99	156	177.0	11.2	8	7	2.067
10	98	152	174.5	14.2	8	6	1.867
11	97	152	159.0	11.8	10	6	1.800
12	92	149	159.5	13.1	9	6	2.200
13	94	153	158.5	11.4	10	6	1.933
14	95	149	187.0	12.6	9	7	2.200
15	97	158	197.5	9.4	11	6	1.667
16	98	153	171.5	11.7	13	6	2.333
17	97	152	170.5	12.2	8	7	1.600
18	97	155	177.5	13.5	9	6	1.867
19	101	159	188.0	13.3	11	6	1.808
20	118	178	232.0	15.0	14	5	1.733
21	116	172	219.0	13.4	13	6	1.933
22	102	159	209.5	13.7	10	6	2.933
23	99	157	175.0	13.3	10	7	2.267
24	101	170	211.5	15.1	10	7	2.817
25	106	149	192.0	12.8	10	6	2.667
26	97	152	170.0	13.1	8	6	2.400
27	97	157	166.0	12.6	10	6	2.000
28	95	152	177.0	14.6	10	7	2.200
29	96	154	177.5	14.8	8	5	2.200
30	98	159	155.5	15.1	9	6	2.467
31	99	152	192.5	11.3	13	6	1.400
32	99	151	188.5	12.2	9	5	1.600
33	100	159	166.5	12.4	11	6	2.433
34	102	162	159.0	10.7	13	6	2.167
35	102	152	168.0	11.1	11	6	1.200
36	96	150	140.0	16.7	8	6	1.933
37	95	157	163.0	12.5	8	6	1.800
38	97	149	153.5	15.3	7	7	1.900
39	94	153	168.0	15.0	8	6	1.567
40	98	157	175.0	14.2	8	6	1.467
41	101	157	156.5	16.3	7	6	1.533
42	98	160	194.0	16.3	7	6	2.267
43	96	156	191.0	15.2	10	6	1.933
44	96	156	180.0	15.5	8	6	2.967
45	96	153	172.0	15.0	8	6	1.533
46	96	157	157.5	15.3	9	6	1.733

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	100seed mass	Primary branches	Seeds/pod	Grain yield ton/ha
47	94	151	160.0	12.3	10	7	2.933
48	94	154	154.0	13.8	10	6	1.800
49	97	155	153.5	14.8	16	6	1.267
50	97	153	162.0	14.3	16	6	1.267
51	98	152	167.5	15.2	17	6	1.467
52	99	155	171.0	16.2	17	7	1.733
53	97	152	168.0	14.4	15	6	1.400
54	90	148	154.0	18.9	15	6	1.400
55	99	156	179.0	15.7	15	6	1.333
56	96	157	136.5	14.6	11	6	1.300
57	98	154	163.0	14.9	12	6	1.267
58	96	151	168.5	13.0	13	6	1.667
59	98	153	133.5	13.3	13	7	0.933
60	97	152	157.0	13.8	9	6	1.200
61	97	148	167.0	13.6	12	5	2.000
62	99	156	187.0	15.0	11	6	2.067
63	96	156	179.0	15.3	12	7	1.933
64	123	175	186.5	15.3	11	6	2.200
65	97	151	191.0	14.7	14	6	1.583
66	98	156	181.5	15.0	12	6	1.200
67	120	180	194.5	14.3	14	7	1.917
68	98	156	195.5	14.7	18	6	2.267
69	111	165	168.0	14.8	16	5	2.333
70	101	162	180.5	17.4	11	6	1.200
71	101	157	173.5	18.4	19	5	2.133
72	98	151	182.5	15.7	17	6	2.133
73	108	168	182.5	16.4	16	6	2.333
74	98	152	192.5	16.1	18	6	1.933
75	99	152	191.5	13.2	15	7	2.467
76	95	152	181.0	12.6	14	6	1.800
77	97	149	131.5	14.6	14	7	2.200
78	96	152	180.5	13.7	13	5	2.200
79	95	155	143.5	14.8	19	8	2.200
80	96	155	112.0	13.1	9	6	2.067
81	97	153	201.0	12.7	10	6	1.867
82	99	159	215.0	14.8	10	5	2.467
83	96	153	173.5	14.8	15	6	2.133
84	97	149	165.0	13.9	11	7	1.867
85	96	149	166.5	13.9	12	6	2.267
86	96	149	179.0	15.3	10	6	1.767
87	94	148	188.0	13.3	12	6	1.800
88	96	151	207.0	14.4	10	6	1.800
89	97	152	202.0	14.8	10	6	2.400
90	103	154	219.0	15.5	9	7	1.133
91	97	152	206.0	13.1	11	6	1.867
92	96	157	220.0	13.9	8	6	2.000
93	96	153	225.0	13.5	11	6	2.267

