EVALUATION OF GENETIC VARIABILITY AND STABILITYOF SELECTED PEARL MILLET GENOTYPES (*PENNISETUM GLAUCUM* (L.BR.) IN ARID AND SEMI-ARID LANDS OF NORTH RIFT, KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university. No part of this thesis may be produced without the permission of the author and/University of Eldoret.

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DEDICATION

The thesis is dedicated to my parents, for instilling in me diligence, discipline and honesty and my family Susan, Chebet and Brian for their support.

ABSTRACT

Thirty-six genotypes of pearl millet (*Pennisetum glaucum)* differing in their performance from local varieties (OPV) were evaluated in two environments (Marigat and Koibatek, Kenya) to examine their yield and stability across the two diverse environment. The main objective is to improve pearl millet production in arid and semi-arid lands of Kenya. Improvements of hybrids have been made in the past and yet no yield ceilings have been reached however germplasm provide little genetic variability for yield and therefore there is need to improve pearl millet in arid and semi-arid lands of Kenya. The genotypes were laid out in randomized complete block design in two replication and data collected on yield and yield components. Data analyses was done using Genstat 12 edition. Data on grain yield was further subjected to GGE biplot analysis to determine stability and genotype by environment interaction of the genotypes. The genotypes were grouped into eleven clusters. The clustering pattern gave indication of classification of genotypes according to the yield and yield components. The test environments provided improved yields levels from low (600kg ha^{-1}) at Koibatek to high (6200kg ha^{-1}) at Marigat hence there was high significant variation at $P \leq 0.001$ observed among the grain yield in both sites. Performance of the hybrids showed various pattern of stability to test environments. More genotypes performed better in Koibatek than Marigat even though Marigat showed good yield performance. Cluster nine showed good yield performance across the location because of its characteristic which might have influence the response to the test environments. Local variety Kat pm 2 appeared to be among the stable genotypes but among the poor performance than the hybrids. Results indicated that best performing genotypes were not best adapted in the test environments hence stable hybrids can be identified through evaluation over diverse environments.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASALS	Arid and semi-arid lands
ATC	Agricultural training college
DDGS	Distil dried grains soluble
EUP	Egerton University pearl millet
FTC	Farmers training college
GE	Genotype by Environment
Gms	Grams
ICRISAT	International crop research institute for semi-arid tropics
KALRO	Kenya agricultural livestock research organization
NPT	National performance trial
PCAs	Principle component analysis
PH	Plant height
R. tillers	Reproductive tillers
SE	Standard error
V. tillers	Vegetative tillers
WGT	Weight

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

1.1.1 Distribution of Pearl millet

Pearl millet (*Pennisetum glaucum* (L.) R.Br) is one of the world's hardiest warm season cereal crop and in the tropical and sub-tropical regions of the world. It is ranks the second among stable foods in east and central Africa Mgonja *et al.,* (2006). Realizing the many uses of pearl millet grain, several research projects are underway to develop new pearl millet varieties and hybrids for high grain yield. Agronomic differences among pearl millet genotypes have been reported earlier which may serve as a guide for breeding and selection depending on the consumption of pearl millet in arid and semi-arid lands of Kenya, e.g. forage or as a grain Dewey *et al.,* (2009). Research been done on pearl millet for grain yield has been centered on developing dwarf hybrids (Rajewski & Andrews, 1995), and stability to local conditions (Maman, 2003).

The crop is grown as a grain crop in over 29 million hectare in the arid and the semi-arid tropics (SATs) of Asia, Africa and Latin America. India is the largest producer with 35% of global production, followed by Niger 28%, Nigeria 16%, Sudan 7%, Mali 6%, Burkina Faso 5% and Senegal 3%. Millets and sorghum constitute an estimated 11.4% of the cereal area harvested and 4.1 percent of the total output of world cereals produced in Eastern and Central Africa, the area under pearl millet is increasing due to its ability to survive under much stressed environments. This has become more apparent in the recent years with the effects of climate change where the dry areas are becoming much drier and hotter Omamo *et al*., (2006).

In Kenya the total area under pearl millets is about 93,310 ha, producing about 68,800 tons per annum with productivity of 200-800 Kg ha^{-1} against yield potential of 1500-3000 Kg ha^{-1}. Pearl millet is, however, important in south eastern Kenya comprising mainly Tharaka, Mbeere, Mwingi, Kitui, Makueni and also drier areas of the Rift Valley mainly in Baringo, Elgeyo Marakwet and West Pokot. Eastern province is the main producer of millet, producing over 60% of the total millet while Rift valley produces less than 10% Omamo *et al.,* (2006).

1.2 Economic importance

Pearl millet is one of the most important food crops in arid and semi-arid region in Kenya among small scale farmers. It is a staple food which matures in a short period in relatively dry regions of Kenya. It is a drought tolerant crop among cereals and millet. Consumption of pearl millets as food varies in different part of the world with Kenya producing little among the African countries. In Sahel region pearl millet account for about 35% of the total cereal as food consumption (Basavaraj *et al.,* 2010). In Africa areas planted with pearl millet are estimated at 15 million hectares and 14 million hectares in Asia, global production exceed10 million tonnes a year (National research council, 1996). It is also source of food for both animals and human being, beside food for human being and animals, pearl millet stem are used for wide range of purpose including the construction of hut walls, fences, thatches and production of brooms (IFAD 1999).

1.1.2 Pearl millet Production Constraints in Kenya.

The major factors limiting yield improvement are biotic and abiotic stresses including diseases, pests, drought, heat stress, low soil fertility and salinity (ICRISAT, 2011).

Grain yield of pearl millet hybrids in Marginal land are low because of poor resource endowed in these areas. The grain yield productions of hybrids are very higher than the local varieties (OPV) which are being grown by farmers in ASALS (Matlon, 1985). In spite of its enormous importance, pearl millet yields in Kenya is currently very low ranging between 200 to 800 Kg ha^{-1} and usually not consistent varying from season to season. Pearl millet breeding program in Kenya has led to release of only one variety i.e. (KAT PM2) Production of 1000-1200kgs/ha.

These varieties are also low yielding and are affected by drought. There is however potential to increase the yields up to 1500-3000 Kg ha^{-1} if improved varieties are used in combination with soil and water conservation, and management of both pests and diseases Mgonja *et al.,* (2006). Elsewhere in ICRISAT India, yields of more 2000kgs/ha due to developing hybrids that are drought tolerant and resistant unlike local variety.

Other reasons for low pearl millet production in Kenya is because of the following reasons namely, cultivation of local cultivars e.g. Open pollinated variety that have low grain yield and susceptibility to diseases, abiotic stresses such as drought due to low erratic rainfall and high temperature especially during short cropping season, this areas include Tharaka, Baringo and Eastern province in Kenya.

1.2 Problem statement

Impressive hybrid improvement have been made in the past and therefore there are no indication that yield ceiling have been reached Larson *et al.,* (2006) however production of pearl millet have been declining from 1,610kg/ha in 1980 to 200-800kg/ha^{-1} (2008) against yield potential of 1500- 3000kg/ha^{-1} (FAO, 2005).

Available germplasm provide little genetic variability for yield and yield components and adaptation traits. Later onset of the rains, the interruption of rains within the growing season and the adverse effects of drought upon soil conditions are all factors which could render crop failure a likely occurrence especially given that the majority of small-scale farmers in the arid and semi-arid region of rift valley and other regions rely largely on rainfall for their staple crops (Demuyakor., *et al.*, 2013). Although government through agricultural organization and Ministry of agriculture have been advising farmers in the drought prone areas to grow hybrids varieties because of their nature to withstand biotic and abiotic condition. Most of the rural households do not even produce enough millet to meet their own needs and they end up purchasing other pearl millet that are expensive than they produce Nevertheless, majority of subsistence farmers are unable to take advantage of high yield potential of the hybrids because of lack of improved varieties which are stable in many location.

1.3 Justification

OPV landraces with lower yield but higher adaptation to local environment are mostly grown hence selection of pearl millet hybrids that grow well and produce high yields in ASALS is the way forward, therefore such strategy can lead to improved pearl millet productivity in arid areas and overall sustainability of food production and food security in marginal areas in Kenya.

Research done shows that greater impact may be made on productivity of the crop through hybrid cultivars as occurred in Asia and Nigeria House *et al.,* (1997).

95% of farmers rely on informal varieties for planting in ASALS of Kenya where the farmers on those areas prefer planting local varieties (OPV) conserved on their own farms, purchased from local market or exchanged from neighbours to cut down on cost of buying pearl millet hybrids, due to improper hybrids varieties the results is low production of pearl millet yield Van de steeg *et al.*, (2009). In view of these constraints, breeding and selection of pearl millet genotypes that grow well and produce high yields in ASALS of Kenya is an important strategy. Such pearl millet hybrids have been produced by ICRISAT researchers in Kenya and India and shown to produce better yields. Therefore such strategy can lead to improved pearl millet productivity on arid areas and overall sustainability of food production and food security in marginal areas in Kenya. Undertaking such research gave an insight with regards to how small-scale farmers incorporate their decision into production of pearl millet hybrids while taking into consideration of climate variability.

1.4 Objectives

1.4.1 General objectives.

1. To Improve pearl millet production in arid and semi-arid lands of Kenya.

1.4.2. Specific objectives

1. To evaluate grain yield performance of pearl millet hybrids in Marigat and Koibatek, Kenya.
2. To identify stability test of selected pearl millet genotypes in Marigat and Koibatek, Kenya.
3. To determine genetic diversity and genotype by environment interaction of pearl millet hybrids in Marigat and Koibatek, Kenya

1.4.3 Hypotheses (H_o)

1. There are no significant differences in yield performance of Pearl millet in ASALs of North rift, Kenya.
2. There are no significant differences in stability of selected pearl millet in ASALs of North rift, Kenya
3. There is no significant genotype by Environment interaction in the performance of the pearl millet varieties.

CHAPTER TWO

LITERATURE REVIEW

2.0 Pearl millet botany and morphology, production and ecology

2.1.1. Plant botany and morphology

Pearl millet is a cross-pollinated, diploid cereal belonging to the poaceae family and panicoideae sub-family. The important wild relatives of cultivated pearl millet include progenitor, include *Pennisetum glaucum* subsp and *monodii maire* among others. The generic name Pennisetum has been derived from two Latin words-penna and seta, meaning feather and bristles i.e. feathery bristle, extensive treatment of the genus Pennisetum was contributed by Stapf and Hubbard (1934) who divided the genus into five sections.

The origin and centre for pearl millet are situated in western Africa. The plant was introduced into India where the earliest records date back to 2000 B.C (Hanna, 1987, Ras *et al.*, 1997, Gari, 2002 and Oumar *et al.*, 2008).Pearl millet is able to grow in a harsh environment where other crops cannot do well Abdullah *et al*., (1998). Beside other characteristic, the crop has a relatively short growing duration and is able to survive in semi-arid conditions with low rainfall of 400 mm or less (Khan, 2002). Pearl millet is a crop reserved for areas where sorghum and maize frequently fail due to low rainfall and adverse soil factors, Mohamed *et al.,* (2002). It can grow under high temperature conditions and in poor soils with low p^H and low fertility. The crop also requires very little inputs and responds well to water and good plant management (Kumar, 1989).

Drought tolerant pearl millet play an important role in frequency of opening and closing of stomata minimizing crop water deficit during pre an thesis hence can be able to produce with little water Winkel *et al.,* (2001). Tillering habit of pearl millet is influence by environmental factors.

This enables the crop to compensate yield loss of the main shoot by producing additional tillers (Bidinger, 1986). In addition, the photosynthetic rates are maintained throughout periods of severe drought (Zegada-Lizarazu and Iijima, 2004). Due to the ever increasing population in the dry areas, the production per capita can only be maintained by expanding the area sown under pearl millet and especially in Africa due to the shortage of arable land, this can only be achieved by intercropping (ICRISAT 2011).

