EVALUATION OF PEARL MILLET (*Pennisetum glaucum* L) GENOTYPES FOR RESISTANCE TO HEAD SMUT DISEASE (*Tolyposporium penicillariae* Bref.) IN DRY AREAS OF KENYA

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A Thesis submitted to the Graduate School in Partial Fulfillment for the Requirements of Master of Science Degree in Agronomy (Crop Protection) of Egerton University.

EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

DECLARATION

This is my original work and has not been previously presented for an award of degree in this or any other university.

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RECOMMENDATION

This Thesis has been submitted with our approval as the university supervisors.

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DEDICATION

I dedicate this thesis to my loving Mom, Eunice Samoei.

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ABSTRACT

Head smut caused by *Tolyposporium penicillariae* Bref, is a devastating fungal disease that cause up to 30% yield losses in pearl millet *Pennisetum glaucum* (L.) R.Br.). Pearl millet is the most drought tolerant cereal grown mainly by small scale farmers who cannot afford fungicides. Development of resistant genotypes offers the most economical means of head smut control however this depends primarily on the availability of sources of resistance. The study evaluated host plant resistance among fifty advanced pearl millet genotypes in two selected dry land sites (Koibatek and Marigat) in Kenya. Three experiments were performed to determine pearl millet genotypes that are high yielding and resistant to head smut. Experiment I, was done in the field in the two sites while experiments II and III were both carried out in the laboratory and glass house. Results from the field experiment showed that yield and disease severity were highly significant among the genotype (Fpr <0.001) with yield ranging from 1172-4122kgha^{-1}. The high yielding genotypes were SDMV 90031, IP 8783, Shibe, ICMV 96603, ICMV221-1, IP 6791 and ICMV 221 Bristled. Genotypes, Shibe, SDMV 90031, IP 94014, IP8783 and SDMV 96603 IP 6791 were both resistance with the best yields. In experiment II, three isolates of head smut from major pearl millet growing areas (Koibatek, Makueni and Mbeere) were cultured in PDA and inoculated to 20 selected genotypes in a glass house at Egerton University. Data on the severity indicated that Makueni isolate was the most virulent with an average AUDPC (Area under Disease Progress Curve) of 108 followed by Mbeere and Koibatek isolates with AUDPC of 68 and 45 respectively. Genotypes ICMV 93771, IP 6791, Tsholotsho, Shibe, SDMV 90031, ICMV 96603, and ICMV 91450 exhibited resistance with the most virulent isolate. In experiment III all the 50 genotypes were inoculated with the most virulent isolate from Makueni. In conclusion genotypes SDMV 90031, IP 6791, ICMV 91450 and ICMV96603 are resistant and high yieding. Other most resistant genotypes were IP 8783, IP9946, ICMV 221-3, ICMV 91450, ICMV 88908, ICMV 94151 and IP 8783. The Commercial resistant checks ICMV 221 and KAT PM1 were resistant to the most virulent isolate from Makueni. All the above genotypes are recommended for further research an evaluation for relese as commercial varieties in Kenya .

Key Words Drought tolerant; Disease severity*;* Economically viable; Sources of resistance; Virulent isolate.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA: Analysis of variance.

ASALS: Arid and Semi Arid Lands.

ASARECA: Association for Strengthening Agricultural Research in East and central Africa.

ATC: Agricultural Training Centre.

AUDPC: Area under Disease Development Progress Curve

CGIAR: Consultative Group on International Agricultural Research.

ECA: East and Central Africa.

FAO: Food and Agriculture Organization.

ICRISAT: International Crops Research Institute for the Semi Arid Tropics.

IPM: Integrated Pest Management.

KALRO: Kenya Agricultural Livestock Research Organization.

MoA: Ministry of Agriculture.

MPEND: Ministry of Economic Planning and National Development.

OPV: Open Pollinated Variety.

PCA: Principle Component Analysis.

RCBD: Randomized Complete Block Design

DEFINATION OF TERMS

Host: An organism harbouring the pathogen.

Inoculate: To bring a pathogen in to contact with a host plant or plant organ.

Inoculum: The pathogen or its parts that can cause infection.

Isolate: A culture or subcultures derived from spores or pathogen collected from different sites.

Pathogen: An entity that can incite disease.

Resistant: Possessing qualities that resist diseases.

Susceptible: Host which succumbs to the disease.

Virulent: Capable of causing a severe disease; strongly pathogenic.

CHAPTER ONE
INTRODUCTION

1.1. Background information

Pearl millet (*Pennisetum glaucum* (L.)R.Br.) is the world's hardiest warm season cereal crop with great potential of ensuring food security in marginal areas because of its suitability to the extreme limits of agriculture (ICRISAT, 2013). It is the only suitable and efficient crop for Arid and semi arid conditions because of its efficient utilization of soil moisture and higher level of heat tolerance than sorghum and maize (Shah *et al*., 2012). It is grown mainly in the Arid and Semi Arid tropics (ASALS) both for its grain and fodder and contributes to both nutritional and food security of the rural resource poor people in these areas (Khairwal *et al.*, 2007). Among the major cereals (maize, wheat, sorghum, finger millet etc), pearl millet has the highest adaptation to drought and heat (Abdullahi *et al*., 1998; Allouis *et al.*, 2001). It is often referred to as the "*Camel of the desert*", because of its exceptional ability to tolerate drought and heat since in many areas where it is grown as a staple food crop, no other cereal would survive to produce any reasonable yield (Pray and Nagarajan, 2009). Besides providing food for humans and forage for livestock, pearl millet stems are used for a wide range of purposes, including construction of hut walls, fences and thatches, and the production of brooms, mats, baskets and sunshades (IFAD, 1999).

Most of the production and consumption of the crop is in the developing countries whose production and acreage account for 95% (FAOSTAT, 2007). The crop is grown as a grain crop in over 29 million ha 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% (FAOSTAT, 2007). 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 (FAOSTAT, 2007). 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; ICRISAT, 2010).

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 1500-4000 Kg ha^{-1}

(KALRO, 2002; MoA, 2008). This is slightly less than that of sorghum with production of approximately 126,433 tons from an area of about 40,000 ha and finger millet production with a production of 260,000 tons from an area of 65,000 ha with average yield of 500-700 Kg ha^{-1} on farm as compared to 3.8-4 tons ha^{-1} on research stations (CGIAR, 2001; KALRO, 2008). 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 (MoA, 2008). Eastern province is the main producer of millet, producing over 60% of the total millet (Omamo *et al.*, 2006) while Rift valley produces less than 10% (MOA, 2008). Statistics indicate that 50% of the total millet grain production is pearl millet, 30% proso and 11% finger millet. The remaining 8 species are of little economic importance and account for only 10% of the world millet production (EPZ, 2005). Moreover amongst all cereals (maize, sorghum, finger millet and others) pearl millet is the most nutritious with high levels of protein (up to 12%) and energy (3600 K cal kg^{-1}). It has a balanced amino acid profile making it a cheap source of grain iron (Fe) and zinc (Zn) (Parthasarathy *et al*., 2006; ICRISAT, 2007).The crop also forms an excellent feed to livestock both as grain and forage and thus advantageous as dual purpose (Yadav *et al*., 2011).

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 3 varieties (KAT PM 1, KAT PM2 and KATPM3) for commercial production, with yield potential of 1000-3000kgs/ha. These varieties are also susceptible to head smuts and thus need to identify high yielding and resistant genotypes. 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 (ICRISAT, 2002; Mgonja *et al*., 2006). Elsewhere in ICRISAT India, yields of >2000kgs/ha have been reported (ICRISAT 2013.) due to development and growing of resistant and high yielding hybrids and OPV like SDMV 90031. The major factors limiting yield improvement are biotic and abiotic stresses including diseases, pests, drought, heat stress, low soil fertility and salinity (ICRISAT, 2010). The major diseases limiting pearl millet production are head smut (*Tolyposporium penicillariae)*, downy mildew (*Sclerospora graminicola.*), ergot (*Claviceps fusiformis* Loveless) and rust (*Puccinia substriata*) (ICRISAT, 2002; Leslie, 2003).

Head smut (*T penicillariae)* is a notable disease in which the pathogen and host combine to produce smut *sori* in the pearl millet heads causing direct damage to the grains (Phookan, 1987; Diagne-Leye *et al*., 2010). Control of the disease through measures such as cultural control, are rendered ineffective by the mode of spore spread through wind during flowering. Complete reliance on fungicides for the control of these diseases has led to environmental pollution thus health hazards, crop failures due to appearance of new strains of the diseases and outbreaks of other pests and disease which had caused no major concerns before. Other limitations associated with fungicides are low monetary value of the crop, and a widespread scarcity of resources available to pearl millet farmers in the semi-arid tropics (Thakur and King, 1988).

Head smut is a very important pathogen common in the semi-arid tropics of the world widespread in India, Pakistan, Africa and the United States (Leslie, 2003). The disease is confined to the inflorescence where the infected ovaries are converted to oval or pear shaped *sori* (Rachie and Majmudar, 1980; Leslie, 2003). Pearl millet is protogynous i.e. stigmas emerge and mature before the stamens making it highly cross pollinated. This fact predisposes the crop to the pathogen infection during pollination and flower formation (Thakur *et al.,* 1986; Thakur, 1989). Apart from reducing the grain yield, the disease also lowers the grain quality by producing smut *sori* on them. Smut severity in a field ranges from 1 to 30% when a crop is infected it can lead to 50-75% field infection, with a damage of up to 100% in individual panicles (Thakur and King, 1988).