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	100seed mass	Primary branches	Seeds/pod	Grain yield ton/ha
94	138	189	248.5	11.3	21	5	0.667
95	139	189	233.0	10.3	20	6	0.533
96	134	190	218.0	15.3	19	5	0.733
97	130	193	218.0	8.8	15	5	1.354
98	125	190	226.0	9.5	14	6	1.167
99	140	188	257.5	11.1	19	5	0.400
100	142	190	234.0	6.8	16	6	0.167
101	141	189	259.5	8.1	15	6	0.200
102	139	193	234.5	12.9	15	5	0.600
103	145	192	249.5	8.5	16	6	0.267
104	143	191	240.5	9.6	16	6	0.333
105	136	-	244.0	10.2	14	5	0.467
106	140	192	235.5	8.0	14	5	0.600
107	138	189	247.5	9.6	15	6	0.479
108	136	190	246.5	9.4	16	7	0.733
109	144	193	234.0	10.6	14	5	0.467
110	146	188	237.0	10.2	13	6	0.400
111	140	192	223.0	12.5	12	6	0.533
112	144	185	212.0	7.6	11	6	0.200
113	136	190	216.5	10.2	11	5	0.733
114	146	193	234.0	10.3	13	4	0.267
115	134	191	210.0	10.8	10	6	0.267
116	121	192	207.0	16.8	9	6	1.000
117	141	189	212.5	9.5	13	6	0.333
118	139	192	217.0	9.2	14	5	0.233
119	143	192	241.0	9.0	15	4	0.100
120	137	188	217.5	10.1	12	5	0.467
121	141	190	199.0	9.6	13	5	0.186
122	141	191	183.0	9.1	12	5	0.133
123	140	191	190.5	8.4	13	5	0.110
Checks							
ICEAP 00020	119	175	181.0	15.0	14	5	0.933
ICEAP 00040	122	175	176.5	14.7	11	6	1.467'
ICEAP 00053	126	187	161.0	12.8	11	5	0.733
ICEAP 00950	133	193	196.0	12.6	14	5	0.467
ICEAP 13076	120	180	176.5	14.7	10	5	1.067
ICP 9145	121	175	151.0	12.1	11	6	0.933
ICEAP 00926	122	179	180.0	12.6	11	6	0.700
T-7	102	164	152.5	9.6	13	5	1.200
ICEAP 00933	113	166	178.0	12.9	13	5	1.200
ICP 6927	92	146	159.0	14.7	11	5	2.133
ICP 7035	90	152	171.5	16.2	11	5	1.200
ICPL 87051	92	153	183.0	13.7	14	5	2.200
ICEAP 00068	94	154	231.5	13.9	8	6	2.067
ICEAP 00540	94	154	149.5	14.0	9	5	1.867
ICEAP 00550	96	157	179.5	13.9	10	6	1.867
ICEAP 00554	97	158	173.0	14.0	7	6	2.000

Accession	Days 50% flower	Days 75% maturity	Plant height (cm)	100seed mass	Primary branches	Seeds/pod	Grain yield ton/ha
ICEAP 00557	96	157	160.5	14.8	7	6	1.500
ICEAP 00911	97	159	166.5	12.5	12	5	2.467
QP 14	99	159	186.0	13.1	11	6	0.600
ICP 12734	100	162	181.0	12.2	13	6	2.200
ICEAP 00790	117	180	204.5	14.7	14	5	2.400
Grand Mean	**108**	**164**	**186.8**	**13.0**	**12**	**6**	**1.531**
SE+	**3.370**	**4.684**	**8.062**	**1.198**	**2.409**	**0.739**	**0.369**
CV%	**3.120**	**2.860**	**4.310**	**9.180**	**20.470**	**13.060**	**24.130**
LSD (5%)	**9.17**	**12.77**	**21.94**	**3.29**	**6.56**	*NS*	**1.003**

NS-Not significant

Appendix 6. Means of 13 quantitative traits recorded on 123 Tanzanian pigeonpea accessions per collection District.

