ADAPTABILITY AND STABILITY OF COWPEA *(Vigna unguiculata)* LINES IN KENYA COASTAL REGION

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DECLARATION

This thesis represent original work done by me and have not been submitted in form for any degree or diploma to any other university. Where use was made of the work of others, it has been duly acknowledged in the text.

Signed …….

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Approval

We, the supervisors, certify the above statement is correct.

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DEDICATION

I dedicate this piece of work to memory of my late father who continuously encouraged me to keep on upgrading myself in my career.

To my mother who missed me so much as a result of few visits due to my various engagements

To my wife and children for their understanding and faith in me.

ABSTRACT

Cowpea (*Vigna unguiculata* L. Walp.) is one of the most important grain legume grown in sub- Saharan Africa. About 12.5 million tons of cowpea grain are produced worldwide each year with the majority (over 94%) of the production taking place on low input, subsistence farms. This crop is most important in the semi-arid and warm areas of Africa where other crops may fail due to poor adaptation to heat, drought and low soil fertility conditions. The experiment was conducted at Kenya Agricultural Research Institute (KARI), Mtwapa and its sub-centres at Msabaha and Mariakani. The agroecological zones (AEZ's) for the sites are; coastal Lowland 3 (CL3) for Mtwapa, coastal lowland 4 (CL4) for Msabaha and coastal lowland 5 (CL5) for Mariakani. The sites have sandy soils with pH of between 5.3 to 6.9. Fifteen cowpea lines were sourced from the KARI Genebank which included three improved cultivars that have been tested in central and eastern regions of Kenya. These genotypes have varying agronomic traits and were collected from various regions of Kenya. They are; K033057, K033073, K003731, K005169, K026753, K027092, K003962, K046781, K028613, K047079, K047078, K047121, KVU 27-1, M 66 and K 80. The checks were the local variety and improve variety K 80. Planting was done in the short rains season of 2012 and in the long rains season of 2013. Planting was done at a spacing of 60 cm × 30 cm. The trial was randomized complete block design (RCBD) with three replications. The location of the sites was at Mtwapa (CL3), Msabaha (CL4) and Mariakani (CL5). The objective of this study was to contribute to increased food production in coastal Kenya through development of high yielding, drought tolerant and farmer acceptable cowpea lines. The data collected included both qualitative and quantitative traits – it was on stand count, days to emergence, days to flowering, days to pod-setting, days to maturity, number of pods per plant and number of seeds in a pod. At maturity the different lines were harvested, weighed with the pods, then threshed and the grain yield per plot measured. 100 seed weight was also recorded per plot. The net plot, or where the data was collected, was from the two middle rows of the plot. The year effects was clearly manifested in the agronomic traits and seed quality of the cowpea evaluated. Generally, the means of 2013 were higher than those of 2012 for days to flowering, podding, maturity, pods per plant, length of pods, height of plants, seeds per pod, seed length, seed width, pod weight, grain yield and seed weight. The potential of the genotypes were better expressed in long rains 2013 compared to short rains 2012 due to conducive weather prevailing in 2013. The superiority of K005169 in all the agroecological zones in grain yield is observed making the genotype a candidate for consideration in the breeding with others to introgress the genes for high yield potential. The 16 genotypes attained maturity within 70 to 76 days after planting and can therefore be classified as early maturing types. Of the 16 genotypes tested in the three agroecological zones of the lowland coast region, five have shown outstanding performance across the test environments. They are K005169, KVU 27-1, M66, K003962 and K046781. These genotypes have manifested their adaptability and stability across test environments and can be recommended for introduction in the region and will contribute to increased production of cowpea.

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LIST OF ABBREVIATIONS

FAO	Food and Agriculture organization
FAOSTAT	Food and agriculture organization statistics division
GEI	Genotype × Environment interaction
IITA	International Institute of Tropical Agriculture
KARI	Kenya Agricultural Research Institute
KALRO	Kenya Agricultural and Livestock Research Organization

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CHAPTER 1

INTRODUCTION

1.1 Background Information

Cowpea (*Vigna unguiculata* L. Walp.) is one of the most important grain legumes grown in sub- Saharan Africa (Ehlers and Hall, 1997; Timko and Singh. 2008). About 12.5 million tons of cowpea grain are produced worldwide each year with the much (over 94%) of the production taking place on low-input, subsistence farms in Africa (Langyintuo *et al*., 2003; FAOSTAT, 2013). This crop is most important in the semi-arid and warm areas of Africa where other crops may fail due to poor adaptation to heat, drought and low soil fertility conditions (Gwathmey and Hall, 1992; Ehlers and Hall, 1997; Singh *et al*., 1999; Singh and Matsui, 2002; Hall, 2004). Of the major six world producers of cowpea, five are in Africa - Nigeria, Niger, Burkina Faso, Senegal and Mali (Fery, 2002; FAOSTAT, 2013).

Cowpea is the second most important grain legume in Kenya after beans *(Phaseolus vulgaris)* (Muthamia and Kanampiu, 1996). The area under cowpea in Kenya is estimated at 215,269 ha (FAOSTAT 2013) as in Table 1.

Table 1: Acreage (ha) and production (tons) of cowpea in Kenya

Year	Acreage (ha)	Production (tons)
2012	215,269	113,961
2011	197,980	81,534
2010	168,273	72,274
2009	124,302	60,152
2008	148,157	47,958
2007	130,163	83,251
2006	161,971	87,808
2005	72,654	36,184

Source: FAOSTAT (2013)

Although 85% of the total area under the crop is in Eastern province, cowpea ranks first among grain legumes in Coast province of Kenya. The crop is mostly grown under intercropping systems with maize *(Zea mays)* and/or cassava *(Manihot esculenta).*Two characteristics add to its agronomic importance: drought tolerance and interaction with bacteria (Rhizobium sp.) to fix nitrogen and so enhance soil fertility (Eloward and Hall, 1987; Sanginga *et al.,* 2003). It also play an important role in suppression of weeds, while at the same time it is eaten as a vegetable while growing and dry seed after maturity (Kamau and Weru, 2001). It is a deep rooted crop and grows well in sandy soils (Dadson *et al.,* 2003; Lauriault and Kirksey, 2007). The crop can fix about 240 kg ha^{-1} of atmospheric nitrogen and make available about 60-70 kg ha^{-1} for the succeeding crops grown in rotation with it (CRI, 2006; Aikins and Afuakwa, 2008; Kamau and Weru, 2001).

Cowpea is often referred to as the ‘’poor man’s meat’’ because of its high protein content of 20 -25% and good nutritional values (Diouf and Hilu, 2005). The mean crude protein levels for leaves, grains and crop residues are 32-34%, 23 -35% and 11-12%, respectively (Imungi and Porter, 1983). The leaves are also a good source of minerals including Iron (Fe), Calcium (Ca), Phosphorous (P) and Zinc (Zn). The crop is highly palatable, very nutritious, and relatively free of anti nutritive factors (Kay, 1979). The fruits are consumed at all stages of growth (e.g., green pods, fresh or dry seeds) and young leaves are often used for soups and stews (Quaye, *et al.*, 2009). In addition to its value as human food, cowpea hay is an important source of animal fodder (Tarawali *et al.*, 2002).

Cowpea is well adapted to arid and semi-arid areas due to its morphological as well as genetic makeup. Its deep rooted system and early maturity are some of the factors that make it adapted to hostile environments. Other than being a major source of cheap

protein, cowpea is a dependable source of income mainly from sale of leaves as a vegetable.

Farmers at the coast of Kenya get very low grain yields (100 -300 kg ha^{-1}) and this has been attributed to a number of factors such as insect pest damage, lack of high yielding cultivars and poor crop management practices (Kega *et al.,* 1994; Otieno *et al.,* 1994). Another problem expressed by the farmers is lack of appropriate seed varieties at planting.

1.2. Statement of the Problem

Cowpea is a tropical grain legume widely distributed in Sub- Saharan Africa, Asia and South America (Singh *et al.,* 1997). Due to its high protein content (20-25%), cowpea plays a major role in human nutrition. It tolerates low soil fertility due to its high rate of nitrogen fixation.

The available new lines of cowpea have not been tested for their adaptability and stability in the coastal region, thus this study will be vital in identifying promising superior genotypes.

In coastal Kenya cowpea is mainly grown under intercropping systems with maize and/or cassava. Despite its importance in Kenya, its yields in the farms remain low ranging from 100 – 300 kg ha^{-1} ((Kega *et al,* 1994; Otieno *et a*l, 1994). This is attributed to both biotic and abiotic stresses e.g., lack of high yielding cultivars and poor crop management practices. Of these, lack of high yielding cultivars is the main cause of low cowpea productivity.

1.3. Broad objective

The broad objective of this study is to contribute to increased food production in Kenya through development of high yielding, drought tolerant and farmer acceptable cowpea lines.

1.4. Specific objectives

The specific objectives of the study are:

1. To screen promising cowpea genotypes for high yielding and drought tolerance at the coastal region that can be exploited in a breeding programme.
2. To assess the genotype by environment interaction and yield potential of cowpea genotypes under coastal lowlands conditions.

1.5. Hypothesis

1. Genetic variability exists in cowpea lines to be evaluated at agro ecological zones in coastal region.

2. The cowpea genotype being tested at the coastal region are widely adapted.

1.6. Justification

Cowpea is the pulse of choice in Coastal Kenya as it does fairly well compared to other pulses in terms of production. It is among the staple foods in the region supplying not only basic energy and protein, but also vitamins and minerals (iron and calcium).

It is an inexpensive source of protein in the diets of most communities at the coast. The varieties the farmers currently grow are inherently low yielding and it is against this background that new varieties could be introduced to the area by testing their adaptability with the objective of availing to farmers suitable high yielding varieties.

The genotypes that show adaptability to the area can also be used in future breeding work for improvement of the local germplasm.

Drought also is increasingly becoming a major yield limiting constraint in coastal region. It is manifested in the form of high variability in rainfall amount and distribution over different agro-ecologies and seasons. Hence, a breeding programme aimed at developing adaptable cultivars needs to be established.

Genotype by environment interaction and yield stability of different cowpea genotypes available in the country, need to be investigated in order to identify the adaptable and stable genotypes for different locations along in the coastal region of Kenya.

There is need therefore to introduce new lines to test their adaptability and stability with the aim of recommending them to the farmers to boost the production of cowpea.

CHAPTER 2

LITERATURE REVIEW

2.1. Origin, evolution and cultivation of cowpea

Cowpea (*Vigna unguiculata* L. Walp.) is also commonly referred to as *southern pea, blackeye pea, crowder pea, lubia, niebe, coupe or frijole* is an annual legume. It originated from Africa where it is widely grown. Outside Africa, it is also grown in Latin America, South East Asia and in the southern United States. It is chiefly used as a grain legume crop, for animal fodder, or as a vegetable. The history of cowpea dates to ancient West Africa cereal farming, five to six thousand years ago, where it was closely associated with the cultivation of sorghum (*Sorghum bicolor (L) Moench*) and pearl millet(*Pennisetum glaucum*) (Waters, 1987). Cowpea provides the major source of dietary protein to millions of people across large swathes of northern sub–Saharan Africa. As one of the most drought tolerant grain legume crops, its productivity is challenged by a number of environmental constraints but, until just recently, little investment has been dedicated to its improvement (Muli and Saha, 2001; Hall, 2012).

Cowpea is one of the most important food and forage legume in the semi-arid tropics that includes parts of Asia, Africa, Southern Europe, Southern United States, and Central and South America (Singh, 2005; Timko *et al.,* 2007). It is a multifunctional crop, providing food for man and feed for livestock as it serves as a valuable and dependable revenue generating commodity for farmers and grain traders (Singh, 2002; Langyintuo *et al.,* 2003). The cowpea plant is a herbaceous, warm-season annual requiring temperature of at least 18°C (Craufurd *et al.,* 1997). A seed of cultivated cowpea types weighs between 80 mg and 320 mg and is round to kidney-shaped.

Cowpea seed is a nutritious component in the human diet, as well as a nutritious livestock feed. It contains 24.8% protein, 1.9% fat, 6.3% fiber, 63.6% carbohydrates, 0.00074% thiamine, 0.00042% riboflavin and 0.00281% niacin (Bressani, 1985). The protein in cowpea seed is rich in lysine and tryptophan, compared to cereal grains. Because cowpea seed is deficient in methionine and cystine compared to animal proteins, it is valued as a nutritional supplement to cereals (Bressani, 1985). Cowpea can be used at all stages of growth as a vegetable crop. The tender green leaves are an important food source in Africa and are prepared as a pot herb, like spinach. Immature snapped pods are used in the same way as snapbeans, often being mixed with other foods. Green cowpea seeds are boiled as a fresh vegetable, or may be canned or frozen. Dry mature seeds are also suitable for boiling and canning (Bressani, 1985).

In many areas of the world, the cowpea is the only available high quality legume hay for livestock feed. Digestibility and yield of certain cultivars have been shown to be comparable to alfalfa. Cowpea may be used green or as dry fodder. It is also used as green manure crop, a nitrogen fixing crop, or for soil erosion control. Similar to other grain legumes, cowpea contains trypsin inhibitors which limit protein utilization (Muli and Saha, 2001).

Cowpea has been reported to be drought tolerant crop (Ehlers and Hall, 1997; Singh *et al.,* 1997a). The crop employs a combination of mechanisms that include escape, avoidance and tolerance. Cowpea drought escape results from the ability to hasten or delay its reproductive cycle (Gwathmey and Hall, 1992); avoidance results from its deep roots, strong stomatal sensitivity, reduced growth rate, leaf area reduction and selective moisture remobilization with major dedication to the upper leaves and growing tips (Turk et al., 1980; Turk and Hall, 1980a; Mai-Kodomi *et al.*,1999a;

Singh, 1999a); while tolerance results from its osmotic adjustment (Turk and Hall, 1980a; Mai-Kodomi *et al.,* 1999a; Chiulele and Agenbag, 2004).

The precise origin of cultivated cowpea has been a matter of speculation and discussion for many years. Early observations showed that the cowpeas types in Asia are very diverse and morphologically different from those growing in Africa, suggesting that both Asia and Africa could be independent centres of origins for the crop (Padulosi and Ng, 1997).