2.1.2. Pearl millet cultivation and ecology

Pearl millet is propagated from seeds usually sown directly in the field. Seed rates vary from 2–5 kg per ha depending on the soil type and the use of the crop. It is sown directly on hills in rows at a spacing of between rows 45-200 cm depending on whether it's intercropped or if grown as a sole crop. The seed is sown to a depth of 1.3-2 cm Gulia *et al.,* (2007). Emergence occurs in 2 to 4 days under favorable conditions (Baker, 2003). Seedling development occurs during the first two to four weeks, and rapid stalk development occurs soon after. The crop tillers extensively in sparse stands, particularly if good soil moisture is available (Baltensperger, 2002). Flowering begins at 30 to 50 days after emergence, and the plant reaches physiological maturity by 75 to 85 days after emergence Yadav *et al.,* (2011). During the first weeding the crop is thinned to 2 or 3 plants per hill.

2.1.3. Pearl millet production and distribution

Pearl millet is the most important crop in the drier parts of semi-arid tropics and accounts for almost half of the global production of the millet species from amongst different species of millets cultivated (FAOSTAT, 2007). It is estimated that of the total global production of millets, pearl millet accounts for 50%, finger millet 10% and other millets 40%. The crop is grown in over 29 million hectares in the arid and the semi-arid tropics of Asia, Africa and Latin America, India being the largest producer (FAOSTAT, 2007; FAO, 2008). In East and Central Africa (ECA), pearl millet is grown in over 2.27 million hectares with most of the area being in Sudan which is 95% of the production in that country. In Kenya the crop is grown in an approximate area of about 93,310 hectares (MOA, 2008). While in Tanzania and Eritrea it is grown in 270,000 hectares and 100,000 hectares respectively Omamo et al., (2006) and Mgonja et al., (2006). It is also grown as a fodder crop, mainly in the developed countries like in Brazil, the United States, South Africa, and Australia (ICRISAT, 2007; FAO, 2008). India is the largest producer of the crop with 35%, followed by Niger 28%, Nigeria 16%, Sudan 7 %, Mali 6%, Burkina Faso 5% and Senegal 3% (FAOSTAT, 2007).

2.2 Pearl millet hybrid utilization

The improved hybrids cultivars are grown 4.5 million hectare against local variety which covers only 0.6-0.8million hectares. Hybrids are not only contributing to increased productivity but resistance to some disease like downy mildew epidemics that were observed quite often in later years Hash *et al.*, (2006). Furthermore hybrids record higher grain and fodder yield over open pollinated variety in a zone having rainfall less than 400mm (Kumar, 2011).Variation of pearl millet genotypes for grain yield has being reported which may serve as breeding and selection programmes, however research are undertaken to develop new varieties of hybrids for grain yield Dewey *et al.,* (2009).

Pearl millet is a multipurpose cereal grain for food, fodder, fuel and mulch on more than 26 million hectares primarily in arid and semi-arid regions of India and Africa.

The low hydrocyanic acid content of pearl millet makes it an excellent forage crop (Burton 1995, Hidalgo, 2004). This is equally or better than some poultry diets like maize- soybean even without grinding and hence its uses can reduce the cost of processing. Pearl millet grain contains 27% to 32% more protein, higher concentration of essential amino acids and gross energy than maize Davis et al., (2003).Pearl millet grain contains lesser anti nutritional factors such as condensed tannins than sorghum grain. Stover of pearl millet is a major source of dry-season maintenance rations for livestock in traditional smallholder production systems on the semi-arid regions. Although the expression of Stover quality in pearl millet is a complex trait Hash *et al.,* (2003), Pearl millet forms an excellent feed for pigs, poultry, duck and turkey. Broilers fed on pearl millet are heavier because they have a better feed conversation rate than those fed on maize. The crop can also be used for fuel and ethanol production resulting in higher economic return from pearl millet than from maize Gulia *et al.*, (2007). A recent finding confirms this and shows that pearl millet can supplement maize and sorghum for fuel ethanol production. There is therefore need of increasing public awareness in Kenyan ASALs about the exceptional nutritional merits of pearl millet compared to other cereals and drawing industrial attention to its suitability for animal, bird feed, and bio fuel. This is essential since it will create a large scale demand for the crop.

The mature panicle is brownish in colour, and spiklets are borne in fascicles of two, surrounded by a cluster of bristles. Each spiklets has two florets, one of which is generally staminate. The upper floret is fertile, with the caryopsis (seed) being enclosed by the lemma and palea from which it threshes free during harvest. (Baker 2003; (< http://database.prota.org/search.htm> Accesse18July 2011).

2.3 Pearl millet cultivation and ecology

Pearl millet is mainly grown as a monocrop but can be intercropped with other crops mainly legumes such as cowpeas and groundnuts (Baltensperger 2002). In ASALS where the crop is grown, more often the soils are depleted of nutrients and legumes are a possible intervention to provide missing nutrients and replenish the soils with other nutrients. It is thus advisable to integrate pearl millet with legumes and also livestock manures. The livestock would provide the manure that would also be used to improve the soils; while the pearl millet straw is in turn used as livestock feed (ICRISAT, 2007).

Pearl millet is a warm season cereal, its growth is proportional to solar radiation interception and the plant development rate is proportional to the accumulated degree days above base temp of 10^{o} C and the plant development slows down when the temperature drops below 15^{o}C Mula *et al.,* (2009).The optimum temperature for germination of pearl millet seeds is 33–35°C.

Germination will not take place below 12°C. The optimum temperature for tiller production and development is 21–24°C, and for spikelet initiation and development about 25°C. Extreme high temperatures before an thesis reduce pollen viability, panicle size and spikelet density, thus reducing yield. Pearl millet takes between 60-70 days from planting to maturity (Baltensperger, 2002).

Pearl millet is adapted to drought and infertile soils hence can produce more grains under the conditions where other grain crops such as wheat and maize cannot produce. Pearl millet has relatively fast root development, sending extensive roots both laterally and downward into the soil profile to take advantage of available moisture and nutrients. It can grow on a wide variety of soils ranging from clay loams to deep sandy soils. Yields and grain quality, however, are best on deep, well-drained productive soils. Soil management and tillage that encourages deep rooting generally enhance yields and seed quality. It is not advisable to grow millet on soils prone to “water logging” in wet seasons, this is because it will cause shallow rooting, low seed protein and poor yields. Irrigation can improve plant stand and establishment if soils are dry during and after seeding. Little is known about pearl millet response to irrigation during growth. It appears that pearl millet responds less to irrigation than other grain crops. Greatest water use occurs during the bloom and soft dough stages. A very deep root system and less defined “critical water use period” makes pearl millet tolerant to short duration of drought Lee *et al.*, (2009).

Pearl millet does well in areas of high temperatures. However, it readily responds to high soil fertility and moisture. Pearl millet grows best in light well-drained loamy to sandy soils. It can tolerate acidic soils to as low as pH 4 with high aluminium content. Annual rainfall in the areas where this crop is mainly grown ranges from 250 to 700 mm but can still perform well in as high as 1500 mm per annum(Baker, 2003). The crop is characterized by the C_4 photosynthetic pathway. e.g. *Gigaspora* and *Glomus* spp. and nitrogen-fixing bacteria e.g. *Azospirillium spp*. are commonly found associated with pearl millet roots, which may assist with the uptake of water, N and P (< http://database.prota.org/search.htm> Accessed 22 July 2011).

2.3.1 Environmental Conditions Suitable For Pearl Millet Production

2.4 Production constraints

The main constraints limiting production and productivity of pearl millet are biotic and abiotic stresses. Pearl millet growing environments are characterized by low and erratic rainfall (between 200-400mm) high temperatures (up to 45^{o}C), poor soil fertility, disease and insect pest pressures, low input use and lack of certified production seed (ICRISAT, 2010). Limited availability of certified seed is a major setback in the spread of the crop in the developing countries *Yadav et al.,* (2011). These and the low harvest index of traditional landrace cultivars lead to poor productivity (200-600kgs ha^{-1} grain yield) (ICRISAT, 2010).

In addition bird damage is major in pearl millet, especially in small fields where they can cause up to 100% yield losses (KARI, 2008). The Quelea species is the most damaging with Quelea aethiopica being the most common in East Africa. Bird scaring for several weeks before the harvest is essential (KARI, 2008; MoA, 2008). The menace from the birds can further be reduced by locating crop fields away from tree lines or woods and also crop monitoring for timely harvesting before the bird damage (Rachie and Majumdar, 1980; Gulia *et al.,* 2007).

Other constraints affecting pearl millet are post-harvest handling, processing and utilization, marketing, policy, institutional support, and access to knowledge and information (ICRISAT, 2010). These constraints are in line with the main areas of production, marketing, and whole value chain as suggested for commodities by ASARECA (Michelson, 2003).

In Kenya pearl millet is a food security crop, however its production remains low due to diseases and pests among other challenges (KARI, 2008).

2.5 Determination of crop Diversity and Genotype by Environment interaction.

Several techniques have been used to assess the diversity, potential usefulness and reliability of traits as selection criteria, with a view of enhancing selection efficiency. Correlation and regression are widely used to estimate the contributions of yield components and other morpho-physiological traits to increased grain yield Solomon *et al.,* (2007).

Assessment of agro-morphological diversity among conserved accessions is important in genotype management and crop improvement practices. Morphological traits including quantitative ones are used to evaluate genetic relationship among genotypes Bajracharya et al., (2012).

The interrelation among yield traits could be useful to study the relationship among grain production criteria Kouhroubas *et al.,* (2009). Yield is a quantitively inherited trait greatly influenced by environment and has low heritability and cannot be used for selection directly, this is because yield depend on many morphological and physiological characters and specific targeting of morpho-physiological characters that enhance yield particularly in early generations may be more cost effective Kimurto *et al.,* (2009). Previous research shows that association between traits varies with locations and years (Abebe, 1984). Yield and yield components varying relationship indicate variation within different seasons, environment and location and thus the need in determining different associations among important traits over a large spectrum of environment and seasons for identifying consistent relationship among traits that are important for effective breeding programs for different traits.

Among the important characters that are associated to predict yield and yield components in breeding programmes are correlation coefficient (r), principle components (PCA) and heritability among others. Correlation coefficient (r) is a linear association between any pair of traits and both association contribute greatly to selection. Similarly, principal components analysis (PCAs) have been used to identify variability present in a population contributing components by deriving principal components of asset of variables by retaining as much as possible of original variables to a new set of uncorrelated variables (Toker, 2004).

Correlation coefficients, principal components and other association parameters estimate only apply to the population sampled to the environment where the population is grown. For example Manyassa *et al*., (2009) identified different PCA variations when they evaluated pearl millet genotypes in FTC Koibatek and Kenya agricultural research Marigat, Kenya. These indicate environmental influence in traits expression and the importance to carry out such evaluation over a wide range of environments for reliable results.

Yield component traits associated with grain yield in pearl millet were analyzed using different approaches with aim of understanding factors influencing grain yield amongst pearl millet hybrid that could increase yield if used in selection breeding.

2.6 Stability of Pearl millet and climatic variability

Climate variability is good for wide range germplasm that perform satisfactory under a wide range of climatic conditions, rather than performing in a narrow subset of conditions Nelson *et al.,* (2009).

This is important because climate change remains unpredictable for small farmers in arid and semi-arid regions, with such high uncertainty on climates outcome, stability of hybrids genotypes need to be considered.

Ensuring continued adaptation of new germplasm to the inter-annual variability in rains should be given first priority to avoid plants stress in preparation for the longer season Washington *et al.,* (2006). The lower the average total rainfall of a site, the higher the rainfall variability Cooper *et al.,* (2008) hence most farmers in arid and semi-arid region are hit hardest by the kind of climate, therefore this can extend poverty and resource degradation.