Several strategies have been recommended to control head smuts including fungicide use (Both as seed dressings and foliar sprays), crop rotation, and use of resistant genotypes. Host plant resistance is the best option because it is environmentally friendly and cost effective under subsistence conditions as compared to other options. Cultural control measures could have been an easier on-farm option but it rarely achieves desired results since the pathogen is both soil borne and airborne (through spores) and infections occur despite measures such as crop rotation and or use of clean seed (ICRISAT 2013).

Despite its importance there is little information on the number and types of strains/isolates of head smut in the current pearl millet growing areas in Kenya. There is also limited information on the incidence, distribution and reaction of local and improved varieties against the disease prevalence in the pearl millet growing regions. This study therefore screened pearl

millet genotypes for resistance to head smut and determined the range of available isolates of head smut as well as severity levels and yield losses due to the disease. The study also identified high yielding improved genotypes resistant to the disease for possible release as commercial varieties in Kenya.

1.2. Statement of the problem

Although pearl millet is one of the most important drought tolerant cereal that can do very well in the ASALS of Kenya, its yields are very low (200-800 Kg ha^{-1}) as compared to its research potential of 1500-3000 Kg ha^{-1} (KALRO, 2008; ICRISAT, 2009). This is attributed to both biotic (diseases mainly head smut and pests) and abiotic stresses (drought, high temperature and low soil fertility among other factors). Growing of low yielding local varieties (local landraces) also contributes significantly to the low yields. Head smut is one of the most damaging and devastating disease causing yield losses of 30% to 100% on infected panicles by replacing the grains with smut *sori.* Currently the disease is controlled mainly by fungicides both as seed dressings and foliar sprays in most growing areas. This control measure is un-economical and not feasible for most small scale-resource poor farmers in the Kenyan ASALS who don't access and afford costly inputs.

Furthermore continuous use of fungicides has potential danger of development of pathogen resistance and possible appearance of new strains of the disease and other pests causing a high risk of future crop failures. Cultural control measure could have been cheaper and easier option for small scale farmers, but it rarely achieves desired results since the pathogen is both soil borne and airborne (through spores) and infections occur in large and wider areas despite measures such as crop rotation and or use of clean seed. Host plant resistance (HPR), therefore would provide the cheapest, environmentally friendly and more sustainable control especially when incorporated in an integrated Disease management (IDM).

In Kenya, however there is limited work done to identify pearl millet genotypes that are high yielding and resistant to head smut. Three varieties released in Kenya for commercial production (KAT PM1, KAT PM2 and ICMV 221) have become low yielding and over time farmers have mixed these varieties. There is also limited information on the incidence, distribution and severity of smuts in major growing areas (especially in Mbeere, Tharaka, Mwingi, Kitui, Makueni) and also in the drier areas of the Rift Valley (Baringo, Elgeyo Marakwet and West Pokot). Information on the level of resistance/tolerance of local land

races and improved varieties against the disease is not well documented. The study therefore evaluated selected pearl millet genotypes for high yield and resistance to head smut in major pearl millet growing areas of Kenya and for possible incorporation in to pearl millet breeding programs.

1.3. Justification

Pearl millet can be an alternative food security crop in dry lands of Kenya where climate change related crop failures and livestock deaths is already causing significant economic losses and undermining food security. It is the most adapted type of millet to harsh dry areas that are too arid for sorghum, finger millet and maize. In addition, apart from being well suited for food, livestock feed and alcohol industry in these regions, pearl millet is also superior nutritionally to maize and sorghum with a high protein content of 12% which is 45% more than that of maize. Despite these merits, pearl millet is not extensively cultivated but neglected as an orphaned crop in Kenya. However current research findings indicate that there is a good potential for pearl millet productivity in Kenyan marginal areas. The use of high yielding genotypes with wide resistance to diseases and pests, wound improve the current productivity from 0.20 -0.80 tons ha^{-1} to a potential of 1.5-3 tons ha^{-1}

Resistant genotypes can be adapted to control head smut which is a devastating disease in pearl millet production would be the best option. This is because the method is environmentally friendly and cost effective for low income subsistence farmers in ASALs as compared to other options. However, information on resistant high yielding and widely adapted genotypes is limited. Furthermore information on the nature and types of strains/isolates available and the extent and levels of damage caused by the disease is limited in major growing areas of Kenya. Hence characterizing the isolates/strains, determining and quantifying the levels of intensity and severity of the disease in major pearl millet growing areas like Tharaka, Mbeere, Mwingi, Baringo, Kerio valley and West Pokot is necessary, especially so when the crop production is expanded in these areas. Screening and selecting genotypes that are tolerant/resistant to this major disease shall increase the crop yields and adoption rates amongst farmers. This study therefore determined the responses of selected pearl millet genotypes to head smut infection, their yield performance and adaptability in selected dry land areas of Kenya.

1.4. General Objective

The broad objective of this study was to improve productivity of pearl millet in dry land areas of Kenya by increasing yields and reducing losses associated with head smut disease for enhanced food security.

1.5. Specific objectives

1. To determine sources of tolerance/resistance against head smut in selected pearl millet genotypes from their yield performance under field conditions in selected sites in Kenya.
2. To characterize the occurrence of *Tolyposporium penicillariae* isolates prevalent in major growing areas of Kenya by severity
3. To determine the resistance/tolerance of the selected pearl millet genotypes against head smut in the greenhouse at the most sensitive stage (booting stage).

1.6. Hypothesis (Ho)

1. There is no significant difference in variability for resistance/tolerance to Head smut and in the yield performance among the selected genotypes of pearl millet.
2. *T. penicillariae* isolates attacking pearl millet in the major growing areas do not show difference in virulence levels, disease incidence and severity.
3. There is no significant difference in tolerant/resistance to Head smut among pearl millet genotypes at the most sensitive stage (booting stage) in the glass house.

CHAPTER TWO
LITERATURE REVIEW

2.1. Pearl millet botany and morphology, production and ecology

2.1.1. Plant botany and morphology

Pearl millet is a tall, erect, annual bunchgrass belonging to the family Poaceae, subfamily Panicoideae, tribe Paniceae, subtribe Poinciana, genus Pennisetum, and section Penicillaria. It grows from 1.5 m up to 4 m in height with a slender stem, 1–3 cm in diameter. The leaves are long pointed with finely serrated margins (Baker 2003). The crop is deeply rooted with roots that can penetrate up to 180 cm. This single characteristic in its rooting system qualifies pearl millet as drought tolerant because it helps exploit water more effectively (Mangat *et al*., 1999).It produces an inflorescence with a dense spike-like panicle 14" long and 1" or less in diameter. The mature panicle is brownish in colour, and in it spiklets are borne in fascicles of two, surrounded by a cluster of bristles (Baker, 2003). Each spiklet has two florets, one of which is generally staminate (Thakur, 1989). The upper floret is fertile and the seed is enclosed by the lemma and palea (Baker, 2003;< http://database.prota.org/search.htm> Accessed 18 July 2015).

Pearl millet has a more efficient C_4 photosynthetic pathway and can fix atmospheric Nitrogen and take up water and Phosphorous more efficiently due to its association with nitrogen-fixing bacteria (*Azospirillium* spp.) and vesicular-arbuscular mycorrhizae (*Gigaspora* and *Glomus* spp.) in its root system (<http://database.prota.org/search.htm> Accessed 22 July 2015). However, there is limited information on the extent of Nitrogen fixation and levels of Phosphorous and water up take by different pearl millet cropping systems in varied agro-ecological zones of Kenya and thus there is need to study this.

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 is intercropped or grown as 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 favourable conditions. 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.

Pearl millet is mainly grown as a mono crop 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 nutrient. The legumes are a possible intervention to provide missing nutrients and replenish the soils. It is thus advisable to integrate pearl millet with legumes and livestock production. The livestock would provide the manure to improve the soils; while the pearl millet straw is in turn utilized as livestock feed (ICRISAT, 2002).

Pearl millet is adapted to poor, droughty, and infertile soils and can produce more reliably under these conditions than most other grain crops such as wheat and maize (Abdullahi *et al*., 1998; Pray and Nagarajan, 2009). It 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 (Mangat *et al*., 1999). 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. The crop grows best in light well-drained loamy to sandy soils. But can also tolerate acidic soils to as low as pH 4 with high aluminum content (ICRISAT, 2004). It is not advisable to grow pearl millet on soils prone to water logging in wet seasons this is because it will cause shallow rooting, low seed protein and poor yields (Baker, 2003).

Annual rainfall in the areas where pearl millet is mainly grown ranges from 250 to 700 mm but can still perform well in as high as 1500 mm per annum (Baker, 2003). Little is known about pearl millet response to irrigation during growth. It appears that pearl millet responds less to irrigation than other grain crops. However Irrigation can be used to improve stand establishment if soil is dry during and after seeding (Baltensperger, 2002). Pearl millet is a warm season cereal thus its growth is proportional to solar radiation interception and the plant development rate is proportional to the accumulated degree days above base temp of 10^0 C. Plant development slows down when the temperature drops below 15^0C (Mula *et al*., 2009).The optimum temperature for germination of pearl millet seeds is 33–

35^0C.Germination will not take place below 12^0C. The optimum temperature for tiller production and development is 21–24^0C, and for spikelet initiation and development about 25^0C. Extreme high temperatures before anthesis reduce pollen viability, panicle size and spikelet density, thus reducing yield (Baltensperger, 2002; Mula *et al*., 2009).