However, the absence of wild cowpeas in Asia as possible progenitors has led some to question whether the Asian centre of origin is valid. All the current evidence suggests that cowpea originated in Southern Africa, although, it should be noted that it is difficult to ascertain where on the continent the crop was first domesticated (Ng and Maréchal, 1985). Based on the distribution of diverse wild cowpeas along the entire length of eastern Africa, from Ethiopia to Southern Africa, Baudoin and Maréchal (1985) proposed that East and Southern Africa to be the primary region of diversity, and West and Central Africa to be the secondary centre of diversity. These researchers also proposed Asia as a third centre of diversity. More recent studies strongly indicate that the highest genetic diversity of primitive wild forms of cowpea can be found in region of the African continent currently encompassed by Namibia, Botswana, Zambia, Zimbabwe, Mozambique, Swaziland, and South Africa, with among the most primitive species observed in the Transvaal, Cape Town and Swaziland (Padulosi, 1987; 1993; Padulosi et al., 1990; 1991). Based on this latter observation, Padulosi and Ng (1997) suggested that southern Africa may be an origin of cowpea with subsequent radiations of the primitive forms to other parts of southern and eastern Africa, and subsequently to West Africa and Asia. The small seed size of

wild cowpeas likely facilitated their dispersal by birds throughout East and West Africa contributing to the diversity and development of secondary wild forms (Ba *et al.,* 2004). Human selection for the larger seeds and better growth habits from the natural variants in the wild cowpeas likely led to diverse cultigroups and their domestication in Asia and in Africa (Steele, 1976; Ng and Padulosi, 1988; Ng, 1995; Ba *et al.,* 2004).

Ng (1995) postulated that during the process of evolution of *V. unguiculata* there was change of growth habit, from perennial to annual breeding and from predominantly outbreeding to inbreeding, while cultivated cowpea (subsp. *unguiculata)* evolved through domestication and selection of the annual wild cowpea (var. *dekindtiana).* During the process of domestication and after the species was brought under cultivation through selection, there was a loss in seed dormancy and pod dehiscene, corresponding with an increase in seed and pod size. The precise location of origin of where cowpea was first domesticated is also still under speculation.

The wide geographical distribution of var. *dekindtiana* throughout sub –Saharan Africa suggests that the species could have been under cultivation in any part of the region. However, the centre of maximum diversity of cultivated cowpea is found in West Africa, in an area encompassing the savannah region of Nigeria, southern Niger, parts of Burkina Faso, Northern Benin, Togo, and the northwestern part of Cameroon (Ng and Maréchal, 1985). Carbon dating of cowpea (or wild cowpea remains from Kimtampo rock shelter in central Ghana) has been carried out (Flight, 1976), and is the oldest archaeological evidence of cowpea found in Africa.

2.2. World Cowpea Production

Cowpea is cultivated on about 10.7 million hectares worldwide out of which more than 96% is located in Africa (FAOSTAT, 2013). Considerable production also takes place in Asia and Oceania, the Middle East, southern Europe, southern USA, and Central and South America (Singh *et al.,* 2002). Most of the world cowpea production comes from the West-Central Africa where countries such as Nigeria, Niger, Burkina Faso, Senegal, Ghana, Cameroon and Mali are the most important producers (Fery, 2002; FAOSTAT, 2013). Nigeria contributes more than 44% of the total world cowpea grain production (FAOSTAT, 2013). The crop also has significant importance in the East and Southern Africa where Ethiopia, Kenya, Tanzania, Malawi, Botswana, Zimbabwe and Mozambique are important producers (Ehlers and Hall, 1997; NGICA, 2006). Despite its widespread cultivation, average cowpea yields on the farmers' field are low (<300 kg ha^{-1}) (Takim AND Uddin, 2010). The low yields have been attributed to a number of the biotic stresses such as insect pests, nematodes, diseases and parasitic weeds and abiotic stresses such as drought, high temperature, low soil fertility, low pH and aluminium toxicity (Singh, 1985; Singh and Jackai, 1985; Ehlers and Hall, 1997; Hall, 2004).

2.3. Nutritional Value of Cowpea

Cowpea is rich in the essential amino acids lysine and tryptophan similar to other legumes, (Timko and Singh, 2008). However, the protein nutritive value of these legumes is lower than that of animal proteins because they are deficient of sulphur amino acids and contain a non-nutritional factors (phytates and polyphenols), enzyme inhibitors (against trypsin, chymotrypsin and R-amylase) and hemagglitinins (Jackson, 2009). In addition to minerals, vitamins and folic acid are some of the important constituents of the cowpea seeds. Folic acid and vitamin B are necessary

during pregnancy to prevent birth defects in the brain and spine. The content is found in higher quantity in cowpea compared to other plants (Hall, *et al.,* 2003; Timko and Singh, 2008). Total seed protein content in seed ranges from 23% - 32% of the seed weight while total crude protein in foliage ranges from 14-21% and in crop residues, it is 6-8% (Nielsen *et al.,* 1993). Although cowpea has no toxic effect to ruminants, for the monogastrics diet containing more than 20-25% cowpea grain should be subjected to heat treatment to reduce trypsin inhibitors (Cook et al., 2005). The presence of the high protein content in all cowpea parts consumable by human and animal (leaves, stems, pods and seed), is the key factor in alleviating the malnutrition among women and children and improvement of health status of the livestock in resource limited households where regular access to animal protein is limited due to low economic status (Hall, 2012).

2.4. Taxonomy of Cowpea

The cytotaxonomy of cowpea is relatively simple, being uncomplicated by polyploidy (2n = 2x = 22) and with apparently little genetic and no chromosomal divergence of the cultivars from their acknowledged ancestors (Steele, 1984).

Cowpea is a dicotyledonous crop in the order *Fabaceae,* subfamily *Faboideae* (Syn. *Papillilnoideae*), tribe *Phaseoleae*, subtribe *Phaseolinae*, genus *Vigna* and section *Catiang*. It is a diploid plant containing 22 chromosomes *(2n=2x=22*) (Timko and Singh, 2008) and its nuclear genome size is estimated to cover 620 mega base pairs (Mbp) (Timko et al., 2008). The genus was divided into subgenera based upon morphological characteristics, the extent of genetic hybridization and geographical distribution of the species. The major groups consist of the African sub-genera *Vigna*

and *Haydonia*, the Asian sub-genera *Ceratotropis*, and the American sub-genera *Sigmoidotropis* and *Lasiopron* (Timko and Singh, 2008). *V. unguiculata* sub-species *unguiculata* includes four cultivated group: *unguiculata biflora* (or *cylindrical*), *sesquipedalis*, and *textilis* (Ng and Maréchal, 1985). *V. unguiculata* sub-species *dekindiana*, *stenophylla*, and *tenuis* are intermediate wild progenitors of cultivated cowpea and form the major portion of the primary gene pool of cowpea. Fatokun and Singh (1987) pointed out that wild species like *pubescence* that do not readily hybridize and show some degree of pollen sterility, form a secondary gene pool.

2.5. Botany of Cowpea

The seed pods contain between 8 to 18 seeds per pod and are cylindrical and curved or straight. The seed coat varies in texture (e.g. smooth, rough, or wrinkled), colour (e.g. white, cream, green, buff, red, brown, black), and uniformity (e.g. solid, speckled, or patterned). Seeds of the most well known cowpea types, such as "blackeye pea" and "pinkeye," are white with a round irregularly shaped black or red pigmented area encircling the hilum that gives the seed the appearance of an eye.

2.6. Phenology of Cowpea

Two of the wild species; subsp. *dekindtiana* in the Africa savannah zone and Ethiopia; and subsp. *mensensis* in forests, have scabrous, dehiscent pods and seed dormancy not found in the cultivars (Ba *et al.*, 2004).

Cowpea is a warm season, annual, herbaceous legume. Plant types are often categorized as erect, semi-erect, prostrate (trailing), or climbing. There is much variability within the species. Growth habit ranges from indeterminate to fairly determinate with the non-vining types tending to be more determinate. Cowpea

generally is strongly taprooted. Root depth has been measured at 240cm (2.4m) eight weeks after seeding (Hall, 2012).

Cowpea pods are smooth, 15 to 25 cm long, cylindrical and generally somewhat curved. As the seed approach the green mature stage for the use as a vegetable, pod colour may be distinctive, most commonly green, yellow or purple. As the seed dry, pod colour of the green and the yellow types becomes tan and brown (Hall, 2012).

Cowpea seed ranges in size from the very small wild types to nearly 35cm long and the number of seeds per 500 grams ranges from 1600 to 4300. Seed shape is a major characteristic correlated with seed development in the pod. Seeds develop a kidney shape if not restricted within the pod. When seed growth is restricted by the pod the seed becomes progressively more globular (Technical Assistance Bureau, Agency for International Development, 1974). The seed coat can be either smooth or wrinkled and of various colours including white, green, buff, red, brown and black. Seed may also be speckled, mottled or blotchy. Many are also referred to as "eyed" (blackeye, pinkeye, purple hull, etc.) where the white coloured hilum is surrounded by another colour. Emergence is epigeal (similar to common bean and lupin) where the cotyledons emerge from the ground during germination (Timko, 2008). This type of emergence makes cowpea more susceptible to seedling injury, since the plant does not regenerate buds below the cotyledonary node. The trifoliate leaves develop alternately. Leaves are smooth, dull to shiny, and rarely pubescent. Commonly, the terminal leaflet is longer and larger than the lateral leaflets. There is a wide range in leaf size and shape.

Cowpea generally is day neutral with flowers borne in multiple racemes on 8 to 50 cm long flower stalk (peduncles) that arise from the leaf axil. Two or three pods per

peduncle are common and often four or more pods are carried on a single peduncle. The presence of these long peduncles is a distinguishing feature of cowpea and this characteristic also facilitates harvest. The open display of flowers above foliage and the presence of floral nectaries contribute to the attraction of insects.

2.7. Environmental Requirements

2.7.1. Climate and Edaphic factors

Cowpea is a warm-season crop well adapted to many areas of the humid tropics and temperate zones. It tolerates heat and dry conditions, but it is intolerant of frost. Germination is rapid at temperatures above 36.1°C. Colder temperatures will cause slow germination. Cowpeas are grown under both irrigation and non-irrigated regimes. The crop responds positively to irrigation but will also produce well under dryland conditions. Cowpea is more drought resistant than common bean. Drought resistance is one reason that cowpea is such an important crop in many under developed parts of the world. If irrigation is used, more vegetative growth and some delay in maturity may result. Application rates should ensure that the crop is not overwatered, as this will suppress growth by lowering soil temperatures. The most critical moisture requiring period is just prior to and during bloom (Technical Assistance Bureau, Agency for International Development, 1974; Hall, 2004).

Cowpea can thrive on highly acid and neutral soil but is less well adapted to alkaline soils and performs best on well drained sandy loams or sandy soils where soil pH is in the range of 5.5 to 6.5 (Duke and James, 1990).

2.8. Constraints to Cowpea Production

2.8.1. Biotic stress

Cowpea is susceptible to many pests and pathogens that attack it at all stages of its growth (Allen, 1983). For instance, cowpea wilt caused by *Fusarium oscyporium*, cowpea root rot caused by a nematode (*Meloidogyne spp*.) and cowpea bacterial blight caused by *Xanthomonus vignicola.* Cowpea Yellow Mosaic Virus (CYMV) is of importance and it is distributed in East Africa (Kenya and Tanzania) and West Africa (Nigeria, Togo). It is essentially an African virus though occasionally reported in America (Surinam, USA). CYMV causes yield losses of 80-100%. The earlier the infection the greater the yield loss.

CYMV is readily sap transmitted and is seed borne at low level (1-5%). But little initial seed borne infection rapidly spreads through entire crops through activity of *ootheca mutabilis* and other beetles, hoppers and thrips which are the vectors.

Control is through growing resistant varieties and either spraying biological or chemical insecticides. Some of the major insect enemies of cowpea are cowpea weevil (*Callosobruchus maculates*), cowpea cuculus (*Chalcodermus serums*), cowpea aphid (*Aphis craccivora*) and the southern cowpea weevil (*Mylabris quadrimaculatus*) (Lars et al, 2012). Losses due to pest attacks or diseases can be as high as 90% (IITA, 2000).

2.8.2. Abiotic stress

2.8.2.1. Environmental stress in plants

The effects of environment on plant growth may be divided into enforced damage effects (stress), caused by environment, and adaptive responses, controlled by the

plant (resistance) (Fitter and Hay, 1987). Damage, which may be manifested as death of all or part of the plant, or merely as reduced growth rate due to physiological malfunction, is a common phenomenon and the agents are various: temperature, water availability, soil chemistry, physical properties and others such as air pollution, wind and diseases. However, the most important environmental agent affecting plant growth in the semi-arid tropical zone is drought (Hall, 2004).

There are both meteorological and agricultural definitions of drought. A meteorological drought is defined as the time period when the amount of precipitation is less than some designated percentage of the long term mean (Linsley *et al*., 1959; Katz and Glantz, 1977. Agricultural drought on the other hand, is defined in term of seasonal vegetation development.

Drought stress occurs when water uptake from the soil cannot balance water loss through transpiration (Levitt, 1980). The subsequent cellular water loss is referred to as dehydration. Drought may start at any time, last indefinitely and attain many degrees of severity. It can occur in any region of the world, with an impact ranging from slight personal inconveniences to endangered nationhood (Hounam *et al*., 1975). Agricultural drought occurs when there is not enough moisture available at the right time for the growth and development of crops. As a result, yields decline (Glantz, 1987). Drought is currently the most important abiotic stress limiting cowpea production worldwide. Breeding for improved drought tolerance offers hope for increasing production and productivity particularly in sub- Saharan Africa. However, progress in cowpea breeding for improved drought tolerance will depend mainly on the availability of genetic variability for the traits conferring drought tolerance, effective screening methods and knowledge of genetic control of trait conferring drought tolerance (Singh *et al.,* 1999a; Hall, 2004).

2.9. Breeding for Wide adaptation

Several methodologies have been proposed to evaluate genotype adaptability and stability in a set of environments, each adopting different criterion to define and estimate these parameters (Claudio *et al*., 2002). Studies of genotype adaptability and stability allow for the identification of those varieties which best respond in a predictable manner to environmental variation (Cruz and Regazzi, 1994). The adaptation of a crop, its ability to survive in a particular environment and to exploit its various features productively, is under extremely complex genetic control.

A plant must be able to withstand extremes of cold and heat, excess or lack of water, varying photoperiods and light intensity, and a range of soil physical and chemical conditions. It must be capable of exploiting both its physical and biological environments, and be able to remain productive under pest and disease pressures. It must thrive in diversity of locations and under conditions that may vary widely, gradually or rapidly, throughout its life cycle. However, it is not possible to have a plant with all those attributes.

The underlying genetic control of a crop's interaction with its environment is complex and often poorly understood. Response to a single factor of environment, such as daylength or to the deficiency of a particular soil nutrient, might be under simple genetic control. The response to such single factors can mask responses to other factors and be overriding in determining a plant's adaptability (Allard, 1992). It also involves an interaction between and among complex gene systems and a multitude of environmental variables. Over the thousands of year of domestication and spread from their centres of origin, crops have become increasingly adapted to a wide range of environments. This broad adaptation has been both through the accumulation of genes responsible for specific adaptation to individual production environments and, more

recently through the development of cultivars with wide adaptability to a great range of environments as in the case of modern wheat and rice cultivars (Evans, 1993).