Better understanding of the mechanisms of coping with climate variability is crucial and solution for adaptation to future climate change. Yield stability of pearl millet hybrids in unpredictably variable environments is necessary. Hybrids could be grown by farmers and therefore be good option in areas where local varieties are still being grown.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site

This study was conducted at two sites, Koibatek (Agricultural Training Centre, ATC-Koibatek), Marigat (Kenya agricultural and livestock research organization –Perkerra, Marigat). Koibatek (Latitudes 1^0 35'S, longitude 36^0 66E) and altitude of 1890m above sea level. It lies in UM 4 agro-zone, with low agricultural potential and mean annual minimum and maximum temperature of 10.9 ^{0}C and 28.8 ^{0}C respectively (Jaetzold and Smith 1983).KALRO Perkerra - Marigat latitude lies at 00^0 26 -00^0 32N and longitude 36^0 00 -36^0 09'E.Average latitude of 900m above the sea level. It is located at agro-climatic zone UM 5 Wasonga, et al., and (2011). In Koibatek the soils are vitric endosol with moderate to high soil fertility, well drain loam to sandy loam soil (Jaetzold and Schmidt, 1983).

In Marigat it is lowland with varying texture and drainages conditions that have alluvial deposits, while some are saline. In Koibatek annual rainfall range between 500-800 mm and the rainfall is characterise as erratic. Long rains occur in the month of April to august and short rain October to November. In Marigat the rainfall average is 500 mm per annum Wasonga et al., (2011). Rainfall starting in March to July while short rains at the end of September to early November

3.2 Genotypes evaluated

The 35 hybrid genotypes that were used in this study were sourced from the International Crop Research Institute of Semi-arid Tropics (ICRISAT) and KARLO Katumani. One variety, KAT PM 2 was the commercial varieties used as check (Table 1). They have varied levels of resistance, yield and phenology.

Table 1. List of pearl millet genotypes and their phenology

TRT NO	GENOTYPES	SOURCE	REMARKS	PHENOLOGY
1	EUP 1	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
2	EUP 2	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
3	EUP 3	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
4	EUP 4	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
5	EUP 5	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
6	EUP 6	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
7	EUP 7	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
8	EUP 8	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
9	EUP 9	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
10	EUP 10	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
11	EUP 11	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
12	EUP 12	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
13	EUP 13	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
14	EUP 14	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
15	EUP 15	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
16	EUP 16	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
17	EUP 17	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
18	EUP 18	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
19	EUP 19	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
20	EUP 20	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
21	EUP 21	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
22	EUP 23	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
23	EUP 23	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
24	EUP 24	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
25	EUP 25	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
26	EUP 26	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
27	EUP 27	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
28	EUP 28	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
29	EUP 29	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
30	EUP 30	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
31	EUP 31	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
32	EUP 32	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
33	EUP 33	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
34	EUP 34	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
35	EUP 35	INCRISAT	HYBRID	MODERATE RESISTANT TO DROUGHT
36	KAT PM 2	KALRO	COMMERCIAL CHECK	HIGH RESISTANT TO DROUGHT

3.3 Experimental designs

The experiment was laid out in randomized complete block design (RCBD) of thirty five genotypes plus one commercial check with two replications at each site. Plot size was 2 m by 2 m with spacing of 0.5 and 0.6 m between and within rows respectively. Sowing was done on September 2011 at Marigat and January 2012. Planting was done at the onset of the rains. Planting fertilizer (DAP) was applied at the rate of 40 kg/ha.

3.4 Data Collection

Measurement of yield traits of pearl millet plants were harvested at physiological maturity (12 to14 weeks after planting) depending on the location and their yield data recorded.

The following parameters were measured according to procedures described by Mustapha and Mustapha (2007) and Addisie and Gebre-Egziabher (2011).

: Plant height (PH), Panicle length, 1000 seed weight, Number of vegetative tillers (Vegetative tillers), Number of reproductive tillers (Reproductive tillers) and grain moisture content. Other parameters were obtained by calculating upon harvesting such as Grain yield in tonnes per hectares (t ha^{-1}) and panicle weight (PW).

(i) Plant height (cm) at maturity taken from five plants in the two middle rows. The height was obtained by measuring the plants from their bases to the top of the panicle and the average height of the plants calculated and expressed in centimeter. Size of panicle (cm) taken as length from tip to the base and its diameter in (cm) taken from five plants from the two middle rows as shown below.

(ii) Panicle weight per plot (PW): was calculated by dividing the average weight by number of plants.

(iii) 1000 seed weight in (g) taken from the five plants in the two middle rows calculated by measuring 100 seed from five shell plants and the weight multiply by 10.

(iv) Grain yield (g/plot) from middle rows per plot estimated in g/m^2 then converted to tons/ha. at 12.1% moisture content in the following way:

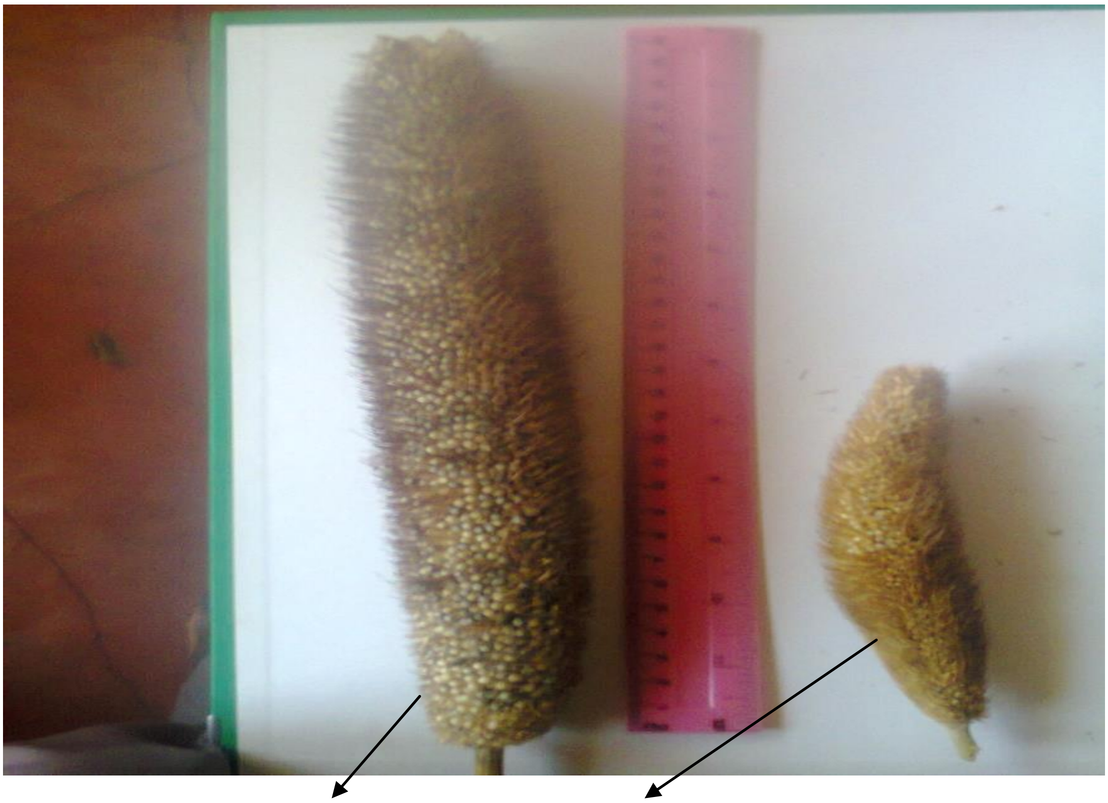
$$GY = \frac{10 \times GW\ (100-\%moist)\ 87.9,}{Area}$$

Where GW = plot grain weight in kilograms;

% moist = plot grain moisture at harvesting time; plot area was $4m^2$.

Grain weight per plant was calculated by dividing the grain weight (GW) by the number of plants counted in the plot.

Fig.1a Vegetative tillers at Koibatek (Source: Author, 2013)



1. **Fig b: Panicle length in Marigat & Koibatek (Source: Author, 2013)**

3.5 Data Analysis

Data analysis was done using statistical package, Genstat 12th Edition and Mean separation done using Duncan New Multiple Range Test (DNMRT). ANOVA carried out in RCBD. Environment and replication were considered random, while genotypes effects were fixed, F- test was used to check the significance of the pearl millet hybrid and the environmental effects, as well as the genotype- by- environment (G X E) interactions.

GGE biplot analysis was done to determine stability and pattern of response of genotypes in the test site using the first two principal components (PC1 and PC2) that were derived from subjecting environment to singular value decomposition.

Cluster analysis was done and similarity matrix generated for eight Agro-morphological traits

General Mathematical Model for Individual Site ANOVA:

$$y_{ijk} = \mu + \rho_i + \tau_j + \tau\rho_{ij} + \varepsilon_{ijkl}$$ (Montgomery, 2005)

Where

$y_{ijk} =$ The individual observation in each Plot;

μ = Overall mean

ρ_i = Complete effect of the block;

τ_j = the estimate of j^{th} treatment (hybrid) effect.

ε_{ijkl} = Overall error effect to the ij observation.

General Mathematical Model for ANOVA across Environments:

$$y_{ijk} = \mu + \alpha_i + \rho(\alpha)_j + \tau\rho_{ik} + \varepsilon_{ijkl}$$ (Montgomery, 2005)

Where:

y_{ijk} = The individual observation in each Plot;

μ =Overall mean for each variable,

α_i= estimate of the environmental effect;

$\rho(\alpha)_j$= estimate of the jth block effect in ith environment;

$\tau\rho_{ik}$= estimate of the kth hybrid or variety.

ε_{ijkl}= Overall error effect in relation to ijkl observation.

CHAPTER FOUR

RESULTS

4.1 Evaluation of grain yields in Marigat season I & II.

The overall mean for grain yield in Marigat was 3.62t ha^{-1} and the highest grain mean was recorded at season I1 (3.79t $hactare^{-1}$). Lowest grain mean was observed at season I (3.44t hactare-^{1}), However genotypes EUP 32 was the best in both season nevertheless the same genotype had highest mean of grain yield in season I and 11 combined of 6.29t $hactare^{-1}$. Lowest was 1.78t $hactare^{-1}$, genotype EUP 4. The highest mean among the genotypes was (6.40t $hactare^{-1}$) and was recorded at season I1 followed by season I with the highest of 6.18t $hactare^{-1}$ (Table 2).

They were variations in grain yields performances among the genotypes in season I with genotype EUP 32 and EUP 35 performing better while EUP 4 was the lowest. However, there was no much different in grain yield performance among individual genotype in season II compared to season I hence the best genotype remain the same in both season.

Mean of yield grain in season I and II were significantly different at $P \leq 0.05$ and therefore in these season, genotypes were grouped into five groups according to their mean separation with EUP 32 and EUP 4 grouped independently on their own group because of their performance, however combined mean yield in season I and II yield separation were grouped into seven groups (Table 2).

Table 2: Means of thirty six pearl millet genotypes for grain yield in Marigat for season I and 11 in tonnes per hectare.