Plate 2.1: Mature pearl millet panicles

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, 2012). 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 2.27m ha with most of the area being in Sudan (95%). In Kenya the crop is grown in an approximate area of 93,310 ha (KALRO, 2002; MoA, 2008). While in Tanzania and Eritrea it is grown in 270,000 ha and 100,000 ha respectively (Omamo *et al.,* 2006; Mgonja *et al.,* 2006). It is also grown as a fodder crop, mainly in the developed countries like 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, 2013).

Production statistics often combine data on all millet species. Estimates based on total millet production (FAOSTAT, 2014) and relative importance of pearl millet in different countries indicate an annual grain production of about 18 million tonnes from a planted area of 26.5 million ha mostly in the dry regions of Africa (60% of area and 58% of production) and the Indian subcontinent (38% of area and 41% of production) (ICRISAT 2004). According to FAO (2013), Sub-Saharan Africa annually produces about 13 million metric tons of millet. Since the published data do not distinguish between various species of millet an estimate that approximately 87% (11.3 tons) of this is pearl millet (ICRISAT and FAO, 1996; Rohrbach, 2003). Exports and imports of pearl millet are negligible suggesting low demand and or unreliable availability of marketable surplus for the grain in world markets (Basavaraj *et al.*, 2010).

2.2. Economic importance of pearl millet

Pearl millet (together with finger millet) and sorghum rank third in importance among staple crops in ECA. Overall they are fourth in importance (after milk, oil seeds and cassava) in contribution to gross domestic product (GDP) in Eastern and Central Africa (Mgonja *et al*., 2006; Omamo *et al*., 2006). Over 30% of the population (over 100 million people) of Eastern and Central Africa (ECA) live in the semi-arid areas and thus depend on agriculture and livestock for their livelihood (Omamo *et al*., 2006). Pearl millet contributes significantly to food and nutritional security of the rural and urban population in drier areas where it is valued both for its grain and fodder (Yadav *et al.*, 2011). In the developed countries, pearl millet is mostly grown as a green fodder crop for silage, hay making and grazing (Khairwal *et al.*, 2007).

As a food grain pearl millet is superior nutritionally, compared to maize and sorghum its protein content is 12% which is 45% more to that in maize (Gulia *et al.*, 2007; Murty *et al.*, 2007). The germ of pearl millet constitutes about 17% of the total seed mass (Rooney and McDonough, 1987) and contains about 25% lipids, 20% protein, and phytin, vitamins, and enzymes (ICRISAT, 2007). In addition it is a very important in both the health and nutrition of children and the elderly (Bhalchandra *et al*., 2013). Further to this pearl millet has low tannin as compared to sorghum besides its seed is half the size of a sorghum seed (Gulia *et*

al., 2007). Pearl millet is an excellent animal feed for poultry and livestock like cattle and pigs. As poultry feed it has been observed that broilers fed on pearl millet are heavier and have a better feed conversation rate than those fed on maize (Gulia *et al.,* 2007). Pearl millet grain contains a high percentage of essential amino acids like tryptophan 189 mg Lysine 332, Methionine 239, phenylalanine 469mg (Rooney and McDonough, 1987; ICRISAT, 2007).

Pearl millet grain can be decorticated and made in to flour which can be consumed as porridge. In India it is used to make unleavened bread (Chapatti). In Sudan pearl millet is more than a crop, it is named "elaish" an Arabic word meaning "living" for its high use in human food as the grain is consumed as porridge called "aseeda" or in form of a thin pancake called "kisra" (ICRISAT, 2006). Its flour is further used to make snacks, fermented and non fermented beverages**.** Pearl Millet flour mixed with wheat flour is used for making baking products like breads, cakes, muffins, cookies, and biscuits (Yadav *et al.,* 2011).

Pearl millet stems can be used for fencing, thatching, roofing and fire wood, split stems are used for basketry. A dye for leather and wood is obtained from red- and purple-flowered types. In African traditional medicine the grain has been applied to treat chest disorders, leprosy, and poisonings, and the ground grain as an anti- helmintic for children. A root decoction is drunk to treat jaundice while the vapour of inflorescence extracts is inhaled to treat respiratory diseases in children. (< http://database.prota.org/search.htm >Accessed 18 July 2015.

Pearl millet can suppress root-lesion nematodes (*Platylenchus penetrans*) thus used as an alternative to soil fumigation in tobacco and potato growing. It is therefore a suitable rotational crop in fields known to be highly infested with nematodes (Gulia *et al*., 2007). The crop can also be used for fuel and ethanol production. Its rate of fermentation is 30% greater than that of maize and its distillers dried grains with solubles (DDGS) co products are higher in protein and fat (Gulia *et al.,* 2007).

This crop however is underutilized in Kenya and most of its uses have not been fully exploited. In areas where the crop is grown in the country the flour is used in making porridge for infants and the elderly and to a small degree mixed with maize flour to make thick porridge 'ugali'(MoA, 2008; ICRISAT 2009). Therefore there is a need to promote this

crop through creation of awareness on its importance to the people living in the ASALs of Kenya.

2.3. Production constraints

The main constraints limiting production and the 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 (ICRISAT 2004; Yadav *et al.,* 2011). These and the low harvest index of traditional landrace genotypes 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 (KALRO, 2008). The *Quelea* spp is the most damaging with *Quelea quelea aethiopica* being the most common in East Africa. Bird scaring for several weeks before the harvest is essential (KALRO, 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 Majmudar, 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, policy to consumption and the whole value chain as suggested for commodities by ASARECA (Michelsen, 2003).

In Kenya pearl millet is a food security crop, however its production remains low due to diseases and pests among other challenges (KALRO, 2000; ICRISAT, 2009). The major diseases that cause significant yield losses include Head smut *Tolyposporium penicillariae* Bref., Downy mildew (*Sclerospora graminicola* (Sacc.) Schroet.), Ergot (*Claviceps fusiformis* Loveless) and Rust (*Puccinia substriata* Ell) (ICRISAT, 2002). Rust, leaf blight, root knot nematodes, also reduces yields (Gulia *et al*., 2007). Head smut is a very important diseases of pearl millet in which the pathogens and host combine to produce fungal masses, sclerotia, and spore balls in the pearl millet heads. The disease can cause up to 30% yield loss besides causing 100% damage to individual panicles (Thakur and King, 1988).

2.4. Pearl millet head smut *(Tolyposporium penicillariae* Bref. (Brefeld 1895)

2.4.1. Importance of *T .penicillariae* in pearl millet

Head smut caused by *Tolyposporium penicillariae,* is a very important disease in pearl millet production second only to downy mildew. It is widespread in India Pakistan Africa and the United States (Leslie, 2003). The disease is common in the semi-arid tropics of the world. It is confined to the inflorescence where the infected ovaries are converted to oval or pear shaped *sori* (Rachie and majmudar, 1980). Pearl millet is protogynous i.e. stigmas emerge and mature before the stamens making it highly cross pollinated (Yadav *et al.,* 2011). This therefore predisposes the crop to the pathogen infection during pollination and flower formation when the pathogen takes advantage and infect before the pollen mature 2-3 days later (Thakur *et al.,* 1986; Thakur, 1989).

Apart from reducing the grain yield, the disease also lowers the grain quality due to the production of smut sori on them. Smut severity in a field ranges from 1 to 30% when a crop is infected, it can lead to 50-75% field infection, with a damage of up to 100% in individual panicles (Thakur and King, 1988). Up to 1963 the disease was not considered of economic importance but in the recent years the disease has become more important in northern India and East and Central African countries (ECA) especially with the widespread use of hybrid Genotypes (Leslie 2003; ICRISAT 2004). In Kenya very little has been done on pearl millet diseases and there is limited information on the relative importance of head smut disease in the major pearl millet growing areas.