District	Days to 50% flower	Plant height (cm)	Days to 75% maturity	Primary branches	Secondary branches	Racemes	Pod length (cm)	Pod width (cm)	Seeds per pod	100 seed mass (g)	Pod yield (t/ha)	Grain yield (t/ha)	Threshing %
Temeke	105	96.4	151	7	9	100	8.7	1.1	6	13.3	1.754	0.961	52.1
Kibaha	104	105.7	154	7	10	91	8.9	1.1	6	14.1	1.477	0.824	54.2
Morogoro	115	124.0	161	8	10	92	8.9	1.1	6	15.2	2.333	1.047	55.9
Handeni	107	111.2	155	7	7	79	8.7	1.1	6	14.3	1.917	1.352	54.7
Masasi	102	103.6	151	7	8	74	8.6	1.1	6	15.7	1.551	0.938	54.4
Lindi	105	109.4	155	7	8	82	8.8	1.1	6	15.5	1.750	0.981	53.9
Babati	158	164.3	231	10	15	119	7.8	1.2	6	15.7	3.128	1.898	53.6
Kondoa	142	160.8	239	10	14	165	8.1	1.2	6	16.4	3.469	1.957	54.2
Karatu	153	149.6	201	9	15	169	7.5	1.1	6	15.4	2.934	1.665	52.3

Appendix 7. Quantitative traits correlation matrix: Kabete

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Days 50% flower																
2. Days 75% maturity	0.679**															
3. Grain yield	0.497**	0.449**														
4. Plant height	0.708**	0.558**	0.509**													
5. Pod bearing length	0.561**	0.558**	0.483**	0.784**												
6. Pod length	0.139	0.070	0.008	0.021	0.000											
7. Pods/plant	0.525**	0.397**	0.675**	0.528**	0.522**	0.007										
8. Pods/raceme	-0.038	-0.096	0.041	-0.019	0.104	-0.008	0.090									
9. Pod width	0.212**	0.212**	0.101	0.189**	0.077	0.002	0.072	-0.049								
10. Pod yield	0.536**	0.478**	0.968**	0.570**	0.519**	0.034	0.699**	0.035	0.127							
11. Primary branches/plant	0.286**	0.145	0.114	0.271**	0.214**	-0.026	0.257**	0.196**	-0.012	0.132						
12. Raceme length	-0.024	0.005	-0.009	0.062	0.104	-0.028	0.059	0.145	-0.038	0.003	0.124					
13. Racemes/plant	0.539**	0.427**	0.378**	0.676**	0.502**	-0.065	0.508**	-0.061	0.114	0.407**	0.292**	0.131				
14. Secondary branches/plant	0.573**	0.442**	0.381**	0.499**	0.370**	0.036	0.492**	-0.243**	0.072	0.412**	0.222**	-0.077	0.460**			
15. Seeds/pod	0.004	-0.002	0.067	0.000	-0.034	0.327**	0.044	0.059	0.072	0.047	-0.086	-0.042	-0.073	-0.020		
16. 100 Seed mass	0.174**	0.199**	0.048	0.179**	0.091	0.253**	-0.018	-0.039	0.176**	0.028	-0.017	-0.092	-0.018	-0.010	-0.021	
17. Threshing %	-0.205**	-0.098	0.077	-0.276**	-0.171**	-0.103	-0.128	0.041	-0.109	-0.155	-0.106	-0.029	-0.122	-0.125	0.109	0.076