Genotype	Season I	Season II	Season I & II
EUP 1	3.44^{abc}	3.93^{abc}	3.69^{abcd}
EUP 2	3.21^{abc}	3.71^{abc}	3.46^{abcd}
EUP 3	3.56^{abc}	4.00^{abc}	3.78^{bcd}
EUP 4	1.57^{a}	1.99^{a}	1.78^{a}
EUP 5	3.13^{abc}	3.59^{abc}	3.36^{abc}
EUP 6	3.97^{abc}	4.18^{abc}	4.08^{bcd}
EUP 7	3.90^{abc}	4.17^{abc}	4.04^{bcd}
EUP 8	3.07^{abc}	3.36^{abc}	3.22^{abc}
EUP 9	3.72^{abc}	4.00^{abc}	3.86^{bcd}
EUP 10	3.82^{abc}	4.30^{abc}	4.06^{bcd}
EUP 11	2.63^{ab}	3.02^{ab}	2.83^{abc}
EUP 12	3.87^{abc}	4.25^{ab}	4.06^{bcd}
EUP 13	3.09^{abc}	3.63^{abc}	3.36^{abc}
EUP 14	2.96^{abc}	3.93^{abc}	3.45^{abcd}
EUP 15	3.90^{abc}	4.30^{abc}	4.10^{bcd}
EUP 16	3.13^{abc}	3.02^{ab}	3.08^{abc}
EUP 17	3.90^{abc}	4.25^{abc}	4.08^{bcd}
EUP 18	3.57^{abc}	3.63^{abc}	3.60^{abcd}
EUP 19	4.37^{abc}	4.85^{abc}	4.61^{cd}
EUP 20	3.19^{abc}	3.63^{abc}	3.41^{abc}
EUP 21	3.13^{abc}	3.52^{abc}	3.33^{abc}
EUP 22	2.60^{ab}	3.02^{ab}	2.81^{abc}
EUP 23	3.92^{abc}	4.47^{abc}	4.20^{bcd}
EUP 24	2.33^{ab}	2.57^{ab}	2.54^{ab}
EUP 25	3.08^{abc}	3.61^{abc}	3.34^{abc}
EUP 26	3.84^{abc}	4.27^{abc}	4.06^{bcd}
EUP 27	3.01^{abc}	3.47^{abc}	3.24^{abc}
EUP 28	3.71^{abc}	3.96^{abc}	3.84^{bcd}
EUP 29	3.43^{abc}	3.83^{abc}	3.63^{abcd}
EUP 30	2.95^{abc}	3.28^{abc}	3.12^{abc}
EUP 31	2.96^{abc}	3.40^{abc}	3.18^{abc}
EUP 32	6.18^{c}	6.40^{c}	6.29^{e}
EUP 33	2.75^{ab}	3.05^{ab}	2.90^{abc}
EUP 34	3.46^{abc}	3.85^{abc}	3.66^{abcd}
EUP 35	5.14^{bc}	5.51^{bc}	5.33^{de}
KAT PM2	3.41^{abc}	2.34^{ab}	2.88^{abc}
G.Mean	**3.44**	**3.79**	**3.62**
C.V%	**38.5**	**35.4**	**33.6**
Genotype	**ns**	**ns**	******

Mean not followed by the same letters are significantly different at $P \leq 0.05$

4.2 Evaluation of grain yields in Koibatek season I & II.

The overall mean for grain yield in Koibatek was 0.87t ha$^{-1,}$ and the highest grain mean was recorded at season I (0.93t hactare^{-1}). Lowest grain mean was recorded at season I1 (0.80t hactare-^{1}). Highest genotype mean across season I and 11 in Koibatek was 1.17t ha^{-1} and lowest was 0.62t hactare^{-1}. The highest mean among the hybrid was 1.23t ha^{-1} and was recorded at season I followed by season I1 with the highest mean of 1.11t hactare^{-1} (Table 3).

The grand mean for grain yield at each season in Koibatek were different only by 0.13t hactare^{-1} (0.93 and 0.80t hactare^{-1} for season I and 11 respectively).Maximum mean grain yield was recorded at season I and it was genotype EUP 7 similarly at season II but differed in production by only 0.12t hactare^{-1}. Koibatek showed different trend where the lowest genotype in season I was not necessary lowest in season I1 but the best genotype in season I remain the best in season I1 with mean of 1.1t hactare^{-1} and the lowest was genotype EUP 23 of 0.58t hactare^{-1}.

Table 3: Means of thirty six pearl millet genotypes for grain yield in Koibatek for Season I and II in tonnes per hectare.

Genotype	Season I	Season II	Season I & II
EUP 1	0.82^{abc}	0.70^{abc}	0.76^{abcd}
EUP 2	0.92^{abc}	0.80^{abc}	$0.86^{abcdefg}$
EUP 3	0.80^{abc}	0.68^{abc}	0.74^{abcd}
EUP 4	0.87^{abc}	0.75^{abc}	0.81^{abcde}
EUP 5	0.72^{ab}	0.60^{ab}	0.66^{ab}
EUP 6	1.02^{abc}	0.96^{abc}	0.99^{defgh}
EUP 7	1.23^{c}	1.11^{c}	1.17^{h}
EUP 8	0.82^{abc}	0.70^{abc}	0.76^{abcd}
EUP 9	0.90^{abc}	0.78^{abc}	0.84^{abcde}
EUP 10	1.17^{bc}	1.05^{bc}	1.11^{fgh}
EUP 11	0.87^{abc}	0.75^{abc}	0.81^{abcde}
EUP 12	1.04^{abc}	0.92^{abc}	0.98^{cdefgh}
EUP 13	0.98^{abc}	0.86^{abc}	$0.92^{bcdefgh}$
EUP 14	0.92^{abc}	0.80^{abc}	$0.86^{abcdefg}$
EUP 15	0.78^{abc}	0.66^{abc}	0.72^{abc}
EUP 16	0.94^{abc}	0.82^{abc}	$0.88^{abcdefg}$
EUP 17	1.06^{abc}	0.94^{abc}	1.00^{defgh}
EUP 18	0.98^{abc}	0.86^{abc}	$0.92^{bcdefgh}$
EUP 19	0.83^{abc}	0.71^{abc}	0.77^{abcd}
EUP 20	0.92^{abc}	0.80^{abc}	$0.86^{abcdefg}$
EUP 21	0.91^{abc}	0.79^{abc}	$0.85^{abcdefg}$
EUP 22	1.18^{bc}	1.06^{bc}	1.12^{gh}
EUP 23	0.70^{a}	0.58^{a}	0.64^{a}
EUP 24	0.78^{abc}	0.66^{abc}	0.72^{abc}
EUP 25	1.00^{abc}	0.88^{abc}	0.94^{cdefgh}
EUP 26	0.88^{abc}	0.76^{abc}	0.82^{abcde}
EUP 27	0.85^{abc}	0.73^{abc}	0.79^{abcde}
EUP 28	1.11^{abc}	0.99^{abc}	1.05^{efgh}
EUP 29	1.05^{abc}	0.93^{abc}	0.99^{defgh}
EUP 30	1.01^{abc}	0.89^{abc}	0.95^{cdefgh}
EUP 31	0.68^{a}	0.56^{a}	0.62^{a}
EUP 32	0.84^{abc}	0.70^{abc}	0.77^{abcd}
EUP 33	1.08^{abc}	0.78^{abc}	$0.93^{bcdefgh}$
EUP 34	0.94^{abc}	0.82^{abc}	$0.88^{abcdefg}$
EUP 35	0.90^{abc}	0.78^{abc}	0.84^{abcde}
KAT PM2	0.90^{abc}	0.78^{abc}	0.84^{abcde}
G.MEAN	**0.93**	**0.80**	**0.87**
CV%	**20.4**	**23.1**	**17.9**
Genotype	**ns**	**ns**	*******

Mean not followed by the same letters are significantly different at $P \leq 0.05$

4.3 Evaluation of grain yields A cross sites

Results of combined analysis for both sites (KALRO Marigat and ATC, Koibatek) and in both seasons showed significant ($P < 0.05$) genotypic variation for all the traits amongst test genotypes (Appendix 2). Interactions between genotype and site (GXE), and genotype and season (GXS) (year) affected the yield and most yield components of tested pearl millet genotypes except vegetative tillers.

Genotype EUP 32 was the best among the pearl millet genotypes a cross site of 3.5t hactare-^{1}. Genotype, Environment and genotype by environment were highly significant ($P < 0.001$) across the environment however genotypes were not significant in both seasons. Season II in both environment i.e. Marigat and Koibatek 2012/13 performed better than season I 2011/12 with mean yield of 2.3t hactare^{-1} and 2.1t hactare^{-1} respectively (Table 4).

The mean grain yield of pearl millet genotypes across the environment ranged from 1.3 to 3.5t hactare^{-1} of which 47.22% of the pearl millet genotypes gave grain yield exceeding grand mean of 2.2t hactare^{-1} and 52.58% of the genotypes showed lowest mean grain yield values including the open pollinated variety which was the commercial check indicating its greatest role to the variation of total grain yield performance among the genotypes of all the tested genotypes (Table 4).

Table 4: Analysis of grain yield for thirty six pearl millet genotypes combined over season I Marigat and Koibatek 2011/12 and season II 2012/13.

Genotype	Season I 2011/2012	Season II 2012/2013	Grand mean
EUP 1	2.1	2.3	2.2
EUP 2	2.0	2.2	2.1
EUP 3	2.1	2.3	2.2
EUP 4	1.2	1.3	1.3
EUP 5	1.9	2.1	2.0
EUP 6	2.5	2.5	2.5
EUP 7	2.5	2.6	2.6
EUP 8	1.9	2.0	1.9
EUP 9	2.3	2.3	2.3
EUP 10	2.5	2.6	2.5
EUP 11	1.7	1.8	1.8
EUP 12	2.4	2.5	2.5
EUP 13	2.0	2.2	2.1
EUP 14	1.9	2.3	2.1
EUP 15	2.3	2.4	2.4
EUP 16	2.0	1.9	1.9
EUP 17	2.4	2.6	2.5
EUP 18	2.2	2.2	2.2
EUP 19	2.6	2.7	2.6
EUP 20	2.0	2.2	2.1
EUP 21	2.0	2.1	2.0
EUP 22	1.8	2.0	1.9
EUP 23	2.3	2.5	2.2
EUP 24	1.5	1.7	1.6
EUP 25	2.0	2.2	2.1
EUP 26	2.3	2.5	2.4
EUP 27	1.9	2.1	2.0
EUP 28	2.4	2.4	2.4
EUP 29	2.2	2.3	2.3
EUP 30	1.9	2.0	2.0
EUP 31	1.8	1.9	1.9
EUP 32	3.5	3.5	3.5
EUP 33	1.9	1.9	1.9
EUP 34	2.2	2.3	2.2
EUP 35	3.0	3.1	3.0
KAT PM2	2.1	1.5	1.8
Mean	**2.1**	**2.3**	**2.2**
Genotype	**ns**	**ns**	*******
Environment	*******	*******	*******
Genotype*Environment	**ns**	**ns**	*******

Key: *, **, * -significant at 0.05, 0.01 and 0.001 respectively.**

4.4 Yield traits (YT) in Marigat and Koibatek

All yield traits were measured in Marigat and Koibatek except time to 50% flowering. Although the site had significantly different for all the traits, the trial means at each site were different with Marigat having higher traits mean than Koibatek but reproductive tillers were higher in Koibatek than Marigat of 10.6 and 6.55 respectively.

For vegetative tillers, average trial means ranged from 12.8 at Koibatek to 13.25 V. tillers at Marigat. Maximum genotype mean was observed at Koibatek (18.67 V.t) and the minimum genotype mean of 9.8 V.t was obtained at Marigat. Overall mean across the two sites was 11.94 V.t. Highest hybrid mean of 18.67 V.t was observed at Koibatek, while at Marigat was 15.21 V.t.

For plant height, highest trials were achieved at Marigat (194.3 cm plant^{-1}) and Koibatek (166.4 cm plant^{-1}). Highest hybrid mean of 209.4 cm plant^{-1} was observed at Marigat and Koibatek with Maximum of 193 cm plant^{-1}.

For panicle length, highest trials were achieved at Marigat (22.45 cm plant^{-1}) and Koibatek (17.9 cm plant^{-1}). The highest hybrid mean of 24.5 cm plant^{-1} was observed at Marigat and Koibatek 21.5 cm plant^{-1}.

For panicle weight, highest trials were achieved at (36.0 g plant^{-1}) and Koibatek (11.0 g plant^{-1}). The best performing hybrid mean of 37.7 g plant^{-1} was observed at Marigat and Koibatek had 14.96 g plant^{-1}.

For panicle diameter, highest means trial was observed at Marigat (6.0 cm plant^{-1}) and Koibatek 2.5 cm plant^{-1} however the highest hybrid mean of 6.6 cm plant^{-1} in Marigat and 3.0 cm plant^{-1} in Koibatek.

For seed weight, maximum mean trial was observed at 12.9 g plant^{-1} Marigat and 9.9 g plant^{-1} in Koibatek. Highest hybrid mean of 17.2 g plant^{-1} in Marigat and 11.3 g plant^{-1} Koibatek (Table 5 & 6).

Table 5: Yield related traits of thirty six pearl millet genotypes evaluated at Marigat in 2012/2013 short and long rains.