The fact that adaptability is determined both by major and minor genes and that more or less complex 'co-adapted genes complexes' may be developed which influence adaptability to specific environments (Allard, 1992). This has important consequences for the conservation of genetic resources, the identification of suitable parental lines for hybridization programmes as well as for breeding and selection methods.

The use of adapted local varieties as the primary source of variation into which desired characters present in modern cultivars are introgressed maybe an effective strategy for producing cultivars adapted to difficult production environments. Modern cultivars often remain the first choice of breeders searching for specific adaptive traits. Once a desired trait has been introduced into a modern cultivar from either a crop relative or a traditional landrace the improved cultivar will become the primary source of the trait for other breeders. There remains substantial variation in the range of modern cultivars grown in many crops (Allard, 1992) although in a number of crops the amount of variation may well be a limiting factor in their adaptation to specific stress environments.

2.10. Geographic distribution of diversity

Genetic diversity is not distributed uniformly throughout the range of environments in which a crop is grown. Current evidence suggests that geographic distribution accounts for most of the observed variation in wild plant species (Hamrick and Godt, 1990). In crops, geographic distribution pattern reflect both the specific selection pressures prevailing in a particular environment as well as crop history. The most widely studied distribution patterns are for disease resistance genes, and there are

many examples in the literature. Resistance is most commonly found in regions where disease pressures are strongest and that coincide with centres of crop diversity.

In the case of gene resistance to abiotic stresses, there is some support in the literature for the hypothesis that the occurrence of such traits can be correlated with the presence of the particular environmental factor concerned (Rusoke, 1994).

In the search for the desirable traits, not only is the absolute geographic distribution important, but also the allelic frequency. Marshall and Brown (1975) recognized four classes of alleles: common, widely distributed; common, locally distributed; rare, widely distributed and rare, locally distributed. Common locally distributed alleles are most likely to include those of adaptive significance which confer an advantage for the population which possesses them or are necessary for survival in a particular environment (Allard, 1992).

2.11. Genotype × Environment interaction

Genotype × environment interaction often complicates a plant breeder's objective of selecting for high yielding varieties with broad adaptation. This is because the phenotypic responses of different genotypes to changes in environments vary under different conditions. The pattern of changes is different from one genotype to another in one environment (Allard and Bradshaw, 1964). These changes are attributed to physical and physiological status of individual genotypes during growth. The differences in phenotypic expression are due to varietal differences in their stability across environments. Eberhart and Russell, (1966) indicated that a stable genotype shows minimum interaction with the environment. According to Comstock and Mull, (1963), genotype × environment interaction implies of genetic and non-genetic factors on development, often evidenced by different performance of genotypes in different

environments. Hill, (1975) indicated that the presence of genotype × environment interaction implies that the behavior of the genotype in a trial depends upon the particular environment in which they are grown. Fluctuations in weather and weather factors make the environment unpredictable (Gardener, 1961) and according to Falconer (1989) a character measured in two different environments is to be regarded not as one but two.

Genotype × environment interaction (G×E) is the differential genotypic expression to the change in environment (Yan and Hunt, 1998; Annicchiarico, 2002). This definition suggests that for detecting and quantifying G×E interaction for any trait, two elements are necessary, different genotypes and different environments. There are two genotype × environment interactions: cross- over or qualitative and non cross-over interaction or quantitative (Kang, 2002). Cross- over or qualitative interaction is the interaction observed when there is change in ranking of cultivars when grown in different environments while non cross-over interaction is the interaction that is observed when genotypes show changes in magnitude of performance but the rank order of genotypes across environment remains unchanged (Kang, 2002). Studies have indicated that for cultivar development, the cross-over type of interaction is more important than the non cross-over type. This is because the cross-over interaction complicates the selection of high yielding genotypes due to inconsistent performance of these genotypes across locations (Kang, 1998; Annicchiarico, 2002).

Genotype × environment interaction has been reported to be advantageous to crop improvement that targets broad adaptation, but it can also represent opportunities to genetic improvement for specific sites. It represents a barrier to crop improvement (Kang, 1998) because it can contribute to temporal and spatial instability of crop yields (Annicchiarico, 2002). Temporal instability in particular, can impact negatively

on farmers' income and, in case of staple crops, it can contribute to food insecurity at national and household level (Annicchiarico, 2002). On the other hand, G×E interactions may offer opportunities for selection and adoption of genotypes showing positive interaction with the location and its prevailing environmental conditions (exploitation of specific adaptation) or of genotypes with low frequency or poor yield or crop failure (exploitation of yield stability) (Simmonds, 1991; Ceccarelli, 1996). In addition, Yan and Hunt (1998) indicated that genotype × environment interaction motivates crop ecologists, agronomists and plant breeders to define ecological regions, mega-environments and ecotypes and to specify adaptation and yield stability of individual cultivars. Yan and Hunt (1998) concluded that exploring the positive aspects of G×E while avoiding the negative could provide a substantial opportunity for further improvement in food production worldwide.

The causes of genotype × environment interaction have been reviewed by various authors. Kang (1998) and Annicchiarico (2002) indicated that the major interaction can be expected when there is a wide variation between genotypes for morpho-physiological characters conferring resistance or avoidance to one or more stresses, and/or wide variation between environments for incidence of the same stresses. Ceccarelli (1989) indicated that large G×E interactions have frequently been reported between pairs of environments with contrasting levels of one major stress defined as favourable when characterized by low stress and high mean yield and unfavourable when characterized by high stress and low yield. However, Annicchiarico (2002) inferred that large G×E interactions may also occur between pairs of unfavourable environments and even between pairs of moderately favourable environments possessing similar mean yield but with differing combinations of stresses or patterns of one major stress. Annicchiarico (2002) further reported that the type of varieties

used may have an effect on G×E interaction. He indicated that pure lines, clones, single-cross hybrids tend to interact with the environment more than open-pollinated population mixture of pure lines because of their lower richness in adaptive genes and therefore, more susceptible to variation in environmental conditions.

The accurate quantification and better understanding of the biological bases of genotype × environment interaction is crucial for improved food production. Quantification of genotype × environment interaction needs crop varieties to be evaluated in multi-environmental trials (METs). These trials can provide information for cultivar recommendation or for the final stages of selection of elite breeding materials (Annicchiarico, 2002). Multi-environmental trials can be balanced or unbalanced (Yan and Hunt, 1998). The METs are said to be balanced when a set of genotypes are all evaluated in a set of environments so that a complete genotype by environment two-way table is available, or unbalanced when a different set of genotypes are evaluated in different sets of environment so that only an incomplete two-way table is available (Yan and Hunt, 1998).

Genotype × environment interaction occurs when different genotypes responds differently to different environments. G×E varies with the material tested and the sites chosen for testing (Darbeshwar, 2000). Especially complex inherited, quantitative traits are influenced by environmental effects. As with breeding, only the genetic effects can be modified, the ratio of the genetic effect within each trait is of importance. The more effect the genotype has the easier the trait selected. If there is no G × E interaction the genotypes need to only be evaluated in one environment and whichever genotype is the best in that environment will also be the best in any other environment.

2.12. Methods used to measure G×E interactions

Several methods have been proposed to analyse and interpret the genotype × environment interaction. These include: contrasts (Yan and Hunt, 1998), linear regression (Finlay and Wilkinson, 1963; Eberhart and Russel, 1966), multivariate analysis such as principal component analysis (Zobel *et al*., 1988) and additive main effect and multiplicative interaction (AMMI) (Zobel *et al*., 1988; Gauch and Zobel, 1997). Recently, the genotype plus the genotype by environment interaction, commonly known as GGE biplot has been proposed (Yan *et al.*, 2000; Yan *et al.*, 2001; Yan, 2002; Yan and Tinker, 2005; Gauch, 2006; Yan *et al*., 2007; Burgueno *et al*., 2008). The GGE biplot has been used in mega-environment analysis (Yan and Rajcan, 2002; Casanoves *et al*., 2005; Sarmonte *et al*., 2005; Yan and Tinker, 2005; Dardanelli *et al*., 2006), genotype and test environment evaluation (Yan and Rajcan, 2002; Blanche and Myers, 2006), trait association (Yan and Rajcan, 2002) and heterotic pattern analysis (Yan and Hunt, 2002).

CHAPTER 3

MATERIALS AND METHODS

3.1. Experimental Sites

The experiment was conducted at Kenya Agricultural Research Institute (KARI), Mtwapa (E 039° 44.680'; S 03° 54.954') and its sub-centres at Msabaha (040° 02.327'; S 03° 54.954') and Mariakani (E 039° 28'; S 03° 50'). The agroecological zones (AEZ's) for the sites as described by Jaetzold and Schmidt, (2012) are: coastal lowland 3 (CL3) for Mtwapa, coastal lowland 4 (CL4) for Msabaha and coastal lowland 5 (CL5) for Mariakani. The sites have sandy soils with pH of between 5.3 to 6.9.

The mean annual rainfall for Mtwapa and Msabaha is 1200 and 1000mm, respectively. For Mariakani, the mean annual rainfall is 800mm. In all those sites rainfall is bimodal with the long rains starting in April/May upto August. Short rains start in October and extend to December. However, due to the prevailing global climate change, rainfall is erratic and therefore cannot be predicted with precision like it was previously. The elevations at Mtwapa centre, Msabaha and Mariakani sub-centres is 30m, 15m 185m above sea level (asl), respectively.

Table 2: Rainfall data in the 3 experimental sites (mm).

	Mtwapa		**Msabaha**		**Mariakani**	
Month	2012	2013	2012	2013	2012	2013
Jan	150.5	8.9	Tr*	0.9		0.0
Feb	0.6	0	0.6	0.5		10.0
March	0.0	260.2	Tr	121.7		7.7
April	60.9	115.1	83.6	112.7		139
May	187.1	390.5	290.8	291.8		337.9
June	35.8	111.3	79.7	91.8		34.6
July	35.7	46.5	32.2	43.1		52.9
August	80.7	59.9	109.9	43.0		18.4
Sept	24.0	47.5	8.6	31.5		80.1
Oct	112.8	132.6	159.2	102.6	82.0	25.8
Nov	184.1	74.3	148.2	82.2	205.3	91.1
Dec	78.8	45.5	88.9	44.4	120.5	405

*Trace

Source: Mtwapa and Msabaha Meteorological offices .

3.2. Genotypes

Fifteen cowpea lines were sourced from the KARI Genebank which included three improved cultivars that have been tested in central and eastern regions of Kenya. These genotypes (Table 3) have varying agronomic traits and were collected from various regions of Kenya.

Table 3: Cowpea genotypes indicating where collected and colour of the seeds

Genotype / Accession	Where collected	Seed colour
K033057	Eastern Province in Embu	Cream
K033073	Eastern Province in Embu	Cream
K003731	Eastern Province in Machakos	Cream.
K005169	Eastern Province in Machakos	grey dotted
K026753	Eastern Province in Machakos	Black
K027092	Eastern Province in Machakos	Cream
K003962	Eastern Province in Machakos	Red
K046781	Eastern Province in Makueni	Red
K028613	Nyanza Province in Siaya	Cream
K047079	Western Province in Busia	Cream
K047078	Western Province in Busia	Cream
K047121	Western Province in Vihiga	Cream
KVU 27-1	improved cultivar	dark red
M 66	improved cultivar	Cream
K 80	improved cultivar commonly grown in the coastal region	Cream
Local variety (Mnyeza)		Dark red

K80 is an improved cowpea variety that is well adapted in the coastal region and was one of the check varieties. It is a dual purpose type and can do well in drier regions at 200mm of rainfall. Its grains are creamy brown and its yield potential ranges from 1.8

– 2.0t/ha. The other check is one of the local landraces in the area where the trials were conducted.

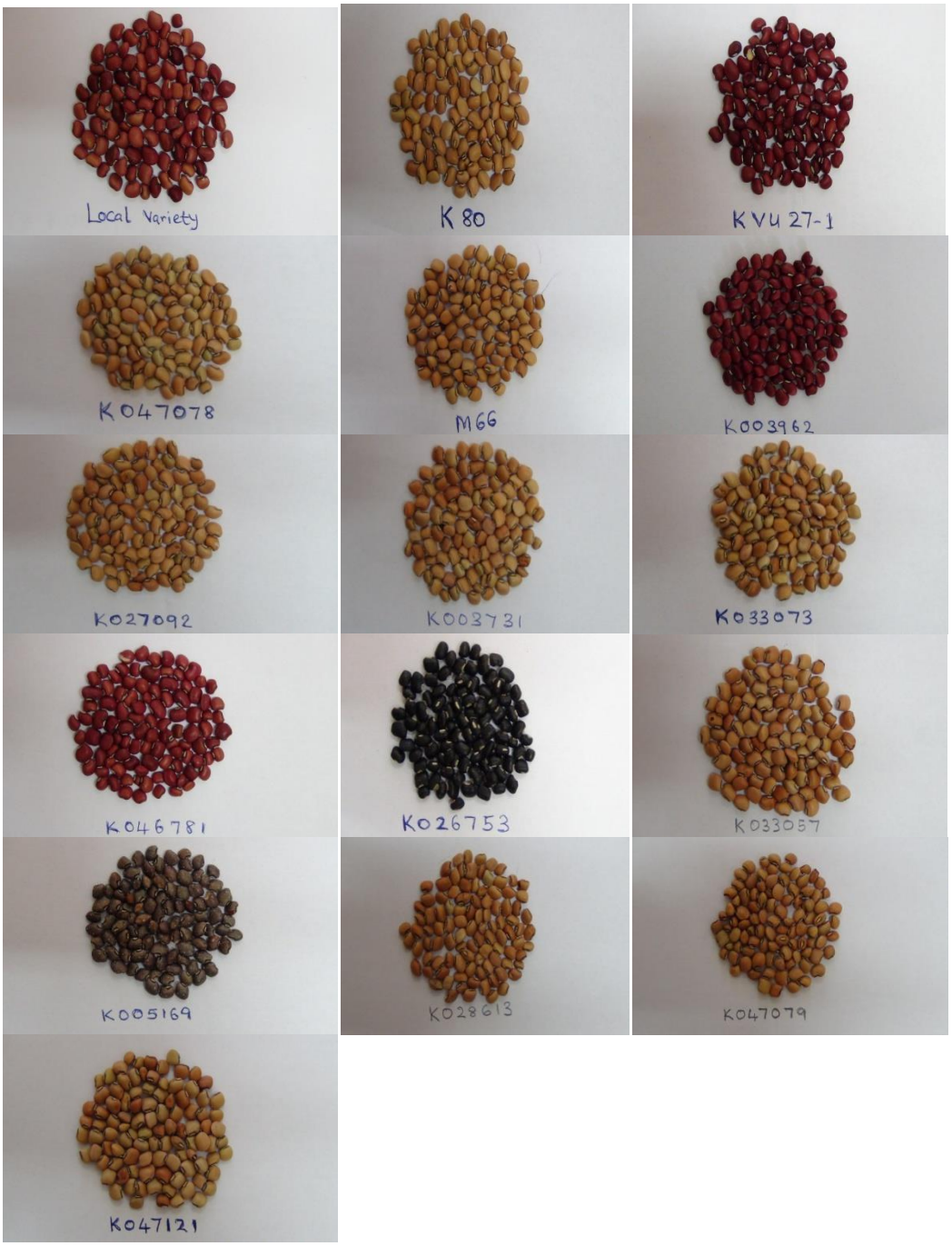

Figure 1: The grain quality and colour of the cowpea (Vigna ungiculata) genotypes evaluated at 3 coastal region locations over 2 years in Kenya.