** $P<0.05$

Appendix 8. Quantitative traits correlation matrix: Kampi ya Mawe

1. **Days 50% flower**													
2. **Days 50% maturity**	0.988**												
3. **Secondary branches/plant**	0.444**	0.428**											
4. **Grain yield**	-0.027	-0.033	0.046										
5. **Plant height**	0.693**	0.704**	0.468**	0.146									
6. **Pod bearing length**	0.660**	0.664**	0.454**	0.045	0.599**								
7. **Pod length**	-0.508**	-0.507**	-0.225**	0.111	-0.212**	-0.536**							
8. **Pods/plant**	0.536**	0.537**	0.377**	0.075	0.526**	0.576**	-0.545**						
9. **Pod yield**	-0.116	-0.120	-0.007	0.953**	0.087	-0.021	0.190**	-0.082					
10. **Primary branches**	0.571**	0.580**	0.511**	-0.045	0.539**	0.585**	-0.498**	0.660**	-0.157				
11. **Racemes/plant**	0.634**	0.631**	0.172**	0.000	0.492**	0.573**	-0.438**	0.594**	-0.102	0.637**			
12. **Seeds/pod**	-0.187**	-0.205**	-0.113	0.086	-0.143	-0.274**	0.409**	-0.180**	0.131	-0.290**	-0.235**		
13. **100 Seed mass**	0.421**	0.410**	0.314**	0.168**	0.441**	0.275**	-0.042	0.315**	0.039	0.383**	0.388**	-0.007	
14. **Threshing %**	0.274**	0.285**	0.088	0.099	0.177**	0.222**	-0.324**	0.472**	-0.118	0.391**	0.299**	-0.107	0.295**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**