Entry	No. Reproductive tillers	No. Vegetative tillers	Plant. Height(cm)	Panicle Length (cm)	Panicle weight (g)	Panicle diameter (cm)	1000 seed weight(g)	Yield t ha^{-1}
KAT PM2	5.8	10.1	185.4	21.1	34.2	5.7	10.4	2.8
EUP 1	6.7	13.7	189.7	22.4	36.0	5.9	13.6	3.6
EUP 2	6.7	10.8	188.6	22.4	35.8	5.9	12.9	3.4
EUP3	6.8	13.3	178.0	22.8	36.0	5.9	13.7	3.7
EUP 4	5.2	9.8	177.3	19.9	32.3	5.3	8.8	1.7
EUP 5	6.5	13.4	185.1	22.2	35.5	5.9	12.9	3.3
EUP 6	7.2	14.5	206.1	22.8	36.9	6.2	14.5	4.0
EUP 7	6.9	14.6	205.2	22.0	36.5	6.1	13.8	4.0
EUP 8	6.0	11.0	181.8	21.3	35.0	5.7	11.4	3.2
EUP 9	6.9	14.3	185.5	23.0	36.4	6.1	13.8	3.8
EUP 10	7.0	13.4	206.4	22.5	36.7	6.2	14.2	4.0
EUP 11	5.7	11.6	184.4	21.0	34.1	5.7	10.1	2.8
EUP 12	7.0	14.4	206.6	23.1	36.7	6.2	14.2	4.0
EUP 13	6.4	12.9	203.6	22.2	35.5	5.9	12.9	3.3
EUP 14	5.8	13.6	187.5	21.4	34.9	5.7	11.4	3.2
EUP 15	7.4	14.7	183.7	24.1	37.1	6.2	14.7	4.1
EUP 16	6.1	13.3	189.4	21.7	35.1	5.7	11.7	3.2
EUP 17	7.3	14.6	207.4	23.8	36.9	6.2	14.6	4.0
EUP 18	6.6	13.9	188.6	22.4	35.7	5.9	12.9	3.7
EUP 19	7.5	14.3	208.8	24.3	37.5	6.3	15.4	4.6
EUP 20	6.4	13.6	187.1	22.4	35.3	5.9	12.7	3.4
EUP 21	6.3	14.4	187.9	22.2	35.3	5.9	12.4	3.3
EUP 22	5.7	11.9	183.5	20.9	33.9	5.4	9.0	2.8
EUP 23	7.4	13.2	208.1	24.2	37.2	6.3	15.2	4.1
EUP 24	5.6	9.8	182.2	20.8	33.4	5.3	9.0	2.5
EUP 25	6.2	14.3	185.1	22.2	35.2	5.8	12.3	3.3
EUP 26	7.0	14.1	206.2	23.1	36.6	6.1	13.9	4.0
EUP 27	6.1	14.1	198.9	21.9	35.1	5.8	12.4	3.2
EUP 28	6.9	14.1	199.6	21.5	36.1	6.0	13.8	3.8
EUP 29	6.8	14.1	198.6	22.9	36.0	5.9	13.7	3.6
EUP 30	5.7	14.1	188.1	21.2	34.5	5.7	11.0	3.1
EUP 31	5.7	11.1	183.6	21.3	34.6	5.7	11.9	3.1
EUP 32	7.8	15.2	209.4	25.4	37.7	6.1	17.2	6.2
EUP 33	5.7	10.1	186.3	21.2	34.4	5.7	10.9	2.9
EUP 34	6.6	13.6	189.4	22.3	35.6	5.9	12.9	3.6
EUP 35	7.7	14.9	209.1	24.5	37.5	6.3	16.4	5.3
G. Mean	**6.5**	**13.2**	**194.3**	**22.4**	**36.0**	**6.01**	**12.9**	**3.6**
C.V (%)	**37.1**	**25.2**	**11.6**	**11.7**	**22.4**	**21.8**	**28.1**	**24.4**

Table 6: Yield related traits of thirty six pearl millet genotypes evaluated at Koibatek in 2012/2013.

Genotypes	Vegetative tillers (No)	Reproductive tillers (No)	Plant height (cm)	Panicle Length (cm)	Panicle weight (g)	Panicle diameter (cm)	1000 seed weight (g)	Yield tha^{-1}
KAT PM2	13.9	10.3	180.7	17.6	10.8	2.5	9.2	0.8
EUP 1	15.0	9.6	138.3	16.7	9.4	2.3	8.2	0.7
EUP 2	12.9	11.0	174.8	18.1	11.2	2.6	9.8	0.8
EUP3	12.9	9.5	139.3	16.6	9.4	2.3	8.2	0.7
EUP 4	11.9	10.0	171.4	16.9	10.5	2.5	9.2	0.8
EUP 5	14.7	8.6	139.0	16.1	8.8	2.1	7.7	0.6
EUP 6	11.7	11.7	176.4	19.0	13.2	2.7	11.3	0.9
EUP 7	13.3	13.8	193.0	21.5	14.9	3.0	13.5	1.1
EUP 8	13.9	9.7	138.9	16.7	9.5	2.4	8.5	0.7
EUP 9	14.9	10.5	180.6	17.8	10.9	2.6	9.5	0.8
EUP 10	14.2	12.9	191.1	20.0	14.4	2.9	13.2	1.1
EUP 11	11.7	10.1	172.0	17.0	10.6	2.5	9.2	0.8
EUP 12	10.7	11.7	176.7	18.9	13.2	2.7	11.3	0.9
EUP 13	11.6	10.1	174.4	18.5	12.7	2.7	10.7	0.9
EUP 14	12.1	10.1	180.9	18.1	11.4	2.6	10.0	0.8
EUP 15	11.0	10.6	138.0	16.5	8.9	2.3	7.8	0.7
EUP 16	10.5	11.1	181.7	18.1	11.4	2.7	10.1	0.8
EUP 17	11.9	12.2	188.0	19.7	13.8	2.8	11.7	1.0
EUP 18	15.6	11.1	173.6	18.3	12.3	2.7	10.6	0.9
EUP 19	13.2	9.8	139.1	16.3	9.6	2.4	8.7	0.7
EUP 20	12.9	10.9	174.1	17.9	11.1	2.6	9.7	0.8
EUP 21	13.6	10.9	170.0	17.9	11.1	2.6	9.6	0.8
EUP 22	12.0	13.5	190.5	20.2	14.8	2.9	13.3	1.1
EUP 23	12.0	7.8	137.5	15.3	8.8	2.0	7.6	0.6
EUP 24	13.3	9.5	138.5	16.1	9.1	2.2	8.0	0.7
EUP 25	11.5	11.3	175.4	18.8	12.9	2.7	10.8	0.9
EUP 26	13.6	10.2	173.0	17.2	10.7	2.5	9.2	0.8
EUP 27	12.4	9.9	140.1	16.9	10.5	2.5	9.2	0.7
EUP 28	12.5	12.8	188.2	20.0	13.9	2.9	12.5	1.0
EUP 29	11.5	11.9	176.8	19.2	13.5	2.7	11.7	0.9
EUP 30	11.3	11.5	175.7	18.9	13.1	2.7	11.0	0.9
EUP 31	11.5	7.2	125.5	15.1	8.1	1.9	17.0	0.6
EUP 32	18.6	9.8	139.2	16.8	10.1	2.5	8.9	0.7
EUP 33	11.8	11.2	173.4	18.6	12.9	2.7	10.7	0.9
EUP 34	11.1	11.1	182.6	18.3	12.1	2.7	10.5	0.8
EUP 35	12.4	11.8	182.3	17.8	10.9	2.6	9.5	0.8
Grand mean	**12.8**	**10.6**	**166.4**	**17.9**	**11.0**	**2.5**	**9.9**	**0.8**
C.V (%)	**27.2**	**18.6**	**13.0**	**15.4**	**14.6**	**18.1**	**16.6**	**19.5**

4.5 Correlation between Grain yield and other character.

There were highly significant ($P < 0.01$) between grain yield/hectare and all grain yield components at cropping season (2011/12) and (2012/13), except vegetative tillers. Grain yield/hectare had highly significant positive phenotypic correlations with 1000 seed weight and reproductive tillers at ($P< 0.001$) and significant at ($p< 0.01$) for panicle diameter, panicle height, panicle weight and plant height at the same period (Table 7).

1000-seed weight had highly significant positive correlation with panicle diameter, panicle length, panicle weight, plant height, Reproductive tillers and vegetative tillers at both phenotypic levels at Marigat and Koibatek (2011/12, 2012/13).Panicle weight, panicle diameter, plant height, Reproductive tillers and Vegetative tillers were highly positive significant with each other except panicle length which was positively non-significant with panicle weight (Table 7).

4.6 Genotype by Environment interaction effects for yield and yield traits of pearl millet hybrids

The environments used in this experiment represent the two agro-ecological lands of Kenya (ATC Koibatek and KARI Perkerra, Marigat).Variation were observed on rainfall, temperature and soil types. There was significantly difference for environment by genotype interaction for grain yield studied across environment (Appendix 7).

The analysis of variance showed significant effects for genotypes, and genotype by environment interaction, (Appendix 7). The large mean squares for environments indicated that the environments included in the study were diverse with large differences among environmental means causing most of the variation in grain yield.

Analysis of variance shows that all genotypes were highly significant across the environment with the traits showing significant at $p \leq 0.001$ (Appendix 2).

Table 7: Correlation coefficients among thirty six genotypes evaluated in two environments in two cropping season 2011/12 and 2012/13.

	1000seed wgt	**Panicle diameter**	**Panicle height**	**Panicle weight**	**Plant height**	**R.tillers**	**V.tillers**	**Yield tha^{-1}**
1000 seed wgt	1							
Panicle diameter	0.2628***	1						
Panicle height	0.2517***	0.9483***	1					
Panicle weight	0.2384***	0.8527***	0.8851	1				
Plant height	0.2828***	0.8196***	0.8775***	0.7235***	1			
R.tillers	0.1650**	0.9155***	0.9494***	0.8655***	0.7542***	1		
R.tillers	0.2811***	0.3832***	0.3636***	0.1412*	0.4644***	0.2341***	1	
Yield tha^{-1}	0.2969***	0.6060**	0.7732**	0.6328**	0.8723**	0.6496***	-0.4581	1

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

5.0 GGE biplot analysis of grain yield response and stability of thirty six pearl millet genotypes.

The biplot in fig 2 and 3 below were based on genotype focused singular value and environment focused value respectively and is appropriate for the relationship among environment (Fig 2) and the relationship among the genotypes (Fig 3). The principal component (PC) axis 1 explained 50.43% of the total variation; while PC2 explained 49.57%, thus these two axes accounted for 100% of the G + G + E variation for grain yield (fig 2).

The results are partition in two sections, section one present result of which is the best genotypes for each environment. Section two: the results of pearl millet hybrids performance and their stability.

Fig 4 of the GGE biplot indicates the best genotype in each environment. The presence of two environments within a sector indicates that a single genotype has the highest yield in those environments. If environment fall into different section, it means that different genotypes were the best in those environment and finally if environments fall into different sectors, it means that different genotypes were the best in different environments.

Based on the above information, EUP 32 and 35 were the highest yielding genotypes in Marigat while EUP 7 and 10 were the highest yielding genotype at Koibatek. No environment fell into the sector where genotypes EUP 4 and 22 were position, indicating that these genotypes were the lowest-yielding genotypes at all environment.

Genotypes within the polygon, particularly those located near EUP 18, 34, 26, 15, and 23 were less responsive than the lowest genotypes.

Genotype by environment interaction continues to be challenging issue among plant breeders who conduct crop performance trials across different environments. For release of a variety for wider and variable environments, stability of performance had considerable importance for yield trials, especially when significant genotype x environment is detected. Therefore, GGE biplot of thirty six pearl millet genotypes for grain yield across two environments was shown in figure 4. Genotypes EUP 4, 31, 23, 32, 7 and EUP 22 had great genotype by environment interaction and therefore they had very low stability across environments. Genotypes EUP 34, 14, 20, 27 and EUP 21 are closer to the origin, so they had little genotype by environment interaction hence stable across environments (figure 2).