(Source: Author, 2013)

3.3. Increase of Seed for the Experiment

The KARI Mtwapa field where the study was conducted was under fallow for one year. Previously, there was cassava planted in the field for about two years. Land was ploughed and harrowed to achieve a suitable tilth for cowpea planting. Because of inadequate seed for three sites, seeds were multiplied in June 2012 at Mtwapa. Cowpea lines were planted in rows at spacing of 60 × 30cm at a seeding rate of 20 $kgha^{-1}$. Two seeds were planted per hill and phosphate fertilizer, double superphosphate (DSP) was applied at a rate of 103 kg per hectare in order to supply an equivalent of 45 Kg P ha^{-1}

Routine spraying as a control measure for the biotic stresses was done using insecticides and fungicides. Pests were controlled by spraying pesticide –"Polythrin" with active ingredient prefenofos 400g per litre plus cypermethrin 40g per litre was applied at the rate 2 litres ha^{-1} to control aphids and sucking beetles. Spraying with fungicide- "Ridomil" with active ingredient mefenoxam 40g per kg plus mancozeb 640g per kg at the rate5kg ha^{-1} to control foliar fungal diseases was done. Weeds were manually controlled by digging them out using hoes.

3.4. Planting the trial

After generating adequate seeds of these lines, the study trials were laid in the short rains season of 2012 and in the long rains season of 2013 in the three sites. Planting was done at a spacing of 60 cm × 30 cm at the rate of 10 kg $ha^{-1.}$ The trial was randomized complete block design (RCBD) with three replications. At Mtwapa the trial site was previously planted cassava and after ploughing and harrowing, planting

was done on 22nd October 2012. In Msabaha the site was on a field where maize was previously planted. Planting was done on 7th November 2012 while at Mariakani the land was under fallow for two years and planting was carried out on 12th November 2012.

The number of treatments per trial was sixteen which is the cowpea accessions (genotypes) being tested that included the local check and the improved check variety (K 80). There were four rows in each plot whose spacing was 60×30 and two seeds were planted per hill. At planting phosphate fertilizer was applied at a rate of 45kg of P ha^{-1} . Routine spraying as a control measure for biotic stresses was done using insecticides and fungicides.

All the agronomic practices required were carried out. Weeding was done three times in all the sites.

In April 2013, ploughing and harrowing of the trial sites was carried out in the three locations. Planting of the trial was on 26th April 2013 at Mariakani, 29th April at Mtwapa and 30th April at Msabaha. As in the previous season, the treatments were sixteen, in a randomized complete block design with three replications. Also at planting, phosphate fertilizer was applied at a rate of 45kg of P ha^{-1} and routine spraying as a control measure for biotic stresses was done using insecticides and fungicides.

3.5. Data collection

The data collected was on both qualitative and quantitative traits – it was on stand count, days to emergence, days to flowering, days to pod-setting, days to maturity, number of pods per plant, and number of seeds / pod. At physiological maturity, lines were harvested separately, pods weighed, then threshed and the grain yield per plot

obtained. A 100 seed weight was also recorded per plot. In each plot data was collected from the two middle rows of the plot.

(i). Stand count- this was done five days after emergence as cowpea usually have a fast emergence if the soil moisture content is optimum. The stand count data was collected individually for each plot. Days to flowering- the onset of the flowering was recorded as well as when 50% of the flowering per plot was attained. This was based on the date of planting.

(ii). Days to pod-setting; the onset of pod setting was recorded as well as when 50% of the plants had set pods based on the date of planting.

(iii). Days to maturity- this was from the date of planting to when 50% of plants in the plot had reached physiological maturity.

(iv). Number of pods per plant- 20 plants per plot was sampled to determine the number of pods per plant.

(v). Number of seeds per pod- at maturity, 20 plants per plot was sampled to determine the number of seeds per pod. In each plant, 5 pods were sampled for the seed count.

(vi). Height of the plant- the height data was recorded at maturity and it was by taking the measurement in centimeter (cm) from the base of the plant to the apical. The data was determined from 20 plants per plot.

(vii). Final stand count- this was determined at maturity from the two middle rows which were the net plot.

(viii). Yield data- each plot was harvested individually. The two middle rows were harvested to determine the pod yield (g/plot) and the grain yield (g/plot) after threshing.

(ix). Number of branches per plant- the mean number of branches was determined from 10 plants per plot.

(x). Length of pod- determined from 10 plants sampled where 3 pods per plant were measured. The average of all the pods measured was then recorded.

(xi). Length of seed- it was determined from mean of 10 seeds measured.

(xii). Width of seed- determined from mean of 10 seeds measured. 100 seed weight- 100 seeds from each plot were counted and weighed.

3.5.1 Data analysis

The data was analysed using the SAS program.

The statistical model was a follows;

$Y_{ijklm} = \mu + Ei + Y_j + R_{k(i-j)} + G_l + GE_{il} + GY_{jl} + GYE_{ijl} + \varepsilon_{ijklm}$

Where;

Y_{ijklm} - is the observation of l^{th} treatments (genotypes) in the k^{th} replication in the i^{th} environment.

μ - is general mean.

E_i - is location.

Y_j - is year (season).

R_k - is k^{th} replication in the i^{th} environment.

G_l - is l^{th} treatment in the k^{th} replicate.

GE_{il} - is the genotype and environment interaction.

GY_{jl} - is the genotype and year interaction.

GYE_{ijl} - is the genotype, year and environment interaction.

ε_{ijklm} - is the random error effect.

3.6. EMS (estimated mean square) for cowpea trial

Source of variation	**Df**	**EMS**
Environment (i)	2	$\delta_e^2 + 288\delta^2_E$
Year (j)	1	$\delta_e^2 + 144\delta^2_{EY} + 432\phi_Y$
Environment ×Year (ij)	2	$\delta_e^2 + 144\,\delta^2_{EY}$
Replicates (within environment and year)	12	$\delta_e^2 + 288\,\delta^2_R$
Genotype (l)	15	$\delta_e^2 + 18\delta^2_{GE} + 54\phi_G$
Genotype × Environment (il)	30	$\delta_e^2 + 18\delta^2_{GE}$
Genotype × Year (jl)	15	$\delta_e^2 + 9\delta^2_{GYE} + 27\phi_{GY}$
Genotype x Environment × Year ijl)	30	$\delta_e^2 + 9\delta^2_{GYE}$
Error (ijkl)	180	δ_e^2
Total	287	

CHAPTER 4

RESULTS

4.1. Performance of the genotypes in the three environment in two seasons

The results shows that there were significance differences in the performance of the genotypes in the three environments. Genotype K026753, flowered the earliest (42 days) at CL 3 compared to K046781, M66 and K80 which took 49.3, 48.6 and 48.5 days, respectively (Table 4). At Msabaha (CL 4), K003731 and K046781 took 42 days to flower compared to the rest of the genotypes. However, it took 46 days for K033073 to flower compared to two check varieties which flowered after 43 and 44 days, respectively (Table 4).

At Mariakani in CL 5, genotypes – K047079 and K047121 flowered significantly earlier at 43 days than others. The improved check (K80) and K033073 took significantly longer to flower than other genotypes at 47 days. Following was K027092 at 46 days. The local check (mnyeza) took 44 days to 50% flowering (Table 4).

K80 and M66 significantly ($p < 0.05$) took the longest to 50% podding at 56 days while the earliest to 50% podding was K026753 at 50 days in CL 3 (Table 4).

At CL 4, the earliest podding (52 days) were detected on genotypes K033057 and K047079 while K033073 and K047078 took 55 days to produce pods. The improved check (K80) achieved 50% podding at 53 days while the local check (mnyeza) at 54 days. It is worth noting that there were no significant differences ($p > 0.05$) for podding days at CL 5 (Table 4).

At CL 3, K003962, K028613 and K027092 matured the earliest in 68 days, while K047078, K047079 and K046781 took the longest time (74 and 73 days respectively) to mature. Further comparison showed that it took 70 days for local variety to mature (Table 6). At CL 4, it took 77 days for the local check to mature compared to 69 days observed on K003962. The improved check (K80) took 76 days to mature (Table 10).

The variation in period it takes cowpea to mature was further noted at CL 5. In this region, K027092 took 69 days to mature followed by K033073 and KVU 27-1 at 72 days. The improved check (K80) attained physiological maturity at 80 days and the local check (mnyeza) 77 days. In fact, K047079 and K046781 took 81 days to mature. In this study, genotypes evaluated at CL 5 took longer time to mature compared to the other agro ecological zones.

There was variability among cowpea genotypes evaluated across the locations for the number of pods per plant. In AEZ CL 3, genotypes, K046781 and K005169 had significant high ($p < 0.05$) number of pods compared to the rest with 24 pods per plant. The improved check (K80) had 23 pods/plant while the local check had 19 pods/plant. KVU 27-1, one of the improved varieties being tested had significantly low ($p < 0.05$) number of pods with 15 pods / plant (Table 4). At CL 4, the local check produced 34 pods per plant, a value that was higher than those observed on other genotypes. In comparison 21 number of pods per plant were observed on K033073 (Table 4). At AEZ CL 5, genotypes K047078 and K028613 produced 25 and 23 pods /plant in contrast to improved check (K80) and M66 which produced 21 pods per plant. However, the lowest number of pods per plant were observed on K005169, K047121 and K003962. The local check (mnyeza) had a mean of 19 pods/plant (Table 4).

Generally, the mean number of seeds per pod also varied across the three environments. An average number of seeds per pod (17) was detected on K047079 at AEZ CL 3 in contrast to 13 seeds/pod observed on genotype K026753. The local check (mnyeza) and the improved check (K80) had 16 seeds per pod (Table 5). At CL 4, K003962 bore pods that contained an average of 19.27 seeds which was significantly higher ($p < 0.05$) than K026753 (16 seeds per pod). The improved check (K80) had an average of 17 seeds per pod as was the local check (mnyeza).

Genotypes K047079 and K033057 produced a mean number of seed per pod of 17 at CL 5. Significantly few ($p < 0.05$) seeds per pod were in variety K026753 with a mean of 13.88 seeds per pod. The local check (mnyeza) and the improved check (K80) had 15 seeds per pod and competed well with other genotypes (Table 5).

Table 4: Mean days to flowering, days to podding, number of pods per plant and length of pods (cm) of 16 cowpea genotypes tested at Mtwapa, Msabaha and Mariakani 2012/13

Genotype	Days to 50% Flowering			Days to 50% podding			Mean No. of pods /plant			Mean length of pod (cm)		
	MTP	MSA	MRK	MTP	MSA	MRK	MTP	MSA	MRK	MTP	MSA	MRK
K033057	44.3 bc	43.34 cde	44.67 bc	50.8 cde	52.67 d	55.00 a	19.3 bcd	22.06 d	16.84 cde	17.4 bcde	19.11 abc	17.91 bcd
K028613	47.5 ab	44.00 bcde	45.84 ab	53.7 abcd	54.00 abcd	54.84 ab	19.5 bcd	24.72 bcd	23.06 ab	16.0 ef	16.34 f	15.33 fg
K047079	44.7 bc	44.17 bcde	43.84 c	53.8 abc	52.67 d	54.00 ab	18.4 cde	23.22 cd	18.45 abc	16.3 ef	18.98 abcd	18.70 bc
K033073	46.8 ab	46.34 a	47.00 a	53.8 abc	55.50 a	55.67 a	19.2 bcde	21.67 d	20.78 abc	15.8 f	16.81 ef	16.73 def
K005169	45.8 ab	44.17 bcde	44.50 bc	52.2 bcde	54.50 abc	55.17 a	24.5 a	27.67 bcd	16.67 cde	17.3 cde	17.31 def	16.67 def
K047121	46.5 ab	42.50 e	43.84 c	52.8 bcde	53.17 cd	54.17 ab	18.4 cde	25.67 bcd	14.56 de	18.0 abc	18.36 bcde	17.63 cde
K026753	42.2 c	43.17 de	45.50 abc	50.0 e	54.17 abcd	54.50 ab	22.9 abc	26.28 bcd	19.17 bcd	14.1 g	16.35 f	14.52 g
K003731	44.5 bc	42.83 de	44.50 bc	51.2 bcde	53.67 bcd	53.84 ab	20.6 abc	29.22 abc	19.50 abcd	17.4 bcde	18.41 bcde	16.04 efg
K046781	49.3 a	42.34 e	44.67 bc	54.0 ab	54.00 abcd	55.50 a	24.7 a	25.73 bcd	17.78 bcde	18.6 ab	20.36 a	20.35 a
K027092	44.2 bc	45.33 abc	46.00 ab	50.7 de	54.00 abcd	54.17 ab	19.5 bcd	23.39 bcd	18.72 bcd	18.**2 abc**	18.74 abcd	19.21 abc
K003962	44.3 bc	43.50 cde	44.67 bc	50.8 cde	53.50 bcd	54.50 ab	14.7 de	24.06 bcd	12.89 e	19.3 a	19.81 ab	19.48 ab
M66	48.7 a	44.34 abcde	45.17 bc	56.5 a	53.33 bcd	54.00 ab	19.7 bc	26.61 bcd	21.17 abc	17.1 cdef	17.69 cdef	16.68 def
K80	48.5 a	44.17 bcde	47.00 a	56.7 a	53.50 bcd	55.00 a	23.5 ab	29.84 ab	21.17 abc	16.4 ef	18.21 bcde	16.73 def
KVU 27-1	45.8 ab	44.67 abcd	44.67 bc	52.2 bcde	53.50 bcd	55.17 a	14.5 e	24.17 bcd	17.73 bcde	18.7 ab	19.76 ab	19.09 abc
K047078	46.2 ab	46.00 ab	44.34 bc	53.2 bcd	55.00 ab	54.84 ab	23.5 ab	26.33 bcd	25.11 a	16.9 cdef	17.76 cdef	16.52 def
LOC (Mnyeza)	46.3 ab	43.67 cde	44.50 bc	54.0 ab	54.33 abcd	53.00 b	18.7 cde	34.61 a	19.50 abcd	16.8 def	18.51 bcde	18.02 bcd
MEAN	**46.0**	**44.03**	**45.04**	**52.9**	**53.84**	**54.58**	**20.1**	**25.95**	**18.94**	**17.1**	**18.28**	**17.48**
CV%	**4.2**	**2.60**	**2.17**	**3.7**	**1.42**	**1.28**	**15.3**	**12.60**	**15.99**	**7.5**	**6.55**	**9.18**

Means with the same letter are not significantly different.