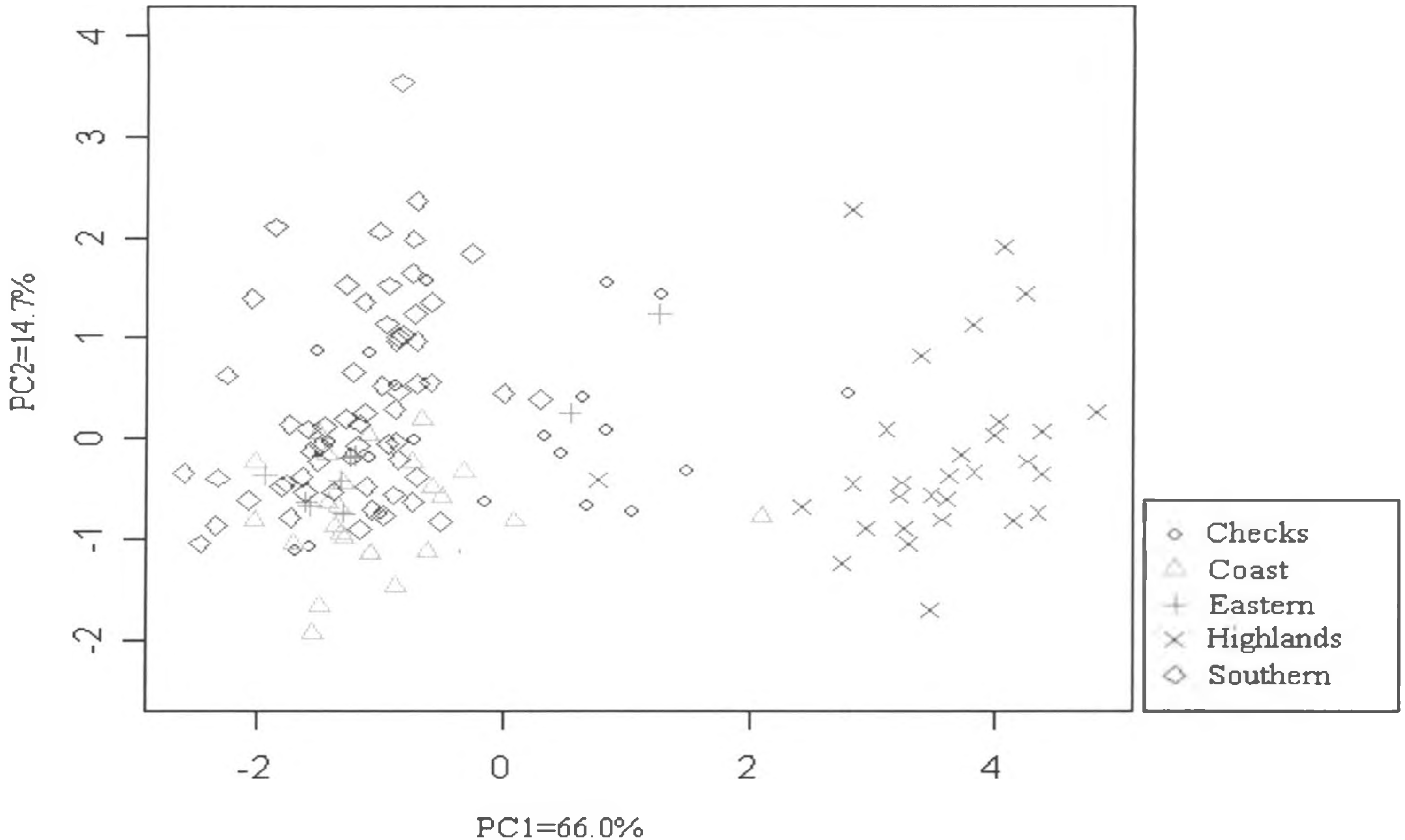
** $P<0.05$

Appendix 9. Quantitative traits correlation matrix: Ilonga

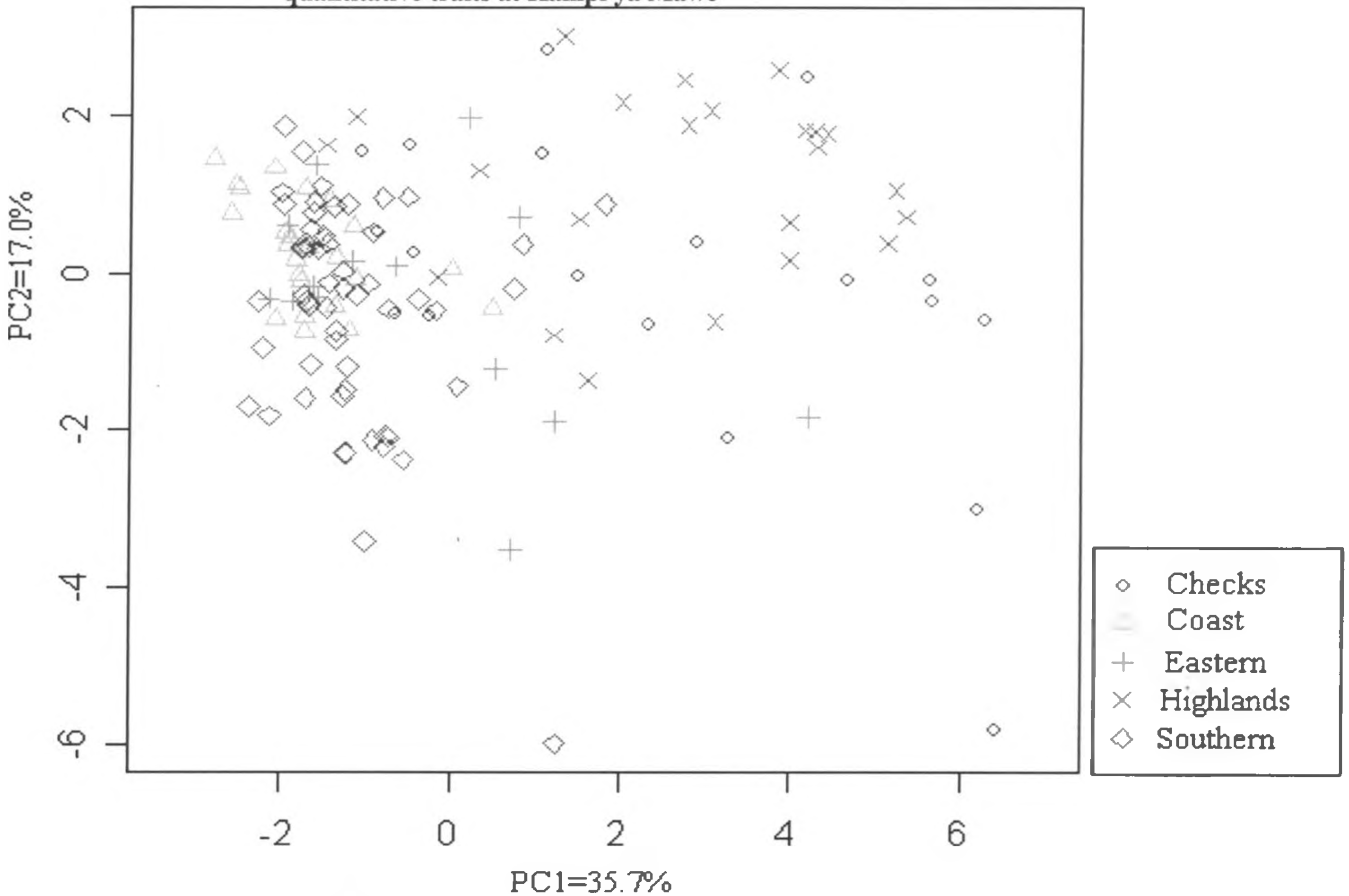
1.	100 seed mass						
2.	Days 50% flower	-0.567**					
3.	Days 50% maturity	-0.510**	0.941**				
4.	Grain yield	0.517**	-0.741**	-0.691**			
5.	Plant height	-0.384**	0.673**	0.642**	-0.388**		
6.	Primary branches	-0.132	0.349**	0.297**	-0.222**	0.323**	
7.	Seeds/pod	0.141	-0.326**	-0.280**	0.272**	-0.177	-0.174
		1	2	3	4	5	6