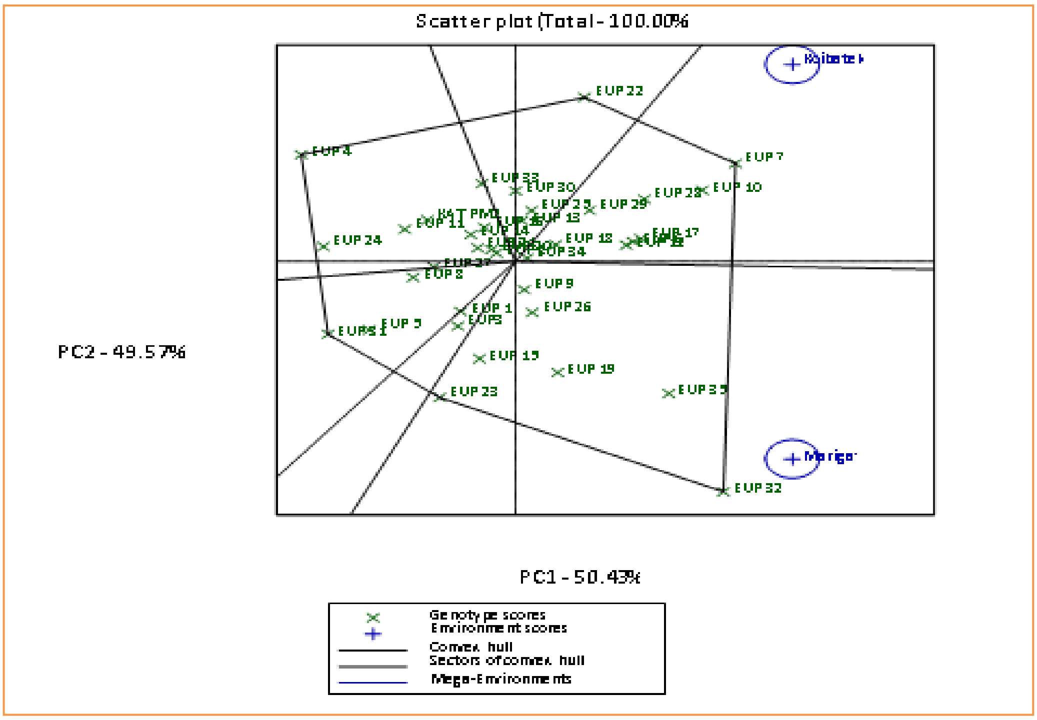


Fig 2: The best genotypes base on genotype by environment interaction.

Distribution of genotypes in the GGE biplot in figure 3 below revealed that the genotypes, EUP 34, 2 and EUP 18 were scattered close to the origin, indicating minimal interaction of these genotypes with locations. Genotypes EUP 32 scattered away from the origin in the biplot indicating that the genotype was more sensitive to environmental interactive forces.

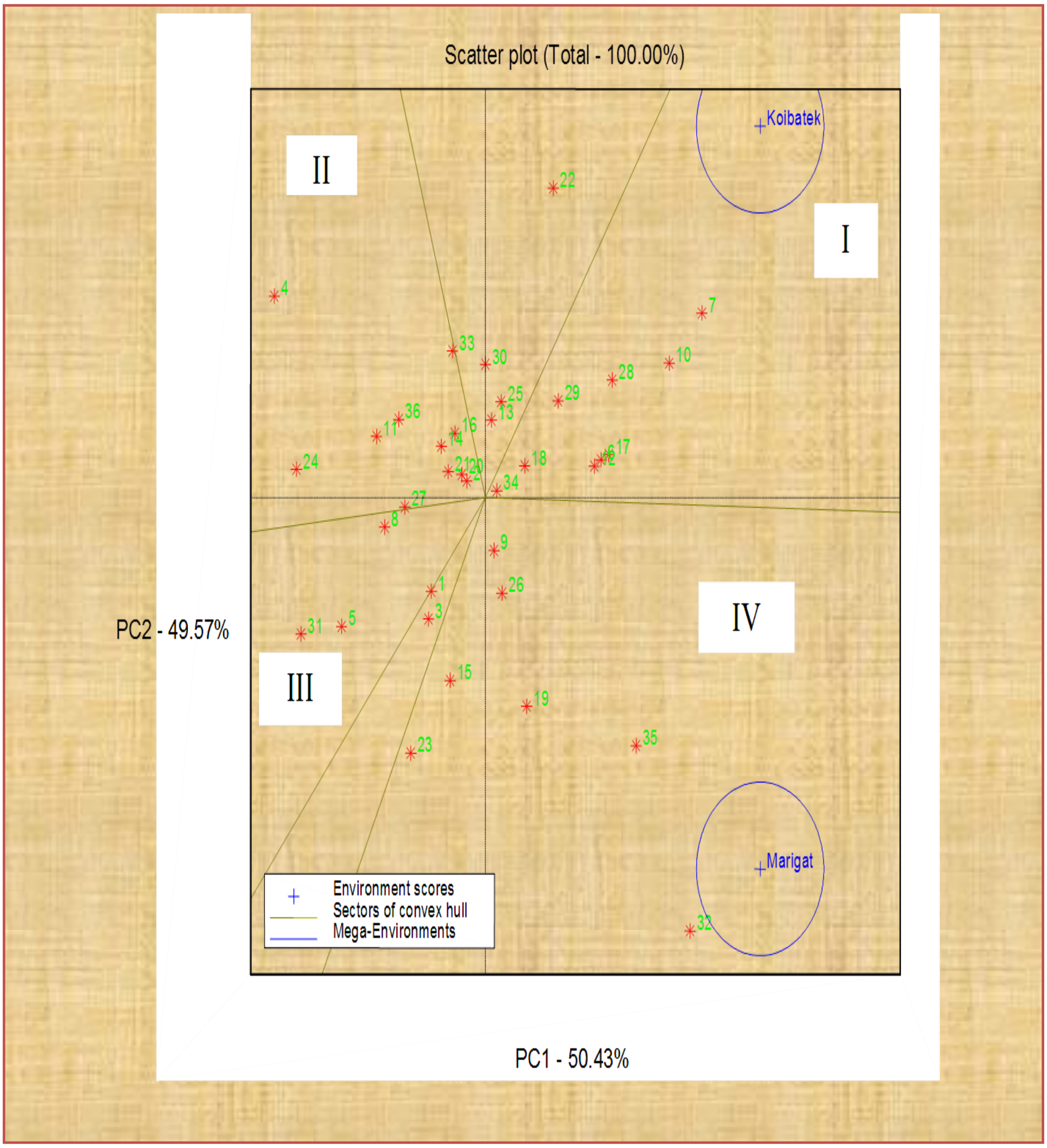


Fig 3. Biplot for PCA 1 vs. PCA 2 scores of different genotypes.

6.0 Evaluation of Genetic diversity of thirty six Pearl millet hybrids in arid and Semi - arid lands of North Rift, Kenya.

Cluster analysis was performed on the pearl millet genotypes to evaluate the genetic distance between 36 genotypes based on eight agro-morphological traits. All 36 genotypes were classified into 12 clusters and the corresponding dendograms was presented (Figure 3). Fig 3 shows the relationship among pearl millet genotypes. The distance between 36 genotypes shows the Euclidean distance between them and hence is a measure of similarity or dissimilarity among the genotypes in different groups

The first cluster contained-five genotypes, EUP 1, EUP 3, EUP 23, EUP 14 and EUP 27.In this group the genotypes were similar in Plant height, Panicle length, Panicle weight, Panicle diameter and reproductive tillers however EUP 1 and EUP were similar in seed weight and yield and EUP 14 and EUP 27 similar to each other by seed weight and yield. EUP 23 differed in the group in two traits i.e. yield and seed weight.

The second cluster had genotype EUP 5 only. The genotype was similar with cluster level I in the following traits, Plant height, Panicle length, Panicle weight, Panicle diameter and reproductive tillers however it was not similar in yield and seed weight.

The third cluster contained seven genotypes namely EUP 2, EUP 20, EUP 34, EUP 30, EUP 13, EUP 25 and EUP 21 with similarity in the following traits, Plant height, Panicle length, Panicle weight and Panicle diameter but dissimilar with level II in reproductive tillers.

Two genotypes were grouped in this cluster that had the same plant height, panicle length, and panicle weight and panicle diameter. They were different in yield and reproductive tillers with cluster III. In the 4th group it had four genotypes namely, EUP 9, EUP 26, EUP 19 and EUP 18.Plant height, panicle length, panicle weight, panicle diameter, seed weight and yield but dissimilar in reproductive tillers with group IV.

In group five the level had only two genotypes were grouped with different in seed weight and reproductive tillers with group V. The level had genotypes EUP 22 and EUP 33

Among themselves in the group, the genotypes performed the same in plant height, panicle length, panicle weight, panicle diameter and yield.

Group seven had six genotypes namely EUP 6,EUP 12,EUP 29,EUP 28,EUP 17 and EUP weight, Panicle diameter, seed weight and reproductive tillers and dissimilar in yield performance and panicle length. Genotype EUP 7 and EUP 10 were in 8th group. In this cluster, EUP 7 differed from EUP 10 in panicle length but similar in all other traits and also similar with group seven in all traits except panicle length and seed weight.

EUP 32 is the only genotype in this cluster nine with different in grain yield performance.

Genotypes EUP 4 and 24 were included in group ten with similarity with group nine in the following traits plant height, panicle diameter, panicle weight and seed weight except panicle length, yield and reproductive tillers were different in the group but similar with group nine in panicle diameter.

Group eleven had three genotypes namely, EUP 8, EUP 36 and EUP 11. EUP 36 was the local check call kat pm 2. All these genotype had the same plant height, panicle length, panicle weight, grain yield and all other traits. Similar with level ten in plant height, panicle weight and panicle diameter and finally in cluster level twelve it had one genotypes i.e. EUP 31.Different with other group in seed weight.

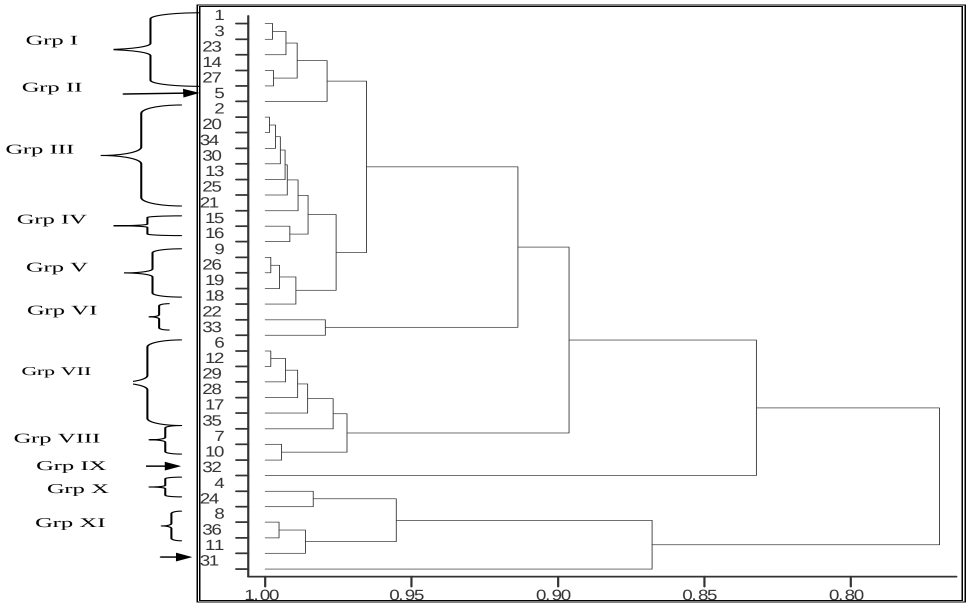


Fig.4.Dendogram from average linkage cluster analysis of grain yield of thirty six pearl millet genotypes grown in two locations and the classification of genotypes was truncated at 16 group levels (above).