MTP=Mtwapa; MSA=Msabaha: MRK=Mariakani.

Table 5: Mean number of seed per pod, seed length (mm), seed width (mm) and number of internodes per plant of 16 cowpea genotypes tested at Mtwapa, Msabaha and Mariakani 2012/13

Genotype	Mean No. of seeds per pod			Mean Seed length (mm)			Mean seed width (mm)			Mean No. of internodes/plant		
	MTP	MSA	MRK	MTP	MSA	MRK	MTP	MSA	MRK	MTP	MSA	MRK
K033057	16.6 ab	17.45 bc	17.00 a	6.94 defg	7.38 bc	7.33 efg	5.95 bc	6.22 bcd	6.07 de	5.72 bc	9.00 c	11.39 bcdef
K028613	15.8 abc	17.28 bc	15.00 ab	6.55 i	7.05 def	6.95 gh	5.29 g	5.72 ghij	5.60 gh	6.11 abc	9.50 bc	13.17 abc
K047079	17.4 a	18.50 ab	17.06 a	6.57 hi	6.92 efg	7.60 def	5.74 cdef	6.15 bcd	6.43 bc	6.89 ab	9.33 c	14.83 a
K033073	14.6 cd	17.78 ab	15.11 ab	6.18 j	6.70 gh	6.88 h	4.83 h	5.40 j	5.68 gh	6.11 abc	9.61 abc	12.06 bcde
K005169	15.6 abc	17.28 bc	15.50 ab	7.03 cde	7.57 b	7.37 efg	5.90 c	5.80 efghi	5.82 fgh	5.67 bc	10.17 abc	11.06 cdef
K047121	14.9 bcd	18.33 ab	15.33 ab	6.82 efghi	7.18 cde	7.25 fgh	6.00 bc	6.12 bcde	6.32 cd	5.56 bc	10.17 abc	10.33 ef
K026753	13.3 d	16.11 c	13.89 b	6.58 hi	7.17 cde	7.27 fgh	5.29 g	5.92 defgh	5.77 fgh	6.78 ab	10.06 abc	11.78 bcdef
K003731	14.3 cd	18.06 ab	15.00 ab	6.90 efgh	7.18 cde	7.32 efg	5.79 cde	6.05 cdef	6.05 def	7.17 a	10.00 abc	10.89 def
K046781	16.3 abc	18.00 ab	15.00 ab	7.74 a	7.93 a	8.55 a	6.39 a	6.75 a	6.95 a	6.22 abc	10.28 abc	11.39 bcdef
K027092	15.5 abc	18.83 ab	15.72 ab	7.27 bcd	7.55 b	7.72 cde	5.71 cdef	5.97 defgh	5.87 efg	6.89 ab	10.06 abc	9.78 f
K003962	16.6 ab	19.28 a	15.89 ab	7.50 ab	7.60 b	8.30 ab	6.21 ab	6.03 cdefg	6.50 bc	6.22 abc	11.06 ab	11.56 bcdef
M66	15.2 bcd	17.67 abc	15.89 ab	6.60 ghi	6.53 h	7.05 gh	5.58 efg	5.77 fghi	5.88 efg	7.11 a	9.95 abc	13.50 ab
K80	16.4 ab	17.95 ab	14.94 ab	6.68 fghi	6.83 fgh	7.27 fgh	5.48 fg	5.68 hij	5.75 gh	5.61 bc	11.33 a	12.28 bcde
KVU 27-1	15.3 bc	18.11 ab	15.61 ab	7.35 bc	7.32 bcd	8.03 bc	5.99 bc	6.32 bc	6.63 b	5.39 c	10.33 abc	12.67 bcd
K047078	14.4 cd	17.72 abc	15.00 ab	6.89 efghi	7.17 cde	7.28 fgh	5.51 efg	5.48 ij	5.55 h	5.72 bc	10.11 abc	12.11 bcde
LOC (Mnyeza)	15.9 abc	17.50 bc	15.50 ab	7.02 cdef	7.62 ab	8.00 cd	5.83 cd	6.42 b	6.30 cd	6.44 abc	10.06 abc	10.44 ef
MEAN	**15.5**	**17.86**	**15.47**	**6.91**	**7.23**	**7.51**	**5.7**	**5.99**	**6.07**	**6.2**	**10.06**	**11.83**
CV%	**6.8**	**4.04**	**5.04**	**5.82**	**5.17**	**6.45**	**6.8**	**5.83**	**6.72**	**9.5**	**5.70**	**10.91**

Means with the same letter are not significantly different.

The seed weights of genotypes tested at AEZ CL 3 were comparatively lower than those in other agroecological zones (Table 6). An average seed weight of 14.9 g was observed on K046781 in CL 3. The seeds of check variety, K80 and local check weighed 10 g and 11 g respectively. The lowest seed weight of 8.7 g was noted on genotype K033073 in CL 3. Just like in CL 3, the genotype with significantly ($p<0.05$) low 100 seed weight recorded in CL 4 was K033073 with 11.81 g. The one with the significantly high ($p < 0.05$) weight recorded was K046781 with a mean weight of 16.31 g. The local check (mnyeza) and the improved check (K80) had 14.5 g and 12.93 g respectively in CL 4 (Table 6).

Comparatively, in CL 5, the highest seed weight of 17.56 g was observed on genotype K046781 and was followed by K003962 (16.37 g) and KVU 27-1 (15.32 g). Seeds from both local check and improved check exhibited an average weight of 14.73 g and 12.47 g respectively. The weight of seed from K028613 and K033073 were among the lowest (Table 6).

At Mtwapa site (CL 3), grain yield also varied among the genotypes and the best yielding genotypes - K005169, produced grain yield of 2025.5 kg ha^{-1} compared to the improved check K80 (1657.4 kg ha^{-1}). These genotypes produced 32% and 17% more than the local check which produced 1377.3 kg ha^{-1}. The lowest significantly different ($p < 0.05$) grain yield was in genotype K047121 with 1159.72 kg ha^{-1} (Table 6).

At CL 4, the highest significantly different ($p <0.05$) grain yield were observed in genotype K005169 with 1439.8 kg ha^{-1}. It was followed by KVU 27-1, K003962, K046781, M66 and K80 at 1395.8, 1331, 1169, 1136.6 and 1092.6 kg ha^{-1} respectively. The local check had yield of 990.7 kg ha^{-1} and had out yielded

K027092, K033073, K033057, K003731 and K047079 which had low significantly different ($p < 0.05$) yield (Table 6).

In Mariakani, CL 5 the highest significantly different ($p < 0.05$) grain yield were recorded in genotype KVU 27-1 with 1782.4 kg ha^{-1}. It was followed by K005169 and M66 with 1708.3 and 1588 kg ha^{-1} respectively. K80, the improved check and the local check (mnyeza) gave yield of 1527.8 and 1463 kg ha^{-1} respectively. The lowest significantly different yield was 993.1 kg ha^{-1} by K047121 (Table 6).

Table 6: Mean height of plants (cm), number of days to physiological maturity, grain yield (kg/ha) and 100 seed weight (g) of 16 cowpea genotypes tested at Mtwapa, Msabaha and Mariakani 2012/13

Genotype	Mean height of plant (cm)			Mean No. of days to 50% physiological maturity			Mean grain yield (kg/ha)			Mean 100 seed weight (g)		
	MTP	MSA	MRK	MTP	MSA	MRK	MTP	MSA	MRK	MTP	MSA	MRK
K033057	56.17 b	54.16 ab	57.67 abc	70.83 bcdef	74.50 bcd	77.34 abc	1481.9 bc	923.61 c	1391.67 ab	11.67 def	14.56 bc	12.83 de
K028613	48.24 c	56.74 ab	62.11 a	69.50 g	76.00 ab	79.50 a	1277.8 bc	1000.00 abc	1315.28 ab	9.53 hi	12.56 ef	11.83 ef
K047079	56.98 b	60.16 ab	50.28 bc	71.50 ab	71.00 fg	81.17 a	1288.9 bc	908.33 c	1430.56 ab	11.29 def	13.14 de	14.41 c
K033073	56.03 b	70.12 a	53.06 abc	69.83 fg	71.67 fg	72.00 cd	1294.4 bc	923.61 c	1113.89 ab	8.78 i	11.81 ef	11.26 f
K005169	65.31 a	51.84 b	50.34 bc	69.67abcde	73.84 cde	80.84 a	2025.0 a	1438.89 a	1708.33 ab	11.16 efg	13.37 bcde	13.06 d
K047121	56.84 b	61.52 ab	58.61 ab	71.50 bcdef	75.34 abc	79.84 a	1159.7 c	1005.56 abc	993.06 b	12.06 cde	13.31 cde	13.41 d
K026753	44.23 c	56.88 ab	51.00 bc	70.5 bcdefg	72.00 ef	78.67 a	1175.0 c	1048.61 abc	1036.11 b	9.67 hi	12.54 ef	12.05 ef
K003731	59.09 ab	60.60 ab	49.10 bc	70.00 defg	76.00 ab	76.00 abc	1179.2 c	913.89 c	1336.11 ab	11.12 fg	13.37 bcde	13.11 d
K046781	60.81 ab	63.99 ab	51.62 bc	73.13 abc	74.00 bcde	81.00 a	1252.8 bc	1168.06 abc	1583.33 ab	14.90 a	16.32 a	17.57 a
K027092	57.88 b	51.84 b	48.34 c	68.34 g	72.67 def	69.00 d	1295.8 bc	958.33 bc	1208.33 ab	12.15 cd	12.83 ef	13.32 d
K003962	59.50 ab	58.82 ab	53.22 abc	68.00 g	69.67 g	80.84 a	1490.3 bc	1330.56 abc	1284.72 ab	13.38 b	14.62 b	16.37 b
M66	57.94 b	57.69 ab	53.28 abc	72.67 abcd	74.17 bcd	80.17 a	1527.8 bc	1137.50 abc	1587.50 ab	10.23 gh	12.76 ef	12.63 de
K80	61.83 ab	65.62 ab	57.95 abc	72.0 abcdef	76.00 ab	79.83 a	1656.9 ab	1093.06 abc	1527.78 ab	10.27 gh	12.93 def	12.47 de
KVU 27-1	48.89 c	59.00 ab	57.84 abc	69.67 efg	74.67 bcd	72.83 bcd	1290.3 bc	1395.83 ab	1781.94 a	12.77 bc	14.09 bcd	15.33 c
K047078	59.91 ab	50.66 b	53.61 abc	74.67 a	74.67 bcd	79.67 a	1176.4 c	1086.11 abc	1409.72 ab	11.01 fg	13.01 def	13.12 d
LOC (Mnyeza)	59.00 ab	61.06 ab	56.56 abc	70.34 cdefg	77.33 a	77.84 ab	1377.8 bc	990.28 bc	1463.89 ab	11.15 efg	14.46 bc	14.73 c
MEAN	**56.79**	**58.79**	**54.03**	**70.76**	**73.97**	**77.91**	**1371.9**	**1082.64**	**1385.76**	**11.36**	**13.48**	**13.59**
CV%	**9.52**	**8.93**	**7.36**	**2.49**	**2.82**	**4.69**	**16.5**	**15.90**	**16.34**	**3.57**	**8.13**	**12.46**

Means with the same letter are not significantly different.

4.2 Effects of the Year and location on the Genotypes

In Table 7, there were no significant differences ($p \geq 0.05$) in the days to 50% flowering in the two years of study while in all other variables there were significant differences ($p < 0.05$). Thus, the effect of the two years is manifested. In 2013, the expression of all characters measured (variables) except the one mentioned earlier (days to 50% flowering) were significantly different from 2012.

The potential of the genotypes were better revealed in 2013. The mean grain yield in the combined analysis was 915.89 and 1644.19 kg ha^{-1} in 2012 and 2013 respectively (Table 7). Number of pods per plant, number of seeds per pod, length of seed, width of seed and weight of seed were also significantly higher in 2013 compared to data obtained in 2012. Cowpea planted in 2013 physiologically matured earlier than 2012 by four days (Table 7). Pod weight was also significantly higher ($p < 0.05$) in 2013 (2591.63 kg ha^{-1}) compared to 2012 (1477.6 kg ha^{-1}). The mean weight of seed was 13.40 g in 2013, significantly different ($p < 0.05$) in 2012 with 12.19 g.

From the combined analysis, the performance of the 16 genotypes in the three across test agro ecological zones (AEZ's) were significantly different ($p < 0.05$) for all traits except in pod weight. The mean grain yield from Mtwapa and Mariakani, 1371.82 and 1385.71kg ha^{-1} respectively were significantly different ($p < 0.05$) from Msabaha's. Flowering at Mtwapa took 46 days and was significantly different from the remaining two agroecological zones (Table 8).

At Msabaha site, (CL 4) mean number of pods per plant, length of pod, height of plant, number of seeds per pod, pod weight and seed weight were significantly higher than the other two sites. In addition, cowpea at CL 4 took shorter time to flower than at CL3 and CL 5. The number of pods per plant was 25.95, significantly different than AEZ's CL 3 and CL 5. Length of pod was 18.28 cm and number of seeds per plant

was 18 in CL 4 significantly different from CL 3 and CL 5 (Table 8). The performance of the 16 genotypes in CL 5, at Mariakani was significantly higher in yield and most of yield components (variables) measured compared with other sites. The highest mean grain yields of 1385.71 kg ha^{-1} were observed at Mariakani (CL 5) while the lowest was at Msabaha (CL 4) with 1082.61 kg ha^{-1} (Table 8).

It was clear that cowpea produced pods and physiologically matured after 52.89 and 70.98 days for CL 3 while for CL 5 it was at 54.58 and 77.90 days. The number of branches per plant, seed length, seed width and number of internodes were also high significantly at CL5 and lowest at CL3. (Table 8). The year effects was clearly manifested of the agronomic traits and seed quality of the cowpea evaluated. Generally, the means of 2013 were higher than those of 2012 for days to flowering, podding, maturity, pods per plant, length of pods, height of plants, seeds per pod, seed length, seed width, pod weight, grain yield and seed weight.

Table 7: Means of agronomic traits and seed quality of 16 cowpea evaluated across 3 environments (Mtwapa, Msabaha and Mariakani) in 2012 and 2013.