** P<0.05

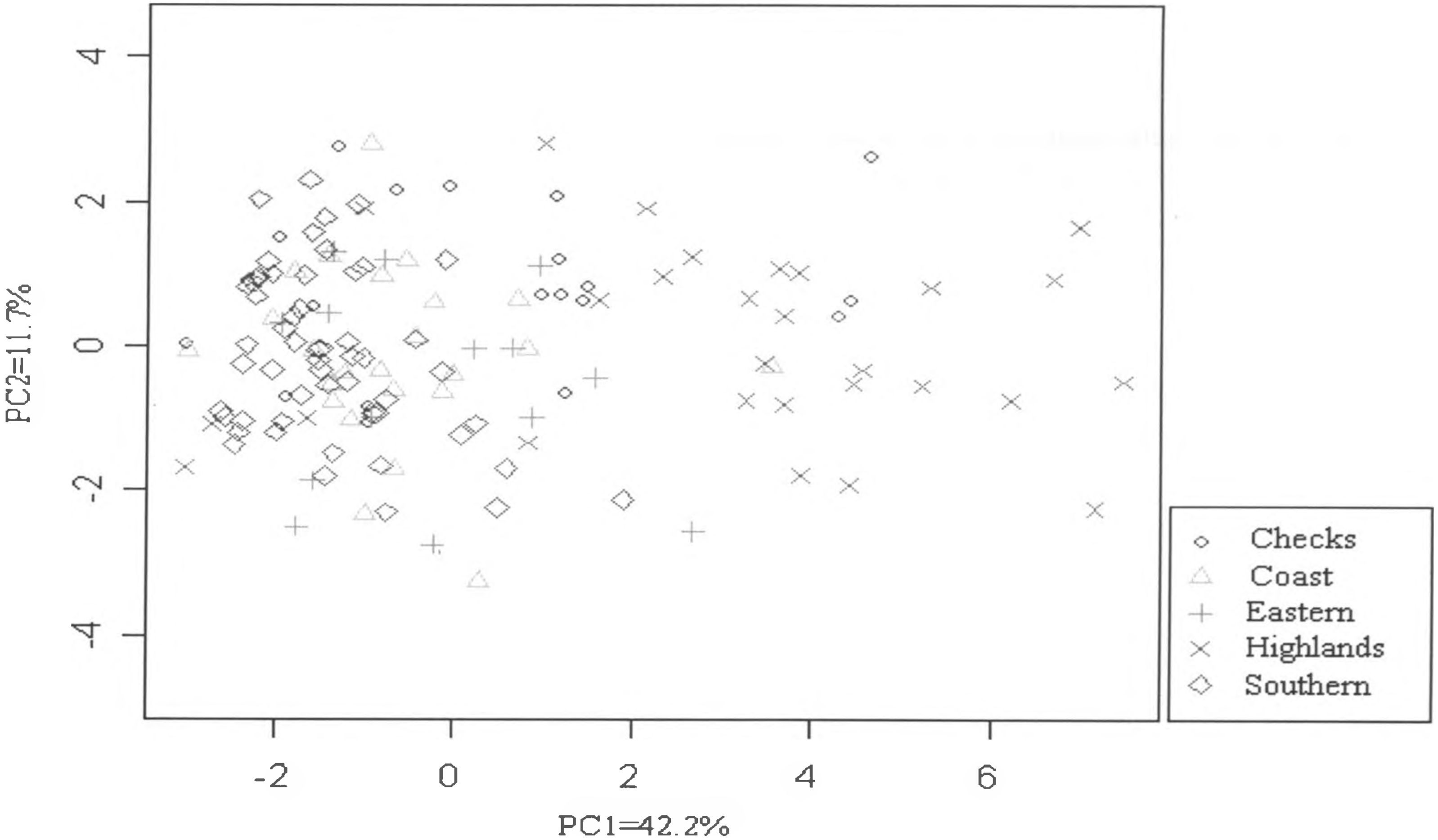
Appendix 10. Scatter diagram for first two principal components based on 14 quantitative traits at Ilonga