CHAPTER FIVE

DISCUSSION

5.1 Grain yield performance and related traits of thirty six pearl millet genotypes.

Significant effect due to G × S interaction for GY and most of the yield traits in Marigat season I and II indicated mean performance of the hybrids changed according to seasons i.e. season II had better performance than season I.

Genetic variation in grain yield revealed that hybrids performed better than the local varieties (OPV) these significant differences could also be attributed to the composition of the hybrids, which is made up of superior genotypes during breeding in the past Abdelrahman *et al.,* (2006).

The performance of individual genotypes in Marigat were good with EUP 32 being the best, these genotypes were introduced by ICRISAT as a high yielding hybrid (6.29t ha^{-1}) hence the genotypes is suitable in arid area e.g. Marigat. Local variety (Kat PM 2) which was popular pearl millet commercial variety in Kenya, even though the cultivar is tolerant to drought but performance was low compared to some hybrids.

Unlike Marigat, grain yield in Koibatek season I were better compared to season II. The best genotypes in Koibatek were different from the best genotypes in Marigat (EUP 7). These was attributed to well distribution of rainfall in season I against season II of high rainfall with low temperatures which affected the formation of flowers and booting stage Zaveni *et al.,* (1989) reported similar findings. Finally genotypes were highly significant $P \leq 0.001$ in grain yield in the site.

Significant differences among the pearl millet hybrids were evident across site which shows the presents of genetic variability among the pearl millet hybrids. Genetic variability is important in expressing morphological variation on grain yield.

GY was sufficient in assigning genotypes in this study into hybrid vigour groups based on their general performance across site (EUP 32 and 35). This suggests that the best performing genotypes had high vigour for grain yield, Bello *et al.,* (2007) in sorghum and in pearl millet reported the same findings. Nevertheless EUP 4

Like grain yield, Marigat had higher mean traits than Koibatek. Consequently, genotypes with large mean number of yield traits have impact on the gain yield because of the correlation of these traits to the GY Musa, (2013).

Under harsh condition and high temperatures supplemented with little irrigation, the number of yield traits in Pearl millet tends to be more (Abdelrahman *et al.,* 2002). Genotypes producing less mean in yield traits e.g. EUP 4 under this condition are not preferable in GY in these particular conditions hence when deciding for the best hybrids, EUP 4 should be avoided because of the negative impact it has on the grain yield.

Correlation coefficients, as indicators of the degree of relationship between different yield components, is useful in determining those characters which are highly related with grain yield and definitely can be used as selection criteria for yield. The correlation between characters to developmentally induced relationship between components is indirectly influenced by gene action. The correlation between traits is often determined as phenotypic correlation, which reflects the relationship of breeding values and environmental conditions Adams, (1967).

The correlation coefficients of grain yield per hectare and other related characters showed different patterns. Grain yield/hectare exhibited strong positive phenotypic correlations with thousand seed weight under the two environments indicating that thousand seed weight can be used as trait in selecting for grain yield/hectare. Also grain yield/hectare had significant positive phenotypic correlations with some of yield components. On the other hand, grain yield/hectare was not significantly and negatively correlated with vegetative tillers at Marigat and Koibatek in the two cropping season (2011/12, 2012/13), under the two environments generally, the negative association would show that selection for improvement of one trait would lead to deterioration of another trait. Thus, special consideration should be put in place for collective improvement of the negatively correlated traits. The results of this study are in agreement with those of Fadlalla, (2003) in pearl millet.

Similar to the trend of grain yield/hectare, panicle weight/plant possessed highly significant positive phenotypic correlations with other yield components across the environments used in this study. On the other hand, it had positive non-significant association with panicle length across the environments. The change in the trend and degree of the correlation observed for some characters could be attributed to the changes in the environmental condition.

Vegetative tillers had highly significant positive and weak positive phenotypic correlations with the other yield components in across the environments. On the other hand, it had significant correlation at ($P < 0.05$) with panicle weight across the environments (2011/12, 2012/13). Plant height had a weak and highly correlation with 1000- seeds weight and strong highly correlated with panicle diameter, panicle length and panicle weight at two environment cropping year (2011/12, 2012/13). These results indicate that the degree of correlation of the traits is influence by the change in the environment. Moreover the decrease in the direction of the correlation between traits could be because of differential influence of the environment on the expression of the different traits under the different conditions as well as the competition among the different traits for assimilates, such as that between number of panicle length and 1000-seed weight. Similar results were reported by Abraham *et al.,* (1989) in finger millet.

The presence of significant environment by genotype interaction showed the inconsistency of performance of pearl millet genotypes across test environment. These is because pearl millet is grown n wide range of arid and semi-arid environment and so the yield of the several genotypes tested across the two sites and two seasons differed due high GE interaction. Similar findings were reported by Abebe *et al.,* (1984) on sorghum, Khalil *et al.,* (2010) on Maize hybrids.

The large significant genotype by environment suggests that some of the traits were most important in contributing to differences in performance of genotypes across the test environment however significant difference of genotypes at $P \leq 0.05$ for grain yield and other traits indicate the presence of variability in genotypes at different sites.

Highly significant G × E interaction reflect the differential response of the genotypes in various environments. Nevertheless G × E interaction influences the genotypes in the two sites to change rank from one environment to the other because of the cross-over G by E interaction. These agree with the findings of Lopez-Dominguez *et al.,* (2001) that the environment affected the productive behavior of a crop.

Means yield of genotypes varied at different environment. Significant variation due to environment represents adequate heterogeneity among the environment for the entire component. Similar results were reported by Asad *et al.,* (2009) in rice. This implies that different pearl millet hybrids could be selected for the different agro ecological zones Derera *et al.,* (2008) and Carson *et al.,* (2002). The relative magnitudes of the different sources of variation varied greatly as shown by their different components. Significant genotype by environment (GE) response in the study indicates that phenotypic response to changes in the environment is not the same for all the genotypes (Abdelrahman and Abdalla, 2006).

Effects of genotype and season interaction were also significant at $P \leq 0.05$ in all the genotype that was experimented in two seasons across environment in North rift, Kenya. This implies that genotypes had similar response over different seasons, Soroush, (2005), however across season significant different were observed on some traits e.g. panicle height, seed weight, panicle weight, panicle diameter and reproductive tillers which showed that yield traits of pearl millet hybrids responded differently to change of environment.

In the study, plant height was significantly influenced by environment and interaction of Environment and Season. This was in conformity with study done by Hakim, (2006) where he reported that plant height expressed their genetic potential at different season, hence plant height fulfill farmers need because of hay and grain.

Environment × Season were significant for the traits like panicle height, panicle weight, panicle diameter, plant height, reproductive tiller and vegetative tillers which elaborate the distinct nature of environment, Environment × Season interaction on phenotype expression. The findings were in conformity with Krishnappa *et al.,* (2009).

Genotype × Environment were significant for the traits like panicle height, grain yield, panicle weight, panicle diameter, plant height, and vegetative tillers but not significant for vegetative tillers and this also showed nature of environment on interaction and expression of phenotypes where by most genotypes in Marigat taller, more reproductive tillers and higher panicle weight were. The findings were in conformity with Deshpande and Dalvi (2006) where yield contributing traits, number of filled grains per panicle, both linear and nonlinear components of Genotype X Environment interaction are significant.

Panicle weight is positively correlated with grain yield because the higher the weight, the higher the yield per hectare. Genotype × Environment interaction are influenced by linear and non-linear components, however the nonlinear component of Genotype × Environment was significant for all characters except the vegetative tillers.

Number of reproductive tiller directly contributed towards higher grain yield according to objective 1 and hence EUP 32 was found to be having higher yield and higher number of tillers Arumugan *et al.,* (2007).The lowest coefficient of variation (CV%) was observed for plant height (12.6%) and panicle length (12.3%) across the environment indicating the highest precision by which they were measured and also suggest less influence by environments compared to other yield components where the highest cv% was recorded for panicle weight (30.6%) and grain yield (35.6%), indication of less precision by which it was recorded as well as higher influence by the environmental variations.

5.2 Stability test of pearl millet genotypes in two ago-ecological zones of Kenya.

Stable and high yielding traits are among the major agronomic characteristics required by farmers in pearl millet adoption as such varieties that can have both of these characteristics would likely be accepted by farmers Van Oosterom *et al.,* (1996) and Weltzien *et al.,* (1998). According to objective 2, the rankings of the genotypes were highly consistent a cross environments for selection for wide adaptation in pearl millet.

Ideal genotype should have both high performance and high stability hence genotypes EUP 34, 14, 20, 27 and EUP 21 was almost qualifying to be best genotypes. Similar findings were reported by Badu-Apraku *et al.*, (2011) in Maize. The line which passes through the origin and is perpendicular to the average environment axis with arrows represents the stability of genotypes. Either direction away from the biplot origin on this axis indicates greater genotype by environment interaction and reduced stability (Yan, 2002). Thus, EUP 32 and EUP 7 are especially suitable for production at Marigat and Koibatek respectively.

Best genotypes in grain yields were not necessary best adapted e.g. EUP 32, similar findings were done by Tollenaar and Lee (2002), they reported that high yielding maize hybrids can differ in yield stability and that yield stability and high grain yield are not mutually exclusive. Identification of hybrids with high grain stability and average stability is very important since stability parameters for grain yield of a single plant indicate linear and non-linear components, similar work have being reported by Panwar *et al.,* (2008) in rice production.

5.3 Genetic diversity of thirty six pearl millets genotypes

The genetic relationship in the study among the thirty six pearl millet genotypes using cluster analysis indicated strong association between yield and yield traits and different genotypes can be grouped according to yield and yield traits hence in the study genotypes that had better performance were grouped together.

The results of the present study revealed that genetic diversity study existed among the study genotype of pearl millet according to yield traits. Similar results were reported by Reddy *et al.*, (2012) that genetic diversity in pearl millet germplasm existed base on cluster analysis. The genotypes were grouped according to their performance in yield traits and not due to source of origin. Gupta *et al.*, (1991) reported that genetic diversity in Mustard was not associated with the geographical distribution of the germplasm as lines from different geographical regions were pooled in the same group.

In the study genotype EUP 32 was grouped on its own cluster because of its different in grain production and other yield components however in genetic diversity, the genetic constant for the traits revealed the percentage of phenotypic variation was higher than the genotypic variation and these is attributed to environmental factors influencing the traits expression.

The narrow differences between the genetic and phenotypic variation revealed low resistance to environmental influence. The grain yield to other traits e.g. height indicated the existence of additive genes vidyadhar *et al.*, (2006).

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusions

1. Objective 1: EUP 32 and 35 need to be evaluated more for National performance trials (NPT) and adopted in Kenya.

2. Objective 2. Significant genotype by environment interaction in pearl millet hybrids under the study is a clear indication of high responsiveness of some genotypes to environment hence more Multilocation evaluation trials in selected agro-ecological zones and across season in Kenya is needed to establish suitability and stability of the evaluated genotypes across environments and seasons.

3. Objective 3.Diversity study revealed higher genetic diversity in yield and yield components among the hybrids hence phenotypic selection for the good traits e.g. height and V. tillers is the most appropriate.

6.2 Recommendation

1 Sensitizing farmers on hybrids seeds and high yielding genotypes that does better in ASAL lands to boost pearl millet production.