2.4.2. Symptoms of *T. penicillariae* on pearl millet

Head smut disease is confined to the inflorescence (Rachie and majmudar, 1980; Diagne-Leye *et al*., 2010) and rarely does it show any symptoms on the foliage. The infected ovaries are converted into oval or pear-shaped *sori* with large numbers of black or brown dusty spores. The part of the head covered by the flag leaf is often ideal for the development of the pathogen (Subba Rao and Thakur, 1983). The *sori* are bigger than the grains and appear as enlarged, oval to conical bodies projecting beyond the glumes often replacing the grains (Thakur and King, 1988). Initially the *sori* are bright green but later they turn brown then black (Plate 2.2). The *sori* are 3- 4 mm long and 2- 3 mm broad at the top; usually covered by a thin membrane which breaks at maturity to release brown to black spore balls (Subba Rao and Thakur, 1983). In case of light infection the sori are lightly scattered among grain on the panicles, but in heavily infested crop the whole panicle is completely covered with *sori.* In

panicles having poor head formation, the lower portion covered by the sheath of the flag leaf is usually heavily infested with sori (Thakur and King, 1988)

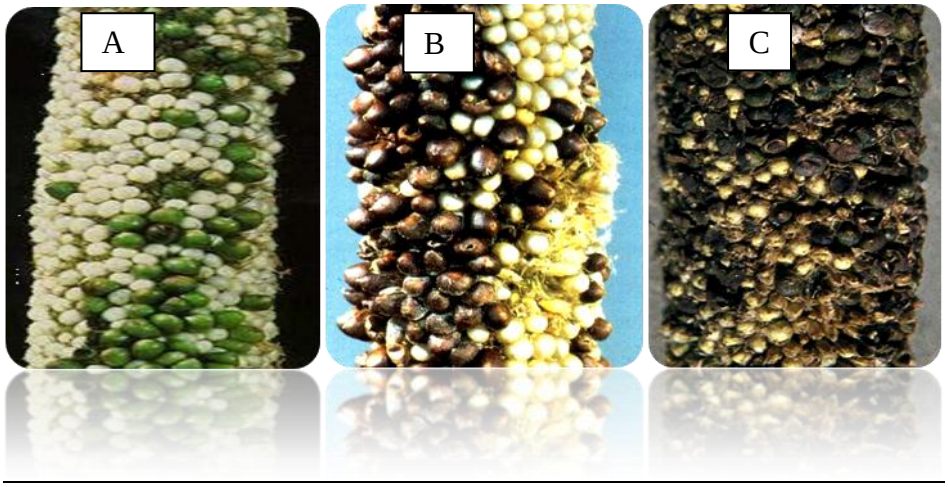

Plate 2.2: Symptoms of *T. Pennicillariea*; A–early, B-Medium and C late stages of infection

2.4.3. Biology and structure of the *Tolysposporium penicillariae* Bref.

The accepted name of the causal fungus is *Tolyposporium penicillariae* Bref. (Brefeld, 1895). The teliospores of *T. penicillarie* are uniformly yellowish brown, globose to sub-globose (Subba and Thakur, 1983; Diagne-Leye *et al*., 2010). They have thickenings at 2 to 3 points in the exospure wall, producing chlamydospores which are intercalary and terminal and measuring 4-8µm in diameter (Thakur and King, 1988). The teliospores occur in compact, balllike masses called sporeballs. Sporeballs vary in shape from circular to near-polyhedral and measure 42-325 x 50-175 µm in diameter (Subba Rao and Thakur, 1983; Diagne-Leye *et al*., 2010). The number of teliospores aggregated in balls varies from 200 to 1400. Individual teliospores do not separate readily and are mostly angular to round, light brown, and measure 7-12 µm in diameter (Thakur and King, 1988). The pro-mycelium is four-celled and forms both lateral and terminal sporidia produced on branched hyphae in chains (Subba Rao and Thakur, 1983) (Plate 2.3).

2.4.4. Disease epidemiology

Smutted pearl millet panicles becomes the primary source of inoculum when they fall to the soil (Subba Rao and Thakur, 1983).The pathogen is soilborne and infection occurs at flowering through young fresh stigmas (Bhatt, 1946; Thakur, 1989). The primary inoculum source is sporeballs in the soil from the previous infected crop and surface contaminated seed used for sowing (Thakur *et al.*, 1986). The pathogen is not internally seedborne, but external

contamination of seed with sporeballs from ruptured *sori* in the field and on the threshing floor is common.

Teliospores remain viable in the soil (soil depths of up to 22.5 cm for about 12 months) where basidiospores and sporidia are produced (Thakur and King, 1988). The teliospores then germinate following rain showers and produce numerous airborne sporidia that infect the pearl millet crop at flowering (Thakur, 1989). Two sporidia of compatible mating types (+ve and –ve) are required to form a dikaryotic infection hypha. Infection occurs through young emerging stigmas and is prevented or reduced by rapid pollination (Diagne-Leye *et al.*, 2010). The optimum temperatures required for maximum germination of teliospores is 30^0C and germination is minimum at 15^0C but generally germination increases gradually from 15^0 C to its maximum at 30^0C (Subba Rao and Thakur, 1983; Rao *et al*., 2006).

Infection occurs when sporidia suspended in rain or dew infiltrate into boot of the crop. Aerial populations of sporidia are greatest when minimum and maximum temperatures range between approximately 21 and 31^0C respectively and maximum relative humidity is greater than 80% (Kousik *et al*., 1988). The latent period (time from infection to spore production) is about 2 weeks and *sori* mature within 3- 4 weeks. Matured *sori* rupture to release masses of sporeballs which, under favourable weather conditions, germinate to produce a second cycle of sporidia. These sporidia can infect late-planted crops in nearby fields or panicles of late tillers in the same field, and the cycle is repeated (Plate 2.4) (Thakur and King, 1988).

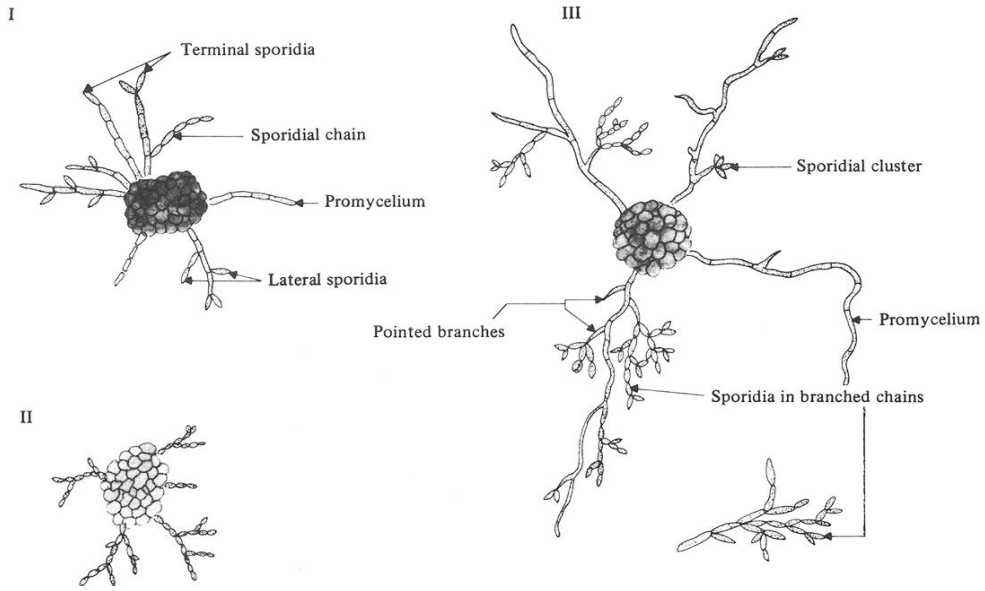

Plate 2.3: Diagram showing the biology and structure of *T. penicillariae*. Source: (Subba Rao and Thakur, 1983)

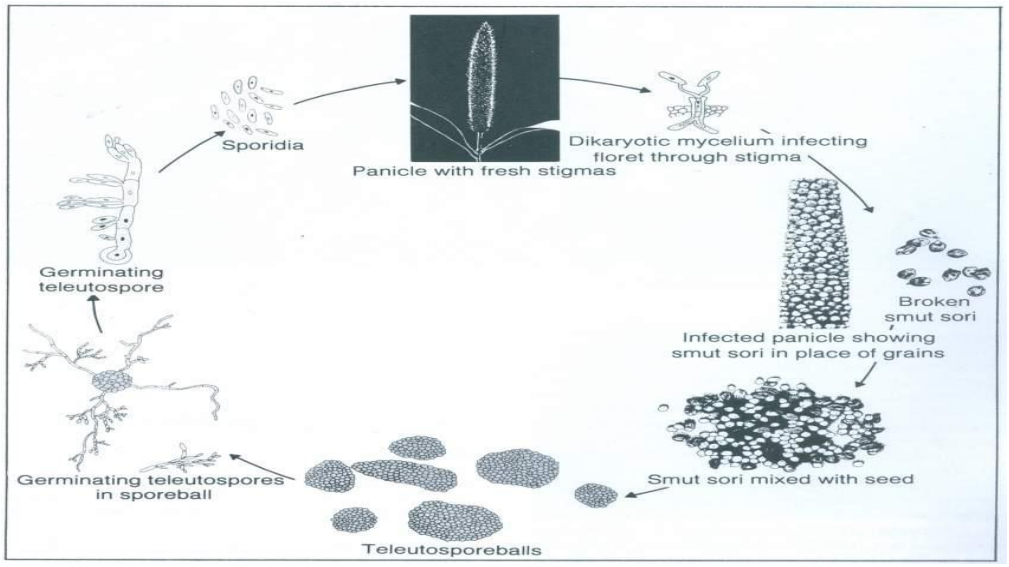

Plate 2.4: The life cycle of *T. penicilllariae*. Source: (Thakur and King, 1988).