Year	Days to 50% flowering	Days to 50% podding	Days to physiological maturity	Number of pods/plant	Length of pod (cm)	Number of branches/ plant	Height of plant (cm)	Number of seeds/pod	Seed length (mm)	Seed width (mm)	Number of internodes	Pod weight (kg/ha)	Grain yield (kg/ha)	100 seed weight (g)
2012	44.31 a	52.92 b	72.52 b	17.68 b	17.21b	3.90 a	54.04b	15.36 b	7.19 b	5.89b	9.59 a	1477.6b	915.89b	12.19b
2013	45.73 a	54.62 a	76.06 a	25.75 a	18.06a	3.55 b	59.04a	17.30 a	7.24 a	5.96a	9.15 b	2591.6a	1644.19a	13.40a
Lsd	0.529	0.474	0.768	1.151	0.316	0.134	2.416	0.389	0.073	0.061	0.354	182.00	114.35	0.216

NB: Means followed by same letter are not significantly different

Table 8: Means of agronomic traits and seed quality of 16 cowpea genotypes evaluated across 3 environments (Mtwapa, Msabaha and Mariakani)

Environ	Days to 50% flowering	Days to 50% podding	Days to physiological maturity	Number of pods/plant	Length of pod (cm)	Number of branches/ plant	Height of plant (cm)	Number of seeds/pod	Seed length (mm)	Seed width (mm)	Number of internodes	Pod weight (kg/ha)	Grain yield (kg/ha)	100 seed weight (g)
Mtwapa (CL 3)	45.97a	52.89 c	70.98 c	20.27 b	17.13b	3.23 c	56.78b	15.66 b	6.91 c	5.71c	6.22 c	2069.9 0a	1371.82a	11.32b
Msabaha (CL 4)l	44.03 c	53.84 b	73.96 b	25.95 a	18.28a	3.52 b	58.79a	17.86 a	7.23 b	5.98b	10.06 b	1954.78a	1082.61b	13.48a
Mariakani (CL 5)	45.04 b	54.58 a	77.90 a	18.94b	17.47b	4.42 a	54.03b	15.46 b	7.51 a	6.07a	11.82 a	2079.28a	1385.71a	13.59a
Lsd	0.648	0.581	1.941	1.410	0.387	0.164	2.959	0.476	0.090	0.075	0.434	222.91	140.05	0.264

NB: Means followed by same letter are not significantly different

In Mtwapa (CL 3) significantly better results in all variables measured were noted in 2013 compared with 2012. The grain yield in 2013 was 1759.26 kg ha^{-1} while in 2012 it was 984.38 kg ha^{-1}. Days to 50% flowering, days to 50% podding and days to physiological maturity were longer in 2013 compared to 2012 (Table 7). Number of branches per plant and the seed width were the only ones not significantly different. It took the longest to attain physiological maturity in CL 3 at 80 days compared to other agro ecological zones.

4.3. Comparison of the genotypes' performance in the 2012 and 2013 in 3 diverse sites

Compared to other zones, physiological maturity in CL 3 was attained earliest in 2012 at 60 days (Table 9).

In Msabaha (CL 4), 2013 grain yield were significantly higher (1188.95 kg ha^{-1}) than in 2012 (976.3 kg ha^{-1}). Except for seed length, seed width, number of internodes and 100 seed weight that were not significantly different between the two years, all other variables were significantly different ($p < 0.05$). Days to 50% flowering were shorter in 2013 compared to 2012 unlike in CL 3 (Table 9).

There was no significant difference between 2012 and 2013 for days to 50% flowering in both years at Mariakani (CL 5). However, the year effects were notable for all other variables measured to be significantly different ($p < 0.05$). Mariakani had the highest mean grain yield of 1984.4 $kgha^{-1}$ in 2013 and the lowest grain yield of 787 $kgha^{-1}$ in 2012 compared to means at Mtwapa and Msabaha. In 2012, cowpea flowered after 43 days at Mtwapa (CL 3) and flowered latest at Mariakani (CL 5) after 45 days. In the same year, pods were produced and plants matured at CL 3 after 50 and 61 days, respectively. The latest in 2012 to produce 50% of pods was CL 4 at

54 days and the latest to attain physiological maturity was in CL 5 at 79 days (Table 9). Compared with 2013, the number of pods produced per plant was lowest in 2012 across all the agro ecological zones (AEZ's) at 12, 16 and 25 pods in CL 5, CL 3 and CL4 respectively. During short rain season of 2012, the highest number of seeds per pod was produced in CL 4 (18 seeds) and lowest in CL 5 (13 seeds). The highest mean number of internodes per plant was also observed at CL 5 (13) and lowest at CL 3 (5). The lowest mean pod weight and the grain yield in 2012 were observed at CL 5 with 1231 kg ha^{-1} and 787 kg ha^{-1} respectively and the highest pod weight of 1705 kg ha^{-1} was detected at CL 4 and grain yield of 984 kg ha^{-1} at AEZ CL 3. The lowest 100 seed weight recorded that year was 10.16 g at CL 3 while the highest was at CL 4 with 13.47 g.

In the long rains of 2013, cowpea took 43 to flower at CL 4 compared to CL 3 where it took 48. Cowpea took 71 days to mature at CL 4 days in contrast to 80 days observed at CL 3. During this season, Mariakani (CL 5) recorded the highest pod weight and grain yield of 2927.1 and 1984.4 kg ha^{-1} respectively while the lowest was at Msabaha (CL 4) with 2204.3 and 1189 kg ha^{-1} of pod weight and grain yield respectively (Table 9). Weight of seed varied across the locations. The highest seed weight was noted at Mariakani (CL 5) (14.24 g) compared to Msabaha (13.49g) and Mtwapa (12.48 g) (Table 9).

Table 9: Means of agronomic traits and seed quality of 16 cowpea genotype across three environments over two years.

Environ	Year	Days to 50% flowering	Days to 50% podding	Days to physiological maturity	Number. of pods/plant	Length of pod (cm)	Number of branches /plant	Height of plant (cm)	Number of seeds/pod	Seed length (mm)	Seed width (mm)	Number of internodes	Pod weight (kg/ha)	Grain yield (kg/ha)	100 seed weight (g)
Mtwapa	2012	43.45 b	50.10 b	61.29 b	15.83 b	16.59b	3.29 a	51.53b	14.18 b	6.80 b	5.67a	4.71 b	1496.2 b	984.38b	10.16b
	2013	48.50 a	55.68 a	80.68 a	24.72 a	17.67a	3.18 a	62.04a	17.14 a	7.02 a	5.76a	7.74 a	2643.5a	1759.26a	12.48a
	Lsd	1.292	1.099	1.041	1.656	0.472	0.220	2.283	0.657	0.120	0.106	0.474	231.99	60.605	0.330
Msabaha	2012	44.14 b	54.43 a	76.67 a	25.25 b	18.75a	3.81 a	55.07b	18.28 a	7.23 a	6.00a	10.31 a	1705.3b	976.27b	13.47a
	2013	43.91 a	53.25 b	71.27 b	26.64 a	17.81b	3.23 b	62.50a	17.44 b	7.22 a	5.97a	9.80 a	2204.3 a	1188.95a	13.49a
	Lsd	0.717	0.639	0.740	2.319	0.607	0.257	5.971	0.584	0.113	0.112	0.608	310.98	157.85	0.444
Mariakani	2012	45.32a	54.22 b	79.58 a	11.98 b	16.26b	4.59 a	55.51a	13.61 b	7.54 a	6.01b	13.74 a	1231.5 b	787.0b	12.94b
	2013	44.77a	54.93 a	76.22 b	25.89 a	18.68a	4.24 b	52.56a	17.32 a	7.47 b	6.14a	9.90 b	2927.1a	1984.4a	14.24a
	Lsd	0.641	0.682	1.957	2.036	0.569	0.227	3.624	0.791	0.152	0.104	0.752	394.75	260.17	0.354

NB: Means followed by same letter are not significantly different

4.4. Year, Environment and their interaction on the genotypes.

The effects due to year, environment and year × environment interaction were significant ($p \geq 0.05$) for days to flowering, days to podding, days to maturity, number of pods per plant, length of pods, number of pods per plant, number of branches and height of the plant (Appendix 8 a) with the exception of seed length in the year, seed width in the year × environment interaction and pod weight in the environment (Appendix 8 b).The genotypic effects were significant ($p \geq 0.01$) in days to 50% flowering, days to 50% podding, days to physiological maturity, number of pods per plant, length of pods, number of branches per plant, number of seeds per pod, seed length, seed width, number of internodes, pod weight and seed weight. However, height of plant and 100 seed weight variables were not significantly different. The genotype × year interaction effects were only significantly different ($p < 0.05$) on the days to podding (Appendix 8 a).

The genotype × environment interaction effects were significant ($p < 0.05$) for days to 50% flowering, days to 50% podding, days to physiological maturity, number of pods per plant , number of branches per plant (Appendix 8 a) and seed length , seed width and 100 seed weight (Appendix 8 b). However, the genotype × year × environment interactions were only significant ($p \geq 0.01$) at 100 seed weight.

CHAPTER 5

DISCUSSION

The fact that that there were significant differences ($p < 0.05$) in most of the traits measured due to the effects of: year (season), environment and the year × environment interaction in the combined analysis is confirms the existence of genetic variability in the 16 genotypes. Thus the objective of the study has been met. The effect of the genotype × year interaction on the 16 genotypes was of no consequence on the seasons.

The genotype × environment interaction (Appendix 8a & 8b) indicates the effect it had on the expression of the genotypes in various characters studied. This is a pointer that not all genotypes express their potential similarly in different environments. So there is need to select particular genotypes in different environments. This observation supports the earlier reports of Agbogidi and Ofuoko (2005) that plants respond differently to environmental factors based on their genetic makeup and their adaptation capability indicating variability among species.

The potential of these genotypes were better manifested in long rains (2013) compared to short rains (2012). This is manifested by the rainfall records in the three agroecological zones during the period of the crops growth (Table 1). In the short rains 2012, the rainfall recorded from November 2012 when the cowpea were planted to February 2013 when the crop was harvested was 67.95mm, 59.63mm and 83.95mm in Mtwapa (CL 3), Msabaha (CL 4) and Mariakani (CL 5). In the second planting in the long rains of 2013, from April to July the rainfall recorded in the sites at Mtwapa, Msabaha and Mariakani was 165.85mm, 134.85 and 141.1mm. This explains the

superior performance observed in 2013 as opposed to 2012 in the grain yield and other yield components.

In the short rains of 2012, in all the agroecological sites where the trials were carried out, it was noted that the days to 50% flowering, to 50% podding and to 50% physiological maturity came much earlier than in the long rains of 2013. This is due to weather condition which triggered the genotypes to mature early for their survival.

In the long rains season of 2013, the mean number of days to 50% flowering was 45.5. The days to physiological maturity were longer with a means of 75.5 days. This is due to the higher rainfall that was well distributed during this season that afforded expression of the genetic potential of the genotypes. In all the agroecological zones, the superiority of genotype K046781 in terms of the highest significant ($p < 0.05$) 100 seed weight is observed across all three agroecological zones. K033073 shows the lowest 100 seed weight across the three AEZ's suggesting its low genetic potential in seed weight.

The superiority of K005169 in all the agroecological zones in grain yield is observed making the genotype a candidate for consideration in the breeding with others to introgress the genes for high yield potential. The 16 genotypes attained maturity within 70 to 76 days after planting. Egbe *et al* (2010) classified cowpea varieties that matured in ≤ 60 days as extra early, 61 -80 as early and > 80 days as late. Therefore, most of the 16 genotypes could be classified as early maturing. In CL 5, two genotypes took significantly longer to attain physiological maturity at 81 days and could be classified as late maturing in that specific environment.

There seem to be a relationship between the number pods per plant and the grain yield. In all the AEZ's, genotype K026753 recorded the lowest number of pods per

plant and is among the lowest grain yielder. K005169 recorded high number of pods in all the AEZ's and it is among the highest grain yielder. The number of seeds per pod follows the same trend. Genotype K026753 recorded significantly low number of seeds per pod in all the agro ecological zones. The genotype having the highest 100 seed weight is K046781 which indicate its genetic potential and is suitable to consider in crossing with other genotypes for introgression of that characteristic. The superiority of the improved cowpea genotypes of KVU 27-1, M66 and K80 is manifested across the three agro ecological environments. Not to be outdone is the local check across the environment too. Other genotypes that performed impressively in specific environment are K003962 and K033057 in AEZ CL 3.

In CL 4, other genotypes that had good performance are K003962 and K046781 while in CL 5 genotypes with promising results apart from the ones with good performance across the environments were K046781, K047079 and K047078. K003962 and K033057 are collections from Machakos and Embu, respectively. K046781 is a collection from Makueni while K047079 and K047078 are from Busia. The climatic condition of all these environments is quite diverse and is indication of cowpea genotypes suitability in wide environments.

The improved check (K80) and the local check performance in terms of grain yield was also quite impressive across the three agro ecological zones where the study was carried out. They will be included in the breeding program so that their unique genetic characteristics can be used in development of new varieties.

Conclusion

Of the 14 genotypes tested in the three agroecological zones of the lowland coast region, five have shown outstanding performance across the test environments. They competed well and some even out performed K80, the improved check variety that is popular in the region currently. They are K005169, KVU 27-1, M66, K003962 and K046781. These genotypes have manifested their adaptability and stability across test environments and can be recommended for introduction in the region and will contribute to increased production of cowpea.

The other genotypes had also some unique qualities which can be exploited for development of new superior genotypes in terms of earliness, drought tolerance, high number of pods, more seeds per pod, etc. All those characteristics contribute to the superiority of the genotype. K026753 and K003731 are early flowering while K027092 and K033073 attain maturity early compared to other genotypes.

Recommendations

A cowpea breeding program can be started at KARI Mtwapa now that some characterizations of those sixteen genotypes have been done. This can be by establishment of a crossing block of all those genotypes where crosses can be done. Meanwhile for the aforementioned five genotypes with superior performance, multiplication of seeds could commence for distribution to farmers in the region.