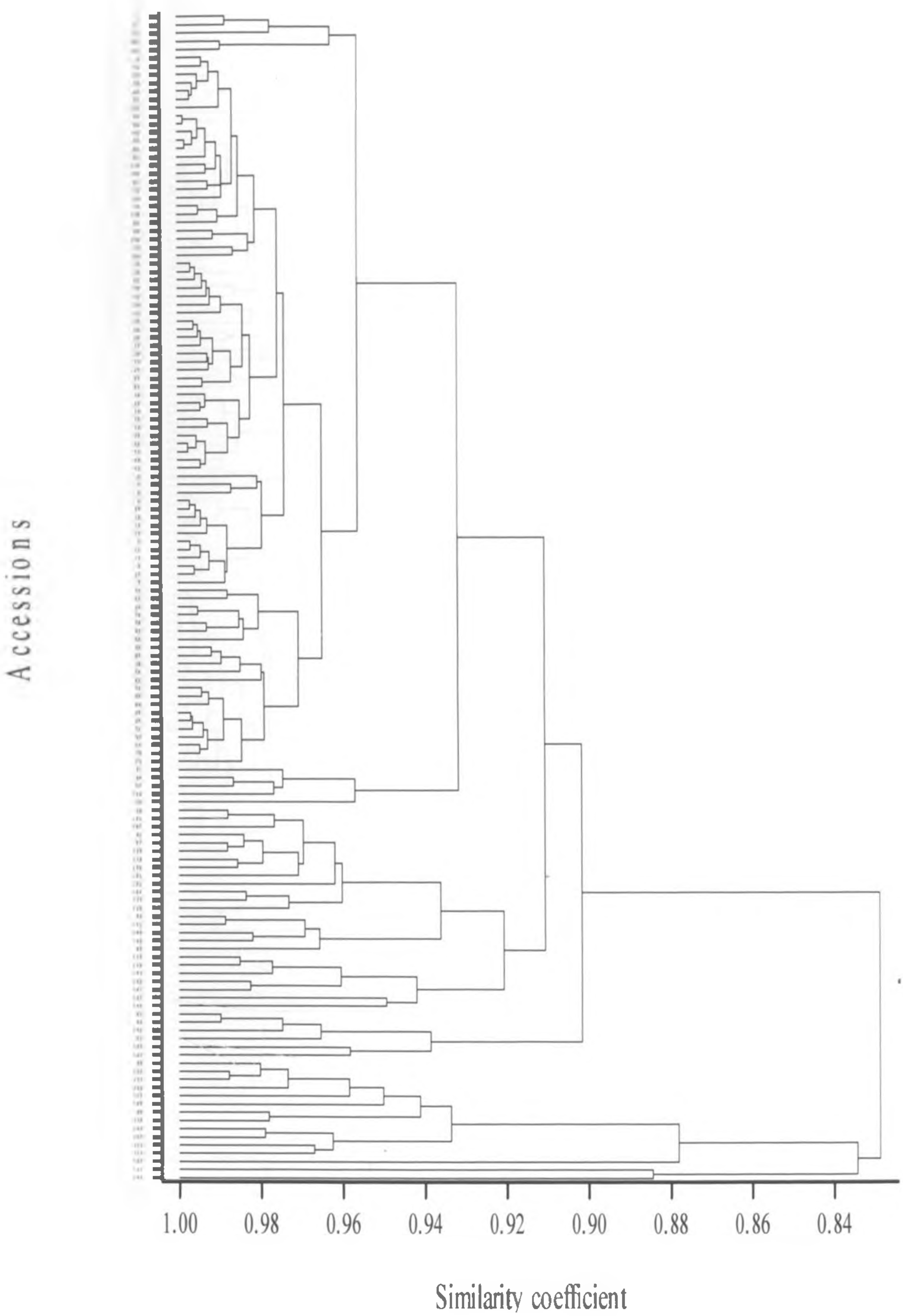


Appendix 11. Scatter diagram for first two principal components based on 14 quantitative traits at Kampi ya Mawe