2.5. Control methods of *Tolyposporium penicillariae* Bref. on pearl millet

2.5.1. Chemical control

Fungicides used on panicles at boot stage can contain the disease to some considerable levels (Thakur *et al.*, 1992: Yadav and Duhan, 1999). This however needs up to four sprays, at boot stage and immediately after (King, 1992). This is impractical for most pearl millet farmers especially those in small scale production since even up to four sprays leads to limited success (Thakur and King, 1988). The major limitations to chemical control of smut in pearl

millet are low monetary value of the crop, and a widespread scarcity of resources available to pearl millet farmers in the semi-arid tropics. However several nonsystemic fungicides such as, zineb, mancozeb, Ceresan, Agrosan and some systemic fungicides like Plantvax, Vitavax, and Benlate have been used to control smut with limited success even under low disease pressure (Rachie and Majmudar, 1980; Phookan, 1987). Antibiotics such as heptaene and aureofungin have been tried either as seed, foliage, or panicle-spray treatments also with limited success (Thakur and King 1988).

Infection occurs from airborne sporidia at or close to the time of flowering, hence seed dressing with fungicides is not effective (Thakur, 1989). However treating seeds with NaOH or KOH at different percent concentration showed reduction of smut spore germination but did not completely eliminate their germination (Chakrabarty *et al.*, 2011). This therefore necessitates the use of other methods to control the disease since chemical control is not effective and expensive to most farmers in the ASALS of Kenya. Use of HPR is the best option hence the need to screen for resistant/tolerant genotypes that can further be used in breeding for disease resistant varieties.

2.5.2. Cultural control

Little information is available on effective control of the disease through cultural practices (King, 1992).However several cultural measures can be used to control the disease with some considerable success e.g. uprooting and burning all infected plants from the field (KALRO, 2000). But this can be tedious especially where the crop is grown in large scale. Although the disease is not seed borne using clean seed reduces chances of infection from contaminated seed (Thakur and King, 1988). Other cultural practices such as crop rotation rouging and burning infected plants have been used with a small degree of success (KALRO, 2000). Use of resistant genotypes is thus the most cost effective and reliable control measure of the disease in the ASALS of Kenya.

2.5.3. Host plant resistance

Host plant resistance is a situation where a host possesses qualities that enables it to resist or tolerate a disease or a pest and still produces normally despite infection. It is the most sustainable and effective management option in managing any disease or pest in crop production. It is cheap to the farmers, does not pollute the environment, has no adverse effects on the non-target organisms and is compatible with other methods of disease management (Sharma, 2007). Growing disease-resistant Genotypes therefore, is the most

economical and feasible method of controlling head smut in pearl millet production (Thakur and King, 1988). This is so because other control measures such as fungicide control and cultural measures are not effective considering the nature of spread of the disease (airborne). Furthermore fungicides use under regular regime becomes very expensive to farmers in the ASALS where pearl millet is grown.

Breeding for disease resistance is the best option but first there is the need to identify sources of resistance. Identified genotypes should have a high level of resistance and the resistance must be stable across environments (King, 1992). Resistance is identified by screening large numbers of germplasm accessions using an effective field-based screening technique (Thakur and King, 1988). Identification of diverse and stable source of resistance to head smut disease is thus a prerequisite to developing resistant genotypes (ICRISAT, 2010). Pearl millet head smut is a widespread disease and thus identifying resistant genotypes would facilitate control of the disease in Kenyan ASALS.

Under field experiments it has been noticed that dwarfs have more smut than medium and tall genotypes. This is attributed to the proximity of the dwarfed varieties to the soil (Thakur *et al.,* 1992). Panicles with good exertion generally have less smut than those with poor exertion this is because of the humid conditions created under poor exertion by the flag leaf (Thakur and King, 1988). A pollen based mechanism has been reported to be operative in smut resistance (Thakur *et al.,* 1992). This is because the disease infects the stigmas before the stamens mature. The pathogen takes advantage of the fact that stigmas in pearl millet emerge 2-3 days before pollen mature and this is when its sporidia settles on the stigmas and causes infection (Thakur, 1989). In some genotypes, a mechanism called disease escape is applicable where improved pollen management facilitates early capture by stigmas and minimizes chances of disease infection (Mantle, 1992).

It has been noted that within 5 hours of compatible pollen reaching the surface of the stigma in some genotypes, a group of cells in the region of the fused styles begin to lose turgidity and progressively collapse hence preventing any further pollen movement and or any opportunistic ovary pathogens like head smut and ergot diseases. This is called stigmatic constriction and is an important aspect in disease escape on pearl millet head smut and ergot. Further to the stigmatic constriction, genotypes with minimum size or exerted stigmas reduce the effective area for pathogen reception (Thakur, 1989). Besides the pathogen is slower in

initiating constriction taking up to 16 hours as compared to 5 hours in the case of the pollen initiated constriction (Mantle, 1992). Identifying genotypes that posses such qualities is crucial to developing varieties that are resistant to head smut.

In screening for head smut resistance the standard field screening procedure (Thakur *et al*., 1983; Thakur *et al.,* 1992) is used. This involves inoculating plants at boot-leaf stage with an aqueous sporidial suspension of *T. penicillarie* grown on potato dextrose agar or potato agar for 2-5 days at 30 ^{0}C. The inoculated boot is immediately covered with parchment bags and high relative humidity maintained through sprinkler irrigation twice every day on rain-free days (Thakur *et al.,* 1992). The parchment bags are then removed 10-20 days after inoculation and the panicles scored for smut severity using the smut severity assessment key (Thakur and King, 1988).

2.5.4. Analysis of correlation and Principal Components of measured traits

The characterization and selection of morpho-physiological traits play an important role in identifying stress tolerant genotypes for dry areas. According to Jackson *et al* (1996) these traits affecting response to important limiting factors like diseases may be used as indirect selection criteria in populations in breeding programs. Therefore, several techniques have been used to assess the relationship, potential usefulness and reliability of traits as selection criteria, with view of enhancing screening efficiency. Correlation and regression are widely used to estimate the contributions of yield components and other traits such as disease resistance to increased grain yield (Fisher and Wood, 1979 and Reynolds *et al*., 2002). Estimates of stability and heritability respectively, gives a measure of responses of traits over different environments and the amount of genetic material that can be transferred from parents to off-springs during breeding (Eberhart and Russel, 1966). Both techniques are important estimates of the usefulness of characters in breeding and their reliability as an indirect selection criterion.

Several authors (Eberhart and Russel, 1966 and Reynolds *et al*., 2002) noted that the use of selection indices with all desired features of high heritability, high genetic correlation and low cost enhanced gains in grain yield under moisture stress conditions than yield based selection *per se* because the traits had greater heritability than yield itself. Correlation coefficient is computed using mean values from each season. Relationships of grain yield and yield components were analyzed as a 1000 seed weight, panicle size and biomass as intermediary variables and other traits as independent variables. Principal component analysis (PCA) is an ordination technique that reduces the dimensionality of data such that a small set

of orthogonal vectors (principal components) account for as much of the variance in the data as possible. In this procedure, eigenanalysis of correlation matrix is carried out where each eigenvalue corresponds to a proportion of the variance in the data set. The greatest amount of variance is assigned to the first principal component. The second principle component accounts for the second highest amount of variance and is orthogonal to the first and so on. The total sum of the principle components (eigenvalues) is equal to the sum of variances of the standardized variables (Broschat, 1979).

CHAPTER THREE
FIELD EVALUATION OF YIELD PERFORMANCE AND LEVEL OF RESISTANCE/ TOLERANCE TO HEAD SMUT IN SELECTED PEARL MILLET GENOTYPES

3.0 Abstract

Head smut caused by *Tolyposporium penicillariae* Bref., is a devastating fungal disease that cause up to 30% yield losses in pearl millet. In the ASALs pearl millet is mainly grown by small scale farmers who rarely use fungicides to control the disease since it is not economically viable to them. The development and use of resistant genotypes offers the most economical means of head smut control. However this primarily depends on the availability of sources of resistance. The study therefore evaluated host plant resistance among fifty advanced pearl millet genotypes in two selected dry land sites (Koibatek and Marigat) in Kenya. The test germplasm were planted in a complete randomized block design (RCBD) in three replicates during the short rains (Sept -Dec 2011) and long rains (April-July 2012). Data on yield performance, disease scores, maturity and tillering ability were collected and subjected to analysis of variance (ANOVA) using GENSTAT release 14.0. Results showed that yield and disease severity were highly significant among the genotype (Fpr <0.001) with yield ranging from 1172-4122kgha^{-1}. The high yielding genotypes were SDMV 90031, IP 8783, Shibe, ICMV 96603, ICMV221-1 and IP6791, Shibe, SDMV 90031, IP 94014, IP8783 and IP 6791 they were also resistant to the disease. Although ICMV 221-1 and ICMV 221 Bristled were among the best performing they were susceptible to head smut. Twenty genotypes were selected to be futher screnned in experiment II.

Key words *Pennisetum glaucum*; *Tolyposporium penicillariae;* Disease severity; Sources of resistance; Host plant resistance.

3.1 Introduction

Pearl millet is a drought tolerant cereal classified as the hardiest among all cereals. It is a very important cereal in the health and nutrition of young children and the elderly (Bhalchandra *et al*., 2013). It is thus a food security crop but its productivity remains low due to diseases and pests, growing low yielding unimproved varieties among other challenges (KALRO, 2000; ICRISAT, 2009). Head smut is a very important disease of pearl millet, where the pathogens and host combine to produce fungal masses, sclerotia, and spore balls in the pearl millet heads. The disease can cause up to 30% yield loss besides causing 100% damage to individual panicles (Thakur and King, 1988).