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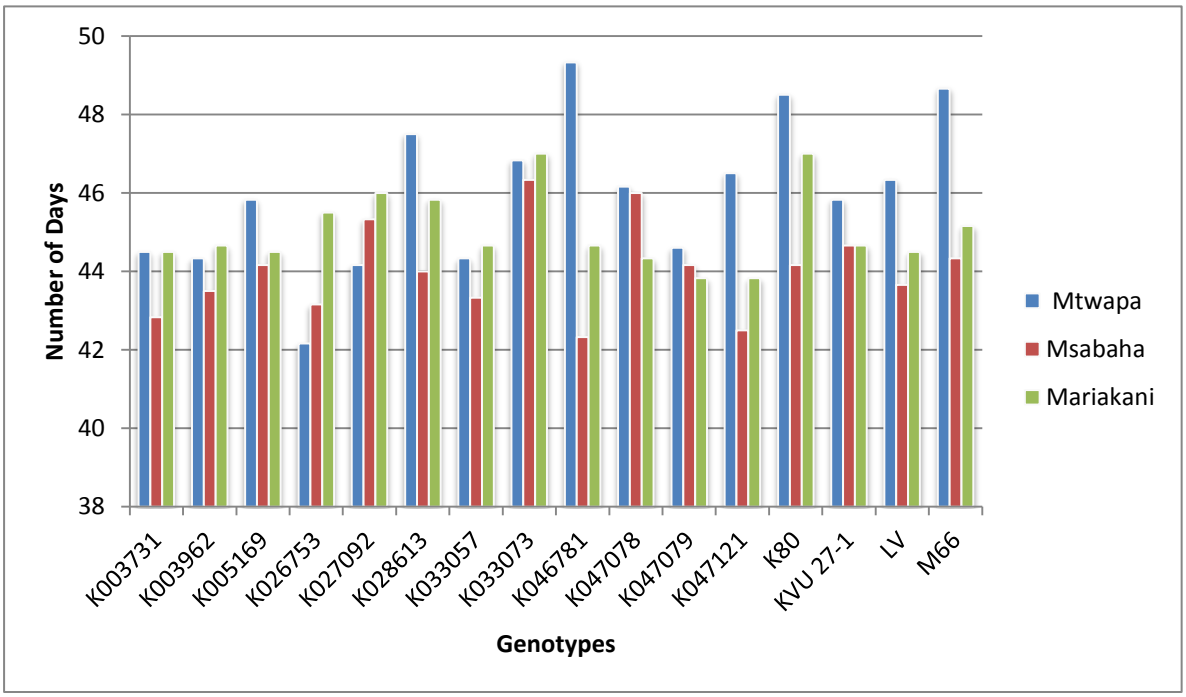
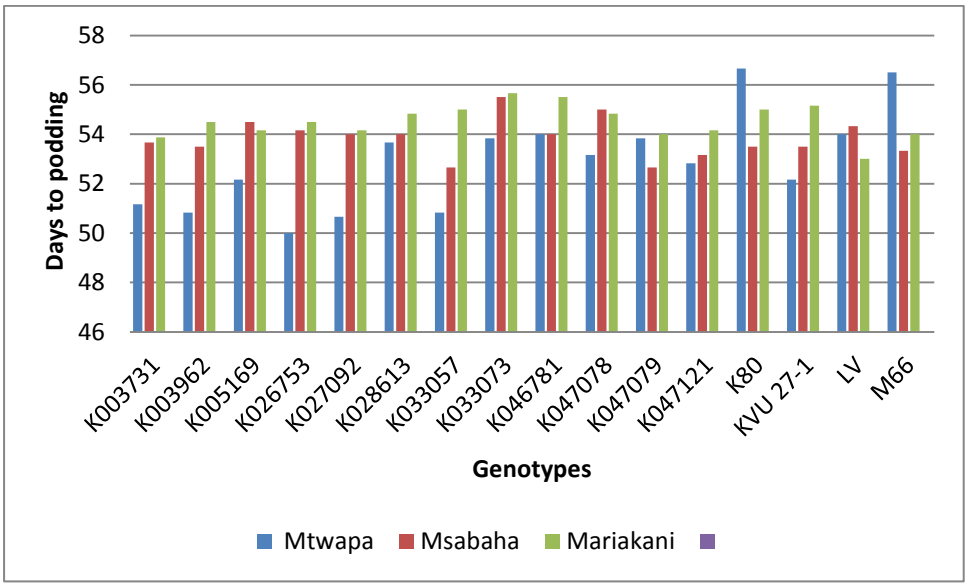
APPENDICES

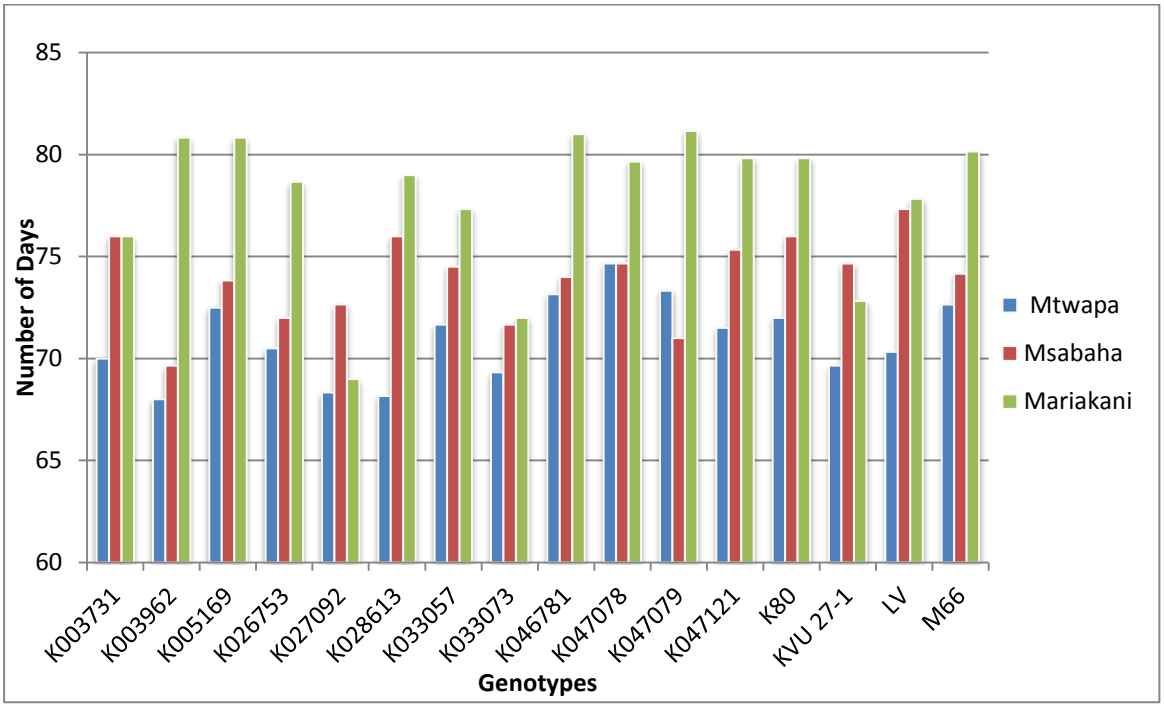
Appendix I: Mean days to 50% flowering of 16 genotypes at Mtwapa, Msabaha and Mariakani



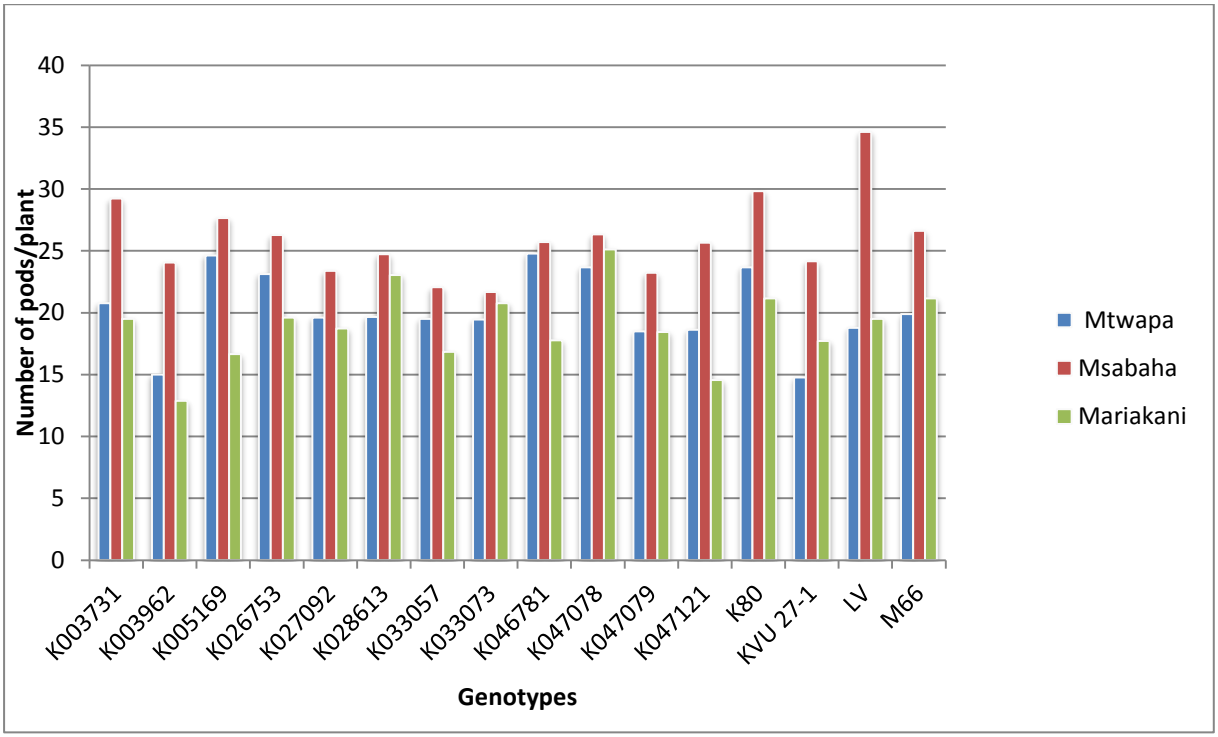
Appendix II Mean days to 50% podding of 16 genotypes at Mtwapa, Msabaha and Mariakani



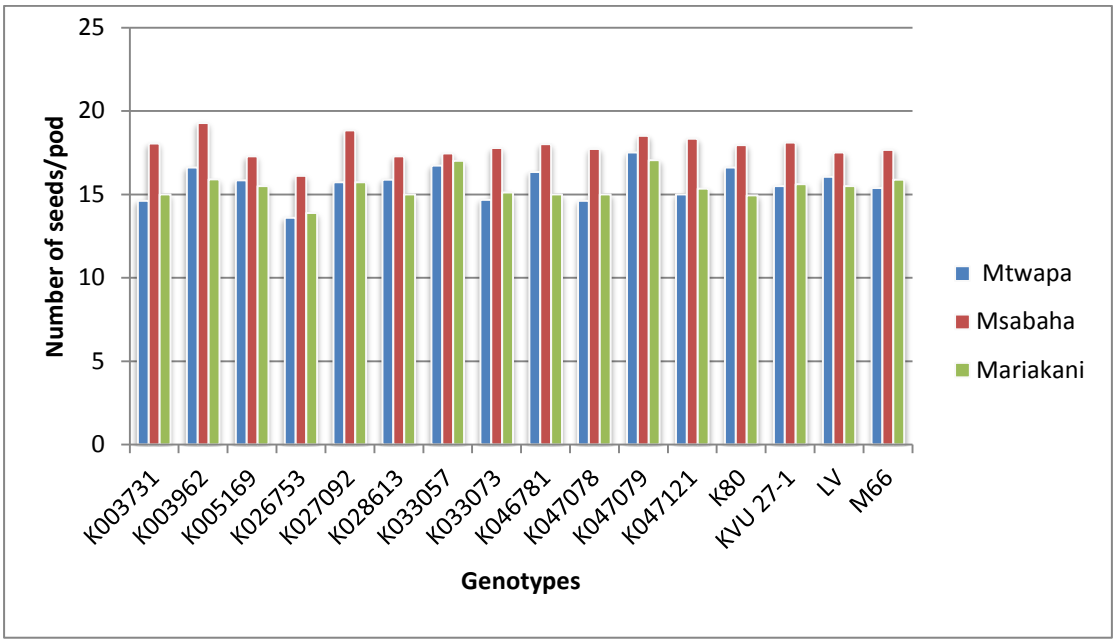
Appendix III: Mean number of days to physiological maturity of 16 genotypes at Mtwapa, Msabaha and Mariakani



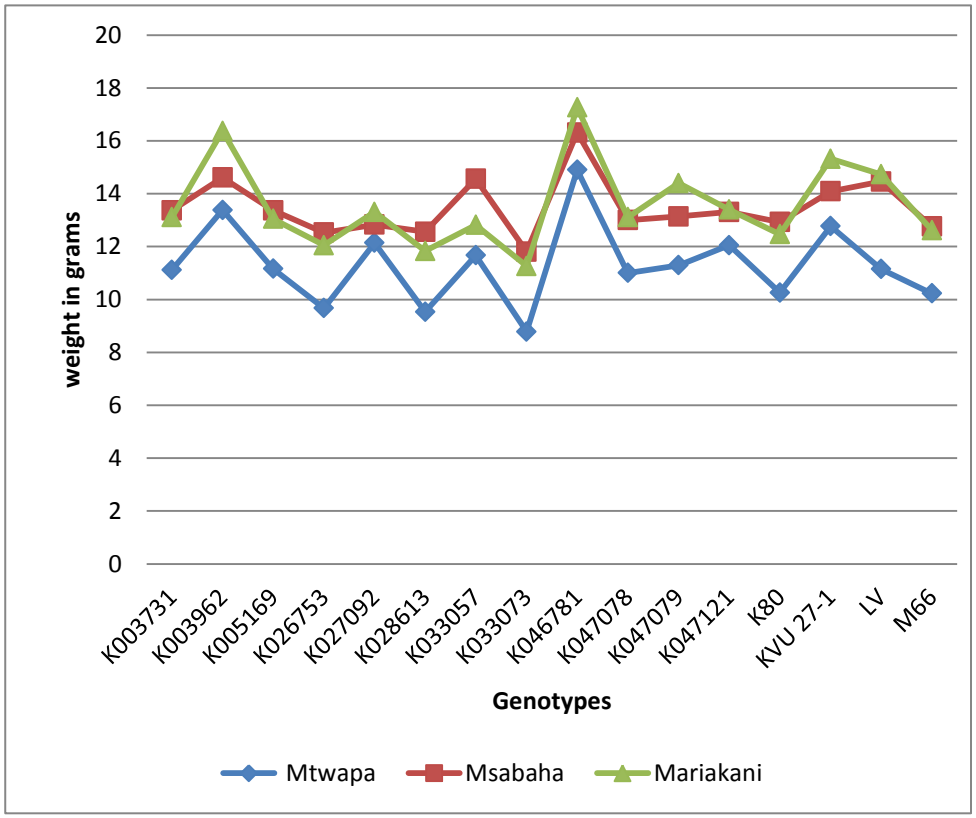
Appendix IV: Mean number of pods per plant of 16 genotypes evaluated at Mtwapa, Msabaha and Mariakani in the coastal region of Kenya