2 More Multilocation evaluation trials need to be considered

3 More research needs to be done on diversity of pearl millet hybrids on yield components

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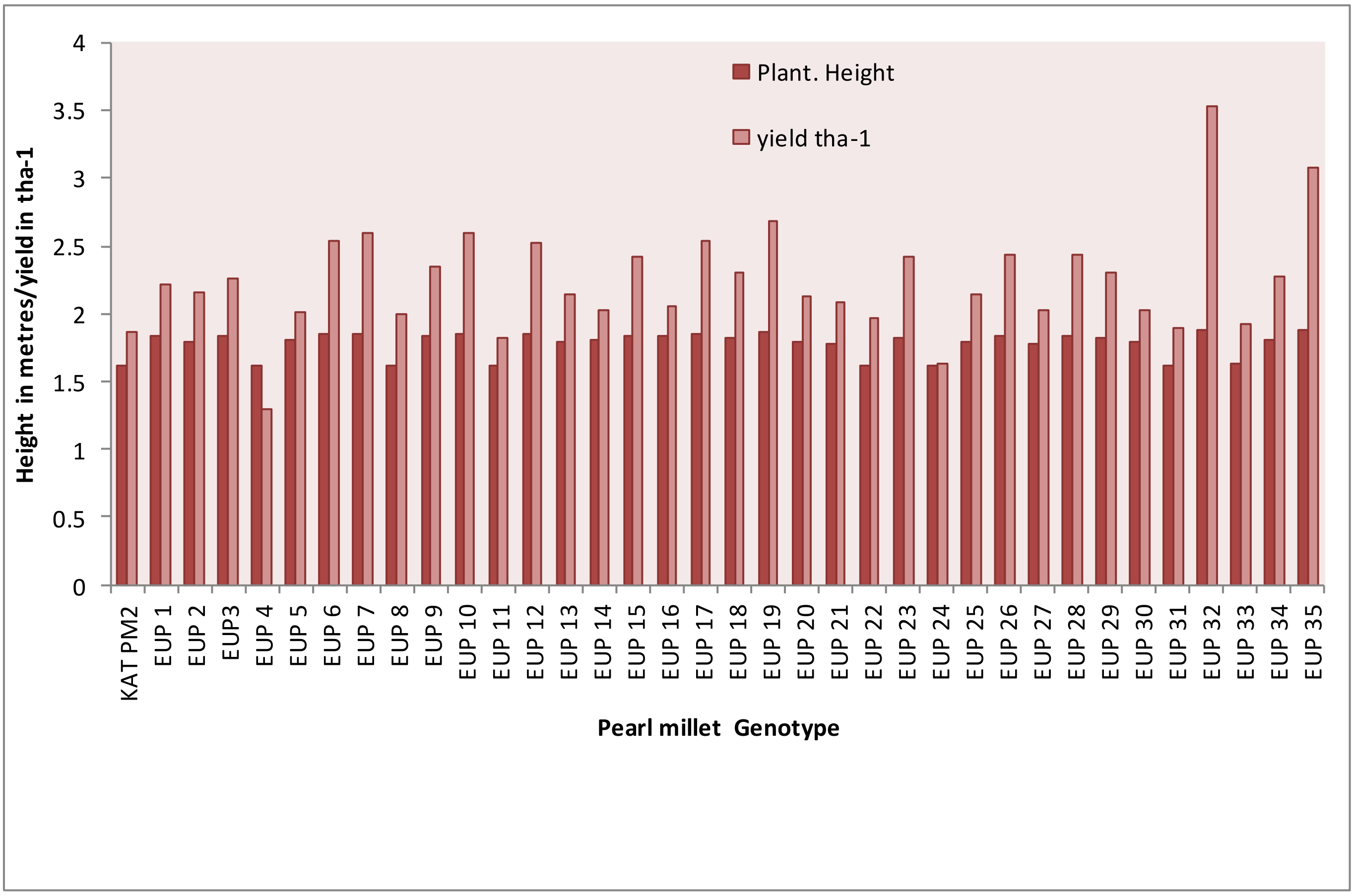
APPENDICES

Appendix I. Relationship of Plant height in metres and grain yield in tonnes/hectare of thirty six pearl millet genotype across location.



Appendix II: Mean square for Grain yield and yield related traits from thirty six pearl millet genotypes evaluated in two sites during the main crop season of 2012/2013

Traits	Source of variation	D.F	Mean square
	Rep	2	10.48
1000 seed weight	Environment	1	406.157***
	Season	1	51.517*
	Genotypes	35	23.249***
	Error	144	7.676
	Rep	2	2.0427
Panicle diameter	Environment	1	841.8159***
	Season	1	921.5461***
	Genotypes	35	0.3611*
	Error	144	0.4614
	Rep	2	16.4908
Grain yield t ha-1	Environment	1	544.76***
	Season	1	0.9207
	Genotypes	35	1.2528*
	Error	144	0.7987
	Rep	2	4063.1
Plant height	Environment	1	30904.1***
	Season	1	650
	Genotypes	35	501.5*
	Error	144	378.1

Appendix II: (Continued)

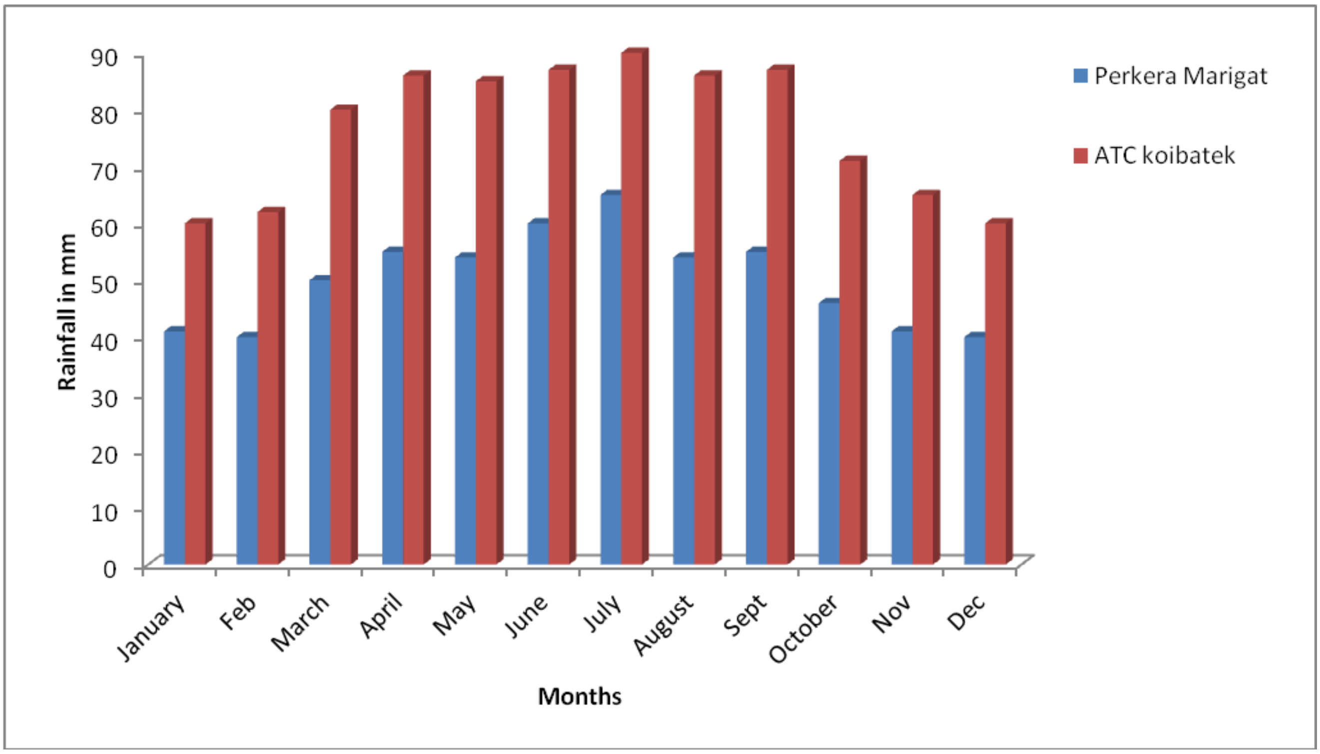
	Rep	2	1.441
Panicle length	Environment	1	1464.42***
	Season	1	238.029***
	Genotypes	35	6.745*
	Error	144	5.332
	Rep	2	6.41
Panicle weight	Environment	1	45148.11***
	Season	1	743.99***
	Genotypes	35	52.40*
	Error	144	47.32
	Rep	2	16.82
Reproductive tillers	Environment	1	3321.125***
	Season	1	18.10*
	Genotypes	35	5.027*
	Error	144	3.304
	Rep	2	3.402
Vegetative tillers	Environment	1	2819.379***
	Season	1	4.728
	Genotypes	35	7.279
	Error	144	7.637

Appendix III: Principal Component of Yield and Yield traits.

	PC 1	PC 2
Percentage variation	56.81	14.86

Yield traits	PC1	PC2
1000 seed wgt	0.05008	0.47245
Panicle. diameter	0.47428	0.04910
Panicle. length	0.48134	-0.03304
Panicle. weight	0.42510	-0.21360
Plant. Height	0.37574	0.23309
Reproductive tillers	0.45137	-0.15737
Vegetative tillers	-0.00636	0.70628
Yield t ha-1	0.12327	0.38696

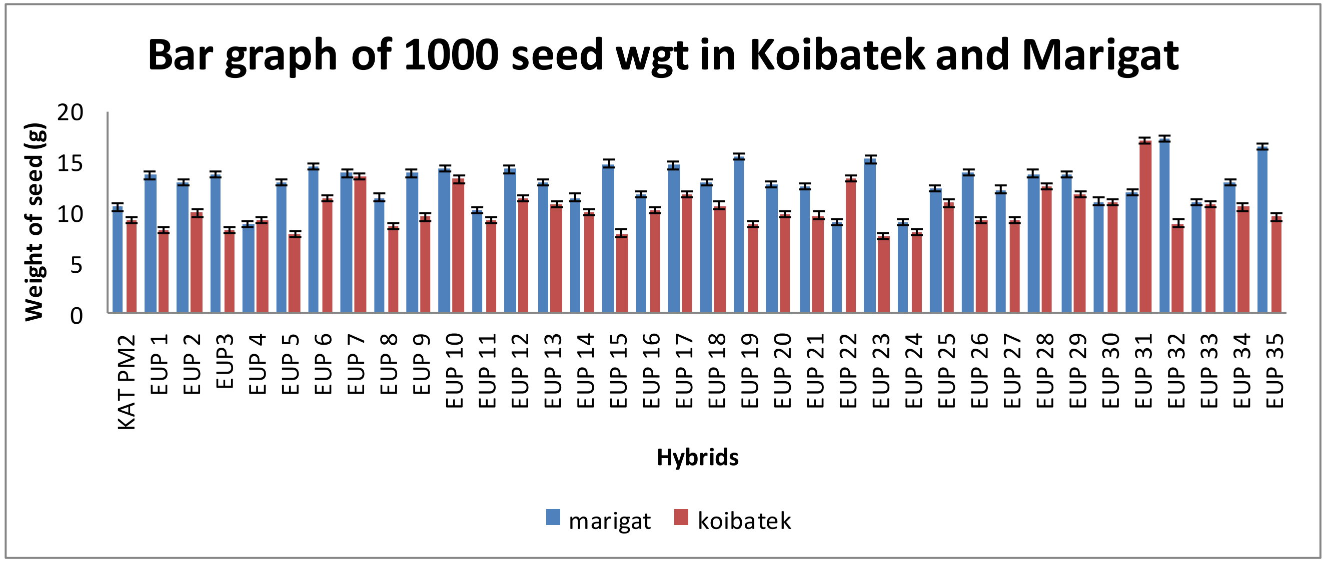
Appendix IV: Rainfall Pattern in Koibatek and Marigat during 2012/2013 Season.



Appendix V: Mature pearl millet (Pennisetum glaucum L.) Genotypes planted in Marigat 2012.

(Source : Author, 2013)

Appendix VI. Relationship of seed weight in grams of thirty six pearl millet genotype across location.



Appendix VII. Mean squares for average grain yield of thirty six pearl millet genotypes (*Pennisetum glaucum*) evaluated in Marigat and Koibatek in 2012/2013

Source of variation	D.F	Mean Square
Replication	2	16.49
Environment (E)	1	544.76***
Season	1	0.92
Genotype (G)	35	1.25*
Environment X Season	1	4.04*
Environment X Genotype	35	1.25*
Season X Genotype	35	0.04
Environment X Season X Genotype	35	0.04
Error	144	0.8

*, *** = Significant at P ≤ 0.05 and P ≤ 0.001, respectively