Current pearl millet yields in Kenya, are very low (200-800 Kg ha^{-1}) as compared to its research potential of 1500-4000 Kg ha^{-1} (KALRO, 2008; ICRISAT, 2013). The yield losses are due to both biotic and abiotic stresses as well as growing of local low yielding varieties Farmers have also recycled seed. These varieties have also become susceptible to diseases like head smut and Downey mildew. Head smut cause substantial yield losses that sometimes go up to 100% (Thakur and King, 1988). Damage by birds also cause substantial yield losses (ICRISAT, 2013). There is therefore need to develop varieties that are smut resistant and high yielding.

3.2. Objective

The objective of this experiment was to evaluate selected pearl millet genotypes for sources of tolerance/resistance against head smut and determine their yield performance under field conditions in selected sites in ASALs of Kenya.

3.3 Materials and methods

3.3.1 Site description

The study was conducted at two sites, Koibatek (Agricultural Training Centre, ATC-Koibatek) and Marigat (KALRO –Perkerra). ATC-Koibatek lies at latitude 1^0 35' S, and longitude 36^0 66' E, altitude 1890 m a.s.l. in agro-ecological zone UM4, with medium to low agricultural potential. Average annual rainfall is 767 mm; mean annual minimum and maximum temperature are 10.9^0C and 28.8^0C respectively. The soils are Vitric Andosols with moderate to high soil fertility, well drained deep to sandy loam soil (Jaetzold and Schmidt, 1983).

KALRO Perkerra-Marigat lies at a latitude of $1^0$45´ N and longitude 36°15´ E with an altitude 1067 m.a.s.l. The centre is situated in agro ecological zone 5 (LM5) with low agricultural potential. The soils are volcanic fluvisols of sandy/silty clay loam texture, slightly acidic to slightly alkaline, with adequate, P, K, Ca, Mg but low N and C. Annual mean rainfall is 654mm. Mean annual minimum and maximum temperatures are 32.4^0 C and 16.8^0 C, respectively (Jaetzold and Schmidt, 1983). Amongst the two sites, Koibatek ATC is fairly wet and humid receiving more rainfall than Marigat.

3.3.2 Plant germplasm evaluation

In this study 50 pearl millet genotypes were evaluated (Table 3.1). The genotypes were sourced from ICRISAT Nairobi Kenya and KALRO Katumani. Amongst these genotypes, three varieties (ICMV 221, KAT PM1 and KAT PM 2) are commercial varieties and served as resistant checks. They all have varied levels of resistance, phenology and maturity.

Table 3.1: List of pearl millet genotypes evaluated

TRT NO	Genotype	Source	Remarks
1	ICMV 221	KALRO	Commercial Resistant check, OPV
2	ICMV 88908	ICRISAT	OPV
3	ICMV 91450	ICRISAT	OPV
4	ICMV 93771	ICRISAT	OPV
5	IP 9946	ICRISAT	OPV
6	ICMV 94136	ICRISAT	OPV
7	ICMV 94151	ICRISAT	OPV
8	ICMV 96603	ICRISAT	OPV
9	KAT PM1	KALRO	Commercial Resistant check
10	KAT PM 2	KALRO	Released in Kenya
11	OKASHANA 1	ICRISAT	OPV
12	OKASHANA 2	ICRISAT	OPV
13	OKOA	ICRISAT	Released high yielding variety in TZ
14	PMV 3	ICRISAT	OPV
15	SDMV 90031	ICRISAT	OPV
16	SDMV 93032	ICRISAT	Susceptible check
17	SDMV 94001	ICRISAT	Susceptible check
18	SDMV 94005	ICRISA	Susceptible check
19	SDMV 94014	ICRISAT	Susceptible check
20	SDMV 95009	ICRISAT	Susceptible check
21	TSHOLOTSO Bearded	ICRISAT	Large bristles bird resistant
22	SDMV 96053	ICRISAT	OPV
23	SDMV 96063	ICRISAT	OPV
24	Shibe	ICRISAT	Released high yielding variety in TZ
25	ICMV-1	ICRISAT	OPV
26	ICMV-2	ICRISAT	OPV
27	ICMV-3	ICRISAT	OPV
28	ICMV White	ICRISAT	White seeded released variety
29	ICMV-4	ICRISAT	OPV
30	ICMV Bristled	ICRISAT	Large bristles bird resistant
31	IP 9976	ICRISAT	OPV
32	IP 8765	ICRISAT	OPV
33	IP 8767	ICRISAT	OPV
34	IP 8773	ICRISAT	OPV
35	IP 6800	ICRISAT	OPV
36	IP 8761	ICRISAT	OPV
37	IP 10470	ICRISAT	OPV
38	IP 8856	ICRISAT	OPV
39	IP8772	ICRISAT	OPV
40	IP 10471	ICRISAT	OPV
41	IP 6791	ICRISAT	OPV
42	IP 9989	ICRISAT	OPV
43	IP 8783	ICRISAT	OPV
44	IP 7389	ICRISAT	OPV
45	IP 7390	ICRISAT	OPV
46	IP 8764	ICRISAT	OPV
47	IP 8768	ICRISAT	OPV
48	IP 8774	ICRISAT	OPV
49	IP 5876	ICRISAT	OPV
50	IP 8766	ICRISAT	OPV

3.3.3 Study materials and experimental design

The study involved evaluation of 50 genotypes of pearl millet at ATC-Koibatek and KALRO Marigat for two seasons in each site. The first season was during the short rains (Sept 2011 and January 2012) and the second season in the long rains (March-Aug 2012). The test entries were evaluated in a Randomized Complete Block Design (RCBD) in three replicates. Each plot consisted of 4 rows measuring 2 m in length, spaced 60cm between the rows (inter-row) and 15cm between the plants (intra-row). DAP fertilizer was applied at the rate of 100kg/Ha during planting. Disease development was allowed through natural infestation.

The panicles were scored for smut severity as a percentage of florets that had smut *sori* at the reproductive stage on a scale of 1-8 (Plate 3.1) (Rao *et al*., 2006). Another set of experiment (B) was conducted to run concurrent with the first experiment as control, where the plots were sprayed with Ridomil at recommended rates four times from booting stage. Spraying was done at intervals of 7 days to control and maintain the experiment disease free. This experiment was set below the first experiment to control fungicide drifts. The two experiments were also separated by 10 rows of Sorghum.

Yield losses from controlled experiment were estimated as percentage yield loss due to disease in the first experiment (A) by calculating the yield differences between the two experiments. The experiment determined the grain yield performance and levels of resistance to head smut for the test genotypes. From this experiment 20 genotypes were selected for further evaluation under controlled conditions in a glasshouse (Exp II). The genotypes were selected on the basis of their yield performance, maturity disease resistance and their level of damage by birds. The selections thus were a mixture of tolerant to susceptible genotypes including the resistant and susceptible checks. Insect pests were controlled by spraying an effective systemic insecticide (Thunder) at recommended rates. Weeding was done manually from emergence to maturity ensuring that the fields were always weed- free to eliminate any competition.

3.3.4 Data collection

3.3.4.1 Yield and yield components

The following data on yield and yield components was taken according to procedures described by Mustapha and Mustapha (2007) and Addisie and Gebre-Egziabher (2011).

i. Germination score (%) for every genotype using a scale of 1-5, where 1 represented poor germination; 2-3 meant average germination and 4-5 good germination**.**
ii. Seedling vigour was scored using a scale of 1-5 for the number of plants in the two middle rows. Where 1 represented poor vigour; 2-3 moderate vigour and 4-5 means good seedling vegetative vigour**.**
iii. Phenological traits which included days to first flower, days to flowering (50%), and days to maturity
iv. Plant height (cm) and plant canopy height (cm) at maturity taken from 5 plants in the 2 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 (mm) taken from five plants from the two middle rows.
v. Total number of tillers/plant and number of tillers with harvestable panicles counted from 5 plants in the middle rows and % reproductive tillers obtained.
vi. 1000 seeds weight in (g) taken from the five plants in the two middle rows.
vii. Grain yield (g/plot) from middle rows per plot estimated in g/m^2 then converted to tons/ha. The yield from the sprayed verses the non sprayed experiments were calculated in the same manner and both given tons/ha

3.3.4.2. Data collection on disease infection

Incidence and severity of head smut were recorded after every 7 days from the booting stage up to harvesting. The incidence was determined by counting the number of plants infected per plot while severity was determined by looking at the percentage infection of the individual plant florets using the standard smut severity scale (Thakur *et al.*, 1992) on a scale of 1-8 (Plate 3.1 and Table 3.2). Where 1= highly resistant, 2 = resistant, 3-4 = moderately resistant, 5-6 = moderately susceptible 7= susceptible, and 8 highly susceptible. Any plants with <10% of florets infected were considered highly resistant, between 11-20% florets infected - resistant, 21-40% florets infected - moderately resistant, between 41-60% ,moderately susceptible, 61-80% florets infected susceptible and 81-100% floret infected as highly susceptible.