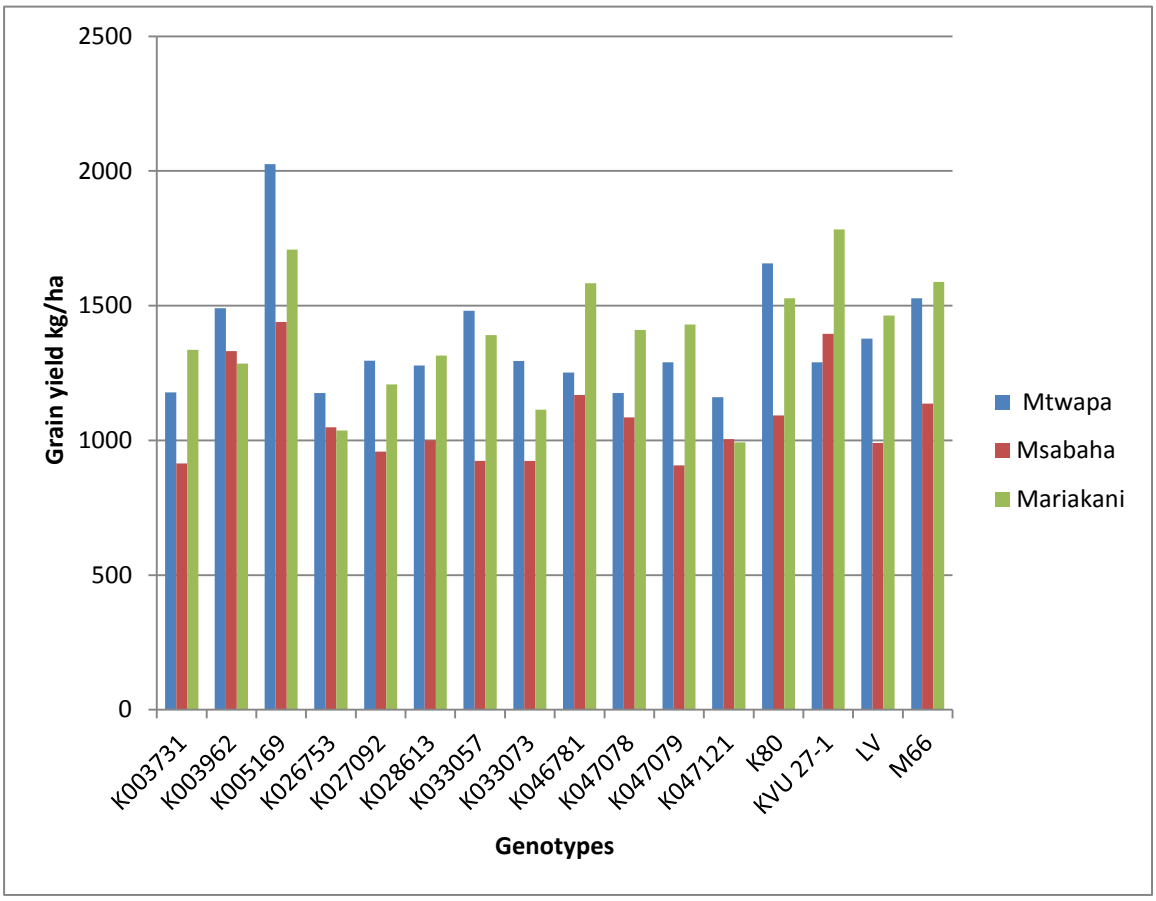
Appendix V: Mean number of seeds per pod of 16 genotypes at Mtwapa, Msabaha and Mariakani



Appendix VI: Trends in 100 seed weight of 16 genotypes at Mtwapa, Msabaha and Mariakani



Appendix VII: Mean grain yield (kg ha^{-1}) of 16 genotypes at Mtwapa, Msabaha and Mariakani



Appendix VIIIa: Mean squares for days to flowering, days to podding, days to physiological maturity, number of pods per plant, length of pod, branches per plant and height of 16 cowpea genotypes evaluated at Mtwapa (CL 3), Msabaha (CL 4) and Mariakani (CL 5) in 2012/2013

Source of variation	Df	Expected Mean Square	Days to 50% flowering	Days to 50% podding	Days to physiological maturity	Number of pods per plant	Length of pod	No. of branches per plant	Height of plant
Year	1	$\delta_e^2 + 144\delta^2_{EY} + 432\ \phi_Y$	145.920**	208.420**	906.670**	4683.587**	51.986**	8.694**	1799.200**
environment	2	$\delta_e^2 + 288\delta^2_E$	182.215**	68.690**	1155.513**	1330.461**	33.196**	36.627**	547.328**
Year ×environment	2	$\delta_e^2 + 144\ \delta^2_{EY}$	236.211**	292.815**	4545.43**	953.035**	69.128**	1.302*	1192.786**
Replicate (within year and environment	12	$\delta_e^2 + 288\ \delta^2_R$	4.086	6.788	12.204	62.235	2.857	0.406	191.767
Genotype	15	$\delta_e^2 + 18\delta^2_{GE} + 54\phi_G$	15.946**	10.736**	63.120**	92.688**	29.903**	1.137**	133.064
Genotype × year	15	$\delta_e^2 + 9\delta^2_{GYE} + 27\phi_{GY}$	8.209	9.449*	14.388	41.215	2.512	0.304	149.286
Genotype × environment	15	$\delta_e^2 + 18\delta^2_{GE}$	9.933*	9.446**	33.591**	41.013*	2.079	0.698**	151.190
Genotype × year × environment	30	$\delta_e^2 + 9\delta^2_{GYE}$	5.378	5.845	13.426	35.879	2.546	0.184	105.451
Error	180	δ_e^2	5.186	4.165	10.927	24.528	1.847	0.332	107.992
R^2			**0.641**	**0.702**	**0.884**	**0.764**	**0.733**	**0.696**	**0.500**
CV			**5.06**	**3.79**	**4.44**	**22.80**	**7.71**	**15.483**	**18.38**

NB:*, ** =significantly different at 0.05 and 0.01 levels

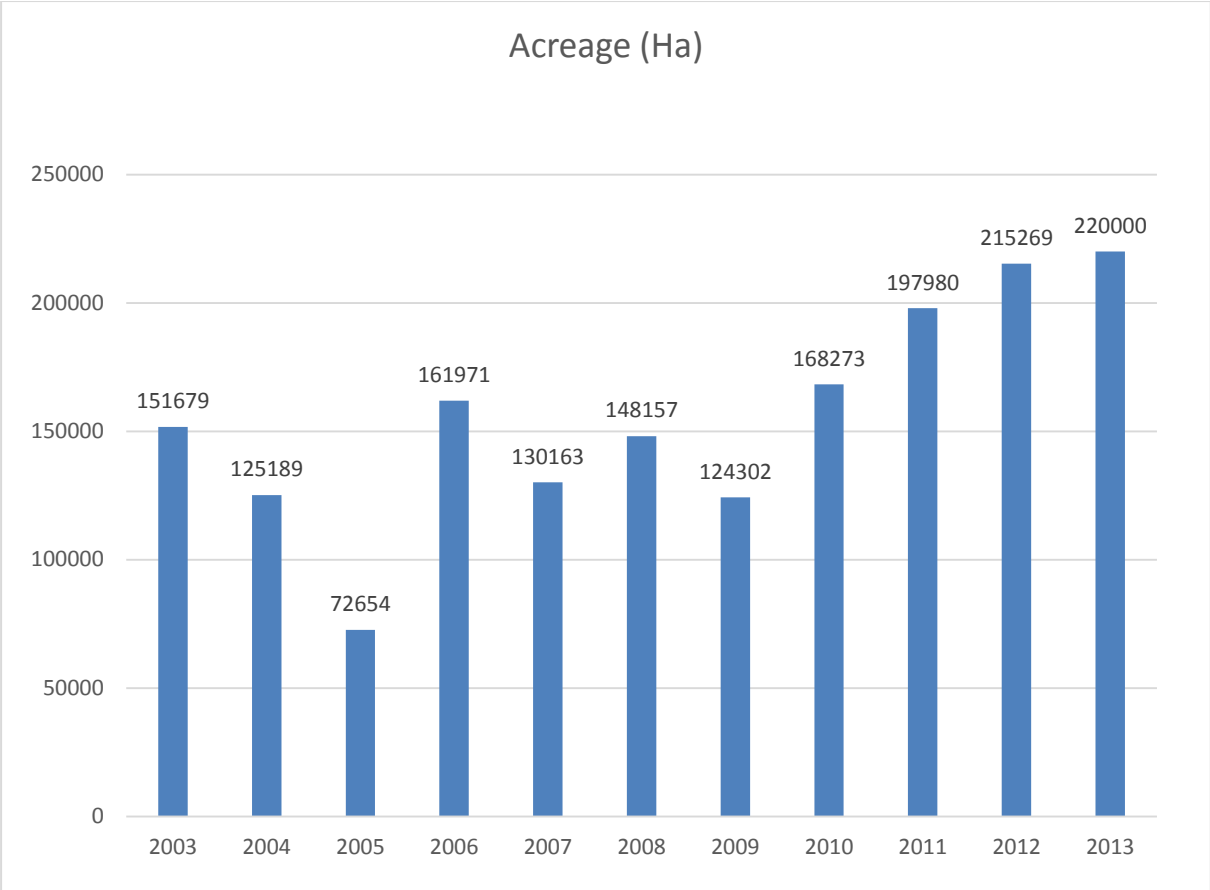
Continuation…

Appendix VIIIb: Mean squares for number of seeds per pod, seed length, seed width, number of internodes, pod weight, grain yield and seed weight of 16 cowpea genotypes evaluated at Mtwapa (CL 3), Msabaha (CL 4) and Mariakani (CL 5) in 2012/2013.

Source of variation	df	Expected Mean Square	Number of seeds per pod	Seed length	Seed width	Number of internodes	Pod weight	Seed weight (yield)	100 seed weight
Year	1	$\delta_e^2 + 144\delta^2_{EY} + 432\ \phi_Y$	271.775**.	0.170	0.361*	13.807*	89346286.90 **	38190107.44**	105.899**
environment	2	$\delta_e^2 + 288\delta^2_E$	170.068**	8.592**	3.252**	787.159**	461432.06	2811213.75**	157.275**
Year ×environment	2	$\delta_e^2 + 144\ \delta^2_{EY}$	142.765**	0.525**	0.184	283.166**	8610885.06**	5856441.93**	31.787**
Replicate (within year and environment	12	$\delta_e^2 + 288\ \delta^2_R$	3.451	0.059	0.0362	9.359	2620980.22	1199535.00	0.839
Genotype	15	$\delta_e^2 + 18\delta^2_{GE} + 54\phi_G$	9.028**	2.840**	2.322**	4.048*	1232985.33*	552044.87**	34.747
Genotype × year	15	$\delta_e^2 + 9\delta^2_{GYE} + 27\phi_{GY}$	3.059	0.140	0.037	2.500	200228.33	120109.7	0.698
Genotype × environment	15	$\delta_e^2 + 18\delta^2_{GE}$	1.868	0.184**	0.154**	5.004	322197.96	120318.22	1.913**
Genotype × year × environment	30	$\delta_e^2 + 9\delta^2_{GYE}$	2.759	0.125	0.100	2.273	656451.71	273109.53	1.864**
Error	18	δ_e^2	2..798	0.100	0.069	2.321	612529.60	241814.5	0.863
R^2	0		**0.714**	**0.801**	**0.801**	**0.860**	**0.632**	**0.678**	**0.879**
CV			**10.24**	**4.39**	**4.45**	**16.26**	**38.47**	**38.42**	**7.26**

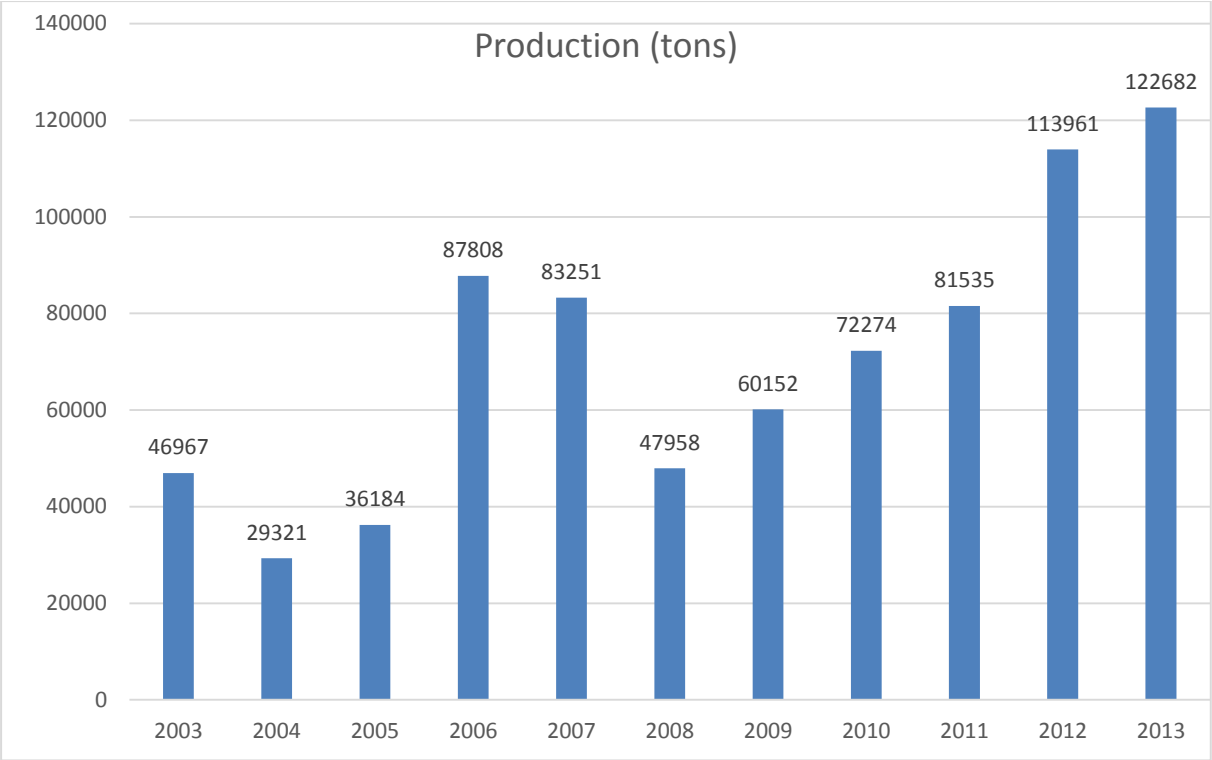
NB:*, ** =significantly different at 0.05 and 0.01 levels

Appendix IX: Acreage (Ha) under cowpeas in Kenya from 2003 to 2013



Source: FAOSTAT 2014

Appendix X: Cowpea production (tons) in Kenya from 2003 to 2013



Source: FAOSTAT 2014