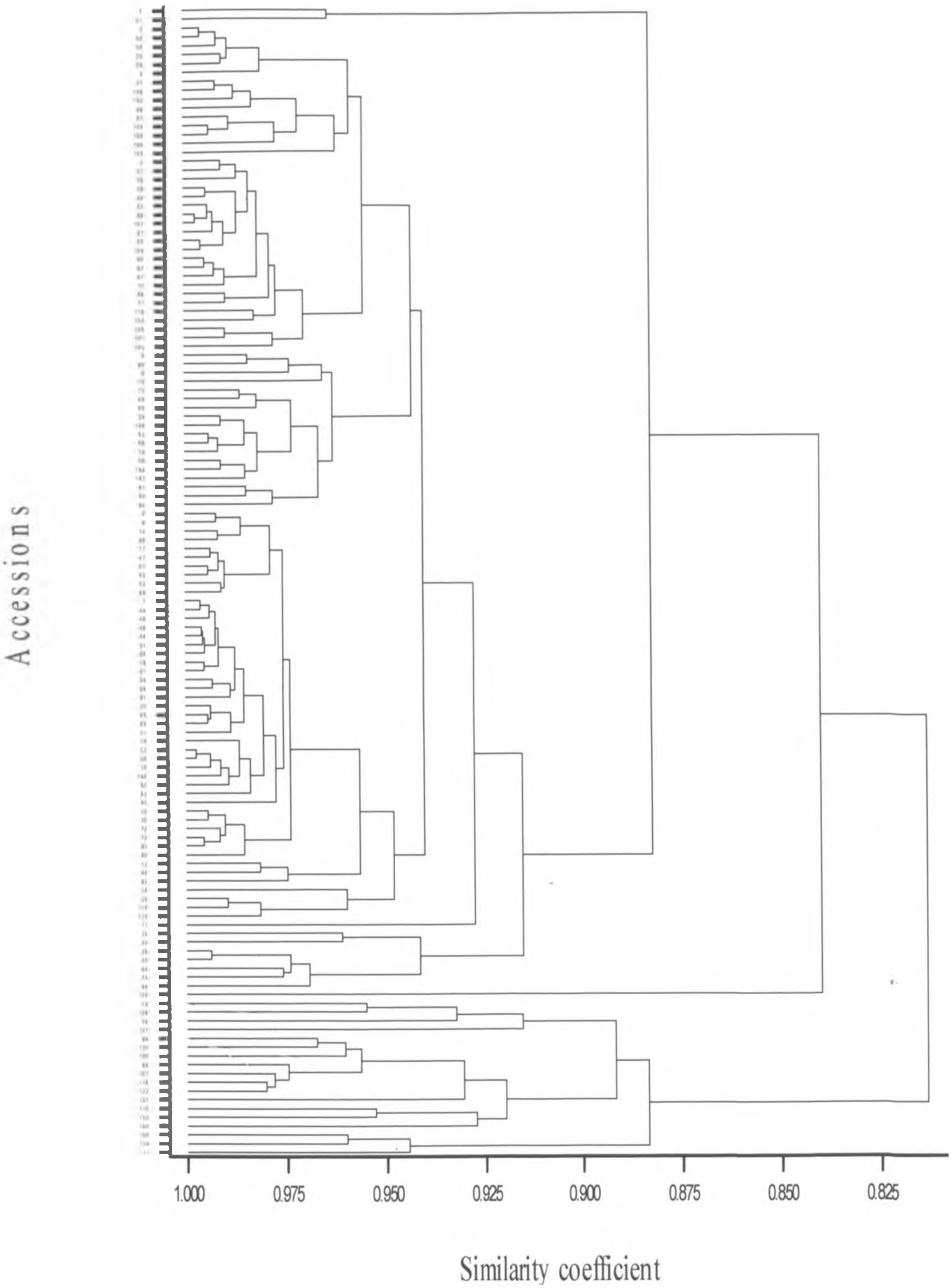


Appendix 12. Scatter diagram for first two principal components based on 14 quantitative traits at Kabete





Appendix 13. Dendrogram for 123 accessions and 21 checks based on average linkage for the 14 quantitative traits means across 3 sites



Appendix 14. Dendrogram for 123 accessions and 21 checks based on average linkage for the 14 quantitative traits means at Kabete