Table 3.2: A 1-8 rating scale for head smut resistance for pearl millet genotypes

Score	Reaction Category	% Rating	Appearance on Panicles
1	Highly resistant (HR)	<10	Less than 10% florets affected
2	Resistant (R)	11-20	11-20% florets affected
3-4	Moderately resistant (MR)	21-40	21 to 30% florets affected
5-6	Moderately susceptible (MS)	41-60	41 to 60% florets affected
7	Susceptible (S)	61-80	51 to 70% florets affected
8	Highly Susceptible (HS)	81-100	>80% florets damaged

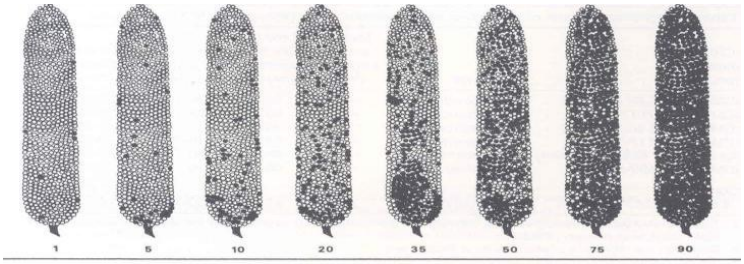

Plate 3.1: Panicles showing disease Rating scale of 1-8 (Source Thakur *et al.*, 1992)

Statistical Model fitted - Randomized Complete Block Design

Single environment

$Y_{ijk} = \mu + G_i + \beta_j + \varepsilon ijk$…… [Equation 2]

Where,

Y_{ijk} = observed mean of the ith genotype in the jth block

μ = overall mean

G_i = effect due to ith genotype

β_j = effect due to jth block

εijk = Random error

Multiple environments

$Yijk = \mu + G_i + \delta j + (\tau\delta) ij + \gamma jk + \varepsilon ijk$……. [Equation 3]

Where,

Yijk = observed mean of the kth replication of the ith genotype in the jth environment

μ = overall mean,

G_i = effect of the ith genotype,

δj = effect due to jth environment,

$(\tau\delta)$ ij = interaction effect of the ith genotype within the jth environment,

γ jk = effect of kth replication in the jth environment,

εijk = random error.

3.3.5. Data Analysis

Data was subjected to analysis of variance using Genstat release 14. Treatment means were separated using DMRT at $P \leq 0.05$. Simple correlation coefficient (*r*) was carried out using Pearson's correlation. Homogeneity of error variance was carried out before pooling the data across environments using Bartlett's test for homogeneity and data transformation carried out by dividing mean response by respective root mean square error (MSE) for respective environments. Simple Principle Component Analysis (PCA) and Multivariate analysis was undertaken using JMP statistical software, version 10. Principal component analysis was applied as a correlation tool in reduction and summary of standardized data from yield parameters.

Correlation was computed using mean values from each season and both seasons combined. Relationships of grain yield and yield components were analyzed as seed per panicle, panicle height and 1000 seed weight as intermediary variables and other traits as independent variables. Similarly Principal component analysis was done in order to obtain an overview of the association between grain yield, yield components and other traits; this was done using eigen analysis of correlation matrix where each eigenvalue corresponds to a proportion of the variance in the data set. The greatest amount of variance is assigned to the first principal component. The second principle component accounts for the second highest amount of variance and is orthogonal to the first and so on. The total sum of the principle components (eigenvalues) is equal to the sum of variances of the standardized variables (Broschat, 1979).

3.3.6. Yield loss estimation.

Yield losses arising from disease infestation on genotypes was estimated by comparing the sprayed trials (Expt B) with non sprayed trials (Expt A) under natural infestation in both sites. The relative losses in yield for all varieties were determined as a percentage of the protected plots for each genotype (Tadesse *et al*, 2010).

Losses were calculated separately for each of the genotypes with different levels of disease, as:

$$\text{RL } (\%) = \frac{Y1-Y2}{Y1} \times 100$$

Where, RL = relative yield loss (reduction of the grain yield)

Y1 = mean yield of respective genotype on protected plots (plots with maximum protection) and

Y2 = mean yield of the respective genotype in unprotected plots (i.e. unsprayed plots).

3.3.7 Classification of test genotypes for resistance or Susceptibility to head smut

Based on disease severity (%) the genotypes were grouped into six categories; highly resistant (HR) with < 10% disease infection, resistant (R), 11-30% florets infected, 31-40% florets infected moderately resistant (MR), between 40-50% moderately susceptible (MS), 51-70% florets infected susceptible (S) and 71-100% floret infected as highly susceptible (HS).

3.4 Results

3.4.1. Effects of head smut disease infestation and grain yield performance of selected pearl millet genotypes in Koibatek and Marigat, Kenya (2010/2012)

The results for combined analysis of variance (ANOVA) showed significant genotypic variation for disease incidence and severity ($P \leq 0.05$) (Table 3.3). The interactions between genotype and site (GxE), and genotype and season (GxS) affected the yield and most yield components of tested pearl millet genotypes except 1000 grain weight and the presence of bristles. Overall mean yield for the short rains and the long rains in the two sites was 2.95 tons ha^{-1} for the sprayed experiment and 2.39 tons ha^{-1} in the diseased plots (Table 3.3). Combined analysis of variance showed that the genotype and environment main effects and the genotype by environment interactions were significant ($P \leq 0.05$) for grain yield and other traits, indicating differential response of genotypes across testing locations and the need for further studies on stability analysis.

Due to the high humidity in Koibatek as compared to Marigat there was more disease development in this site. The disease progressively increased in season 2 in both sites because of high humidity in season 2 as compared to season 1. The severity in Koibatek progressed to a maximum of 3.0 in the long rains from 2.8 in the short rains as compared to 2.0 in the short rains to 2.6 in long rains for Marigat (Table 3.8). The results however show that there was more disease infection in Koibatek for both the seasons as compared to Marigat (Table 3.4, 3.5, 3.6 and 3.7).

Overall mean yield for all the short and long rains in the two sites was 2.95 ha^{-1} tons for the sprayed experiment and 2.39 tons ha^{-1} in the diseased plots (Table 3.3). This showed an average of 20% yield losses due to disease pressure for both the sites and the seasons. The results for combined ANOVA showed significant genotypic variation in grain yield and yield components

Table 3.3: Results of combined yield performance and yield components traits of selected genotypes for both sites and seasons

Genotype	DAF	DAM	PHT	DSI	DSS	BRD	VT	RT	PDM	PLT	SWT	YLDNS	YLDS
SDMV 90031	35	81	188	1	1	2.	6.7	5	9	22	11	4171	4294
ICMV 221-1	25	80.4	196	3.5	5.5	4.6	6.5	5	9	20	11	3482	3793
ICMV bristld	25	75	234	2.5	4	2.6	6	4.5	11	28	11	3199	3427
IP 8783	33	85	223	1	1	3.2	7	4.5	10	31	12	3184	3265
IP 6791	32	81.6	221	1.2	1	2.3	5.7	4	9	24	8	3172	3523
SDMV 94014	29	78.5	213	4	8	4.5	6	3.5	8	20	10	3141	3858
ICMV 93771	32	79	217	1	2	4.6	6	4.8	7	24	9	3115	3279
ICMV 96603	34	81.5	277	1	1	2.6	6	4	9	23	11	2970	3097
ICMV 91450	29	81.3	208	3	5	5	6.7	5	9	20	11	2932	3013
IP 221-3	27	74.8	212	1	1	4.5	7	5	8	19	10	2886	3155
Tsholotsho	35	81.6	260	1	1	1.5	6	4.8	8	24	7	2883	2940
KAT PM 2	28	74.8	199	1.3	2.3	5	7	5	8	22	9	2835	2939
KAT PM 1	28	74.8	205	1	1	1.2	6	4.5	9	22	12	2833	3096
SHIBE	32	80	220	1	1	5	7	5	9	26	10	2726	2843
SDMV 96063	32	80.2	204	4.5	6	4.5	7.9	5	9	24	10	2453	2913
IP 7390	32	80.3	227	1	1	1.6	6.5	5	11	31	10	2563	2829
ICMV 221	27	73	206	1.5	2.1	4.7	6.5	4.8	8	20	11	2498	2707
OKOA	32	79	221	1	1	5	5.5	4	9	29	9	2370	2638
ICMV 94136	32	79.6	175	3	4.6	4.6	5.7	5	8	21	10	2260	2780
IP7389	34	80.5	239	1	1	1l	7	5	10	34	9	2179	2438
221 white	29	76	199	4	7	4.8	5.7	4	8	23	10	2101	2613
IP 8764	30	77.3	190	2.6	5.5	1.8	6.7	4.8	10	22	11	2004	2246
Okashana 2	32	78.8	231	1.6	2.5	5	6.3	4	8	20	9.	1963	2223
SDMV 94001	29	77	202	3.3	5.5	5	6.5	3	8	22	8	1907	2598
IP 10470	33	86	219	1	1	2	6.5	4	10	28	9	1882	2518
IP9989	34	81.6	184	2	3	1.6	6.8	5	10	26	10	1825	2075
IP 6800	33	80.6	201	2.1	5	4.3	7	5	8	26	9	1798	2038
ICMV 88908	28	74	182	1	1	4.8	8	5	9	23	8	1642	1838
IP 8856	34	81.8	216	1	1	1.5	7	2	10	23	8	1330	1568

IP9976	39	88	219	1	1	3.6	7	5	9	23	9	1218	1383
Range	**21-60**	**70-98**	**110-305**	**1-7**	**2-8**	**1-6**	**3-12**	**2-9**	**5-14**	**13-38**	**4-18**	**810-5203**	
Mean	**32**	**80**	**211**	**1.6**	**2.6**	**3.4**	**6.5**	**4.7**	**9**	**24**	**9.4**	**2391**	**2946**
CV%	**17**	**4.2**		**31**	**16**	**25.4**	**15.8**	**17**	**15.1**	**16.5**	**16.7**	**14.5**	**13**

KEY: Disease scoring scale, 1 to 8 scale, where score 1, <10% Head area damaged, 8>80% head area damage, where 1- highly resistant, 2-resistant, 3-4- moderately resistant, 5-6 moderately susceptible, 7- susceptible, and 8-highly susceptible; **DM**= Days to maturity; **YLDNS**=Grain yield tons Ha^{-1} in non sprayed, **YLDS**=Grain yield tons Ha^{-1} in sprayed, **PHT**= Plant height, **DSI**= Disease incidence, **DSS**= Disease Severity, **BRD**= Bird Damage, **VT**= Vegetative tillers, **RT**= Reproductive tillers, **PDM**= Panicle Diameter**, PLT**= Panicle Length, **SWT**= 1000 Seed weight in grams.

The following genotypes had the highest grain yields in decreasing order; SDMV90031, ICMV 221-1, ICMV 221 Bristled, IP 8783, IP 6791, SDMV 94014 , ICMV 91450, ICMV221-3, KATPM1, KATPM2, Shibe, SDMV96063, ICMV96603, IP7390 with yield range of (4271-2736Kg ha^{-}) (Table 3.3). Combined analysis over the sites and seasons showed that the IPs genotypes were among the lowest yielding (Table 3.3) they also had many vegetative tillers compared to the reproductive tillers and matured late. These IPs included; IP 9976, IP8767, IP8856, IP10470, IP5876 and IP8773 with grain yield ranging from (1218- 1468 kg ha^{-1}). The highest yielding genotypes were SDMV 90031 (4271 Kg ha^{-1}) and ICMV 221-1 (3482 Kg/ha) while the lowest yielding were IP9976 (1218 Kg ha^{-1}) and IP8767 (1305 Kg ha^{-1}).

The interaction between pearl millet genotypes and seasons did not significantly affect the panicle length and diameter as well as the number of tillers per plant in sites and seasons tested (Tables 3.4 and 3.5). There was significant variability for plant height (Fpr<.001), ranging between 110-298 cm (Table 3.3 and Appendix 4). The IP genotypes were among the tallest (IP10471, IP7390, and IP7389) followed by ICCV 221 Bristled and Tsholotsho Bearded (Table 3.3). Days to maturity (DAM) ranged between 71- 98 days showing considerable variability as shown in Table 3.3. The test genotypes were categorized into super early maturing (<75 days), early (75-80 days), medium maturity (80-85 days) and late (85-100 days). Among the super early maturing genotypes were ICMV 221, ICMV 88908, KAT PM1 and KATPM2 which matured after 73-75 days (Table 3.3). All the three checks ICMV221, KAT PM1 and KATPM2 were among the super early maturing. Other early maturity genotypes included ICMV white, ICMV221-3, ICMV Bristled, ICMV 94136, ICMV 93771, Okoa SDMV 9001, and SDMV 94014 which matured between 75-79 days (Table 3.3). Medium maturing genotypes were the majority and included among others Shibe, IP7390, SDMV90031, ICMV 94150, ICMV 96603, SDMV 96063 taking between 80-81 days (Table 3.3). The late maturing included IP 6791, IP 10470 IP9976 and IP8783 maturing in 86- 88 days (Table 3.3). Generally all genotypes took long to mature in Koibatek with mean of 84 days as compared to 76 days in Marigat.

Grain yields in the long rains were higher compared to the short rains for both the sites (Tables 3.4, 3.5, 3.6 and 3.7). The disease was high in the long rains as compared to the short rains. In the short rains average yields in ATC Koibatek were lower (2.36 tons ha^{-1} in the non sprayed experiment and 2.49 tons ha^{-1} in the controlled experiment as compared to the long rains yield with 2.43 tons ha^{-1} in the non sprayed experiment and 2.53 tons ha^{-1} in the controlled

experiment. Similarly the yields in Marigat were higher during the long rains as compared to the short rains, 2.34 tons ha^{-1} non sprayed experiment and 2.7 tons ha^{-1} as compared to the long rains Sprayed 2.4 tons ha^{-1} non sprayed and 2.9 tons ha^{-1} (Tables 3.4, 3.5, 3.6 and 3.7). The relationship between the presence of bristles and bird damage was evident across the sites and the seasons. Genotypes with conspicuously long bristles such as Tsholotsho, IP7389, IP 8856, IP8764, IP7390, had less than 10% bird damage while genotypes with medium bristles including ICMV Bristled, ICMV96603, IP6791 IP90031, and IP10471 had an average percent bird damage of less than 50% as compared to non bristled genotypes with damage greater than 90 % bird damage (Table3.3).

3.4.2 Effect of head smut disease infestation and grain yield on selected pearl millet in Koibatek Kenya, during short rains (Sept -Dec 2011)

There was significant genotypic variation ($P \leq 0.05$) for all the traits measured among genotypes in respect to yield and disease infections (Table 3.4 and Appendix 1). Grain yield range in tones per hectare was (0.98 - 4.5). The mean grain yield recorded for this season was 2.3 tons ha^{-1} in the diseased plots as compared to 2.8 tons ha^{-1} in the controlled experiment (Table 3.4). The best performing genotypes; SDMV 90031, ICMV 221-1, IP6791, IP 8783, ICMV96603, IP7390 had lower yield losses due to disease pressure of < 10%. The commercial checks ICMV221, KATPM1 and KATPM2 had yield losses ranging between7-10% due to the disease pressure. Susceptible genotypes (SDMV 94014 and SDMV 94001) had yield losses of 11% and 14% respectively. Susceptible genotype SDMV 94014 had average yields of 3.9 tons ha^{-1} under the controlled experiment and 3.6 tons ha^{-1} in the diseased experiment while SDMV 94001 was among the worst performing with 2.3 tons ha^{-1} in the controlled experiment and 2.0 tons ha^{-1} in the diseased experiment with yield loss of 15%.

The ICMVs genotypes matured early in this site during the short rains, ICMV 221, ICMV 88908, KAT PM1 and ICMV white matured in less than 75 days (Table 3.4). Bird damage ranged from 1-5 with an average of 3 in Koibatek for the short rains. It was noted that the genotypes with bristles were not seriously affected by birds especially those with conspicuous long bristles like IP 10471, IP 7390, IP 6791, IP7389, IP 8856, ICMV 96603 and Tsholotsho bearded all with less than 10 % bird damage (Table 3.4).

Table 3.4: Mean head smut disease infestation and yield parameters for selected pearl millet genotypes in Koibatek (Short rains)

GENOTYPE	DAF	DAM	PHT	BRD	VT	RT	PDM	PLT	1000 SWT	DSI	DSS	YLD NSD	YLDSD
SDMV 90031	41	84	168	2	6	6	10	23	10	1	1	4501	4791
SDMV 94014	27	83	176	4	3	7	7	17	6	1	1	3602	3917
ICMV 221-1	25	86	171	4	3	8	7	29	12	4.7	7.3	3790	3907
IP 6791	41	86	207	1	5	6	8	20	7	1.3	1.3	3617	3877
IP 8783	42	89	205	1	4	8	10	32	1	1	1	3390	3517
TSHOLOTSHO	41	87	231	1	4	6	8	25	7.6	1	1	3329	3417
ICMV BRISTLED	30	76	223	2	4	6	10	26	10	3	5	3354	3360
SHIBE	39	84	211	5	5	7	10	27	7.6	1	1.3	2997	3137
ICMV 93771	38	83	165	4	4	6	8	24	7	1	1	2888	3083
SDMV 96063	35	84	181	5	3	8	9	22	9	1	1.3	2878	2967
KAT PM 1	30	75	195	1	4	6	9	20	9	1	1	2744	2943
ICMV 96603	40	85	255	1	4	8	10	22	9	1	1	2741	2887
IP 221-3	30	77	193	4	4	7	7	28	7.6	1	1	2802	2850
OKOA	41	83	188	5	4	6	8	25	7	1	1	2550	2780
IP 7390	39	83	238	1	4	7	12	31	11	1	1	2576	2780
ICMV 91450	32	85	187	5	4	7	8	19	9	4	7	2657	2746
IP7389	36	89	216	1	3	7	10	32	10	1	1	2576	2676
ICMV 94136	28	81	186	4	5	6	10	28	5	2	2.6	2445	2543
ICMV 221	29	74	214	4	4	6	7	33	9	1.3	1.3	2309	2500
KAT PM 2	35	77	165	5	4	6	9	23	8	2	6.3	2204	2437
IP 10470	39	94	235	1	3	7	11	28	8	1	1	1787	2413
SDMV 94001	36	79	208	5	4	6	6	21	8	1	5.3	2012	2353
ICMV 221 WHITE	28	77	238	5	4	5	8	22	8	2	5	2156	2277
OKASHANA 2	33	81	200	5	4	7	8	19	7	1.7	3.3	1845	1973
IP 8764	38	81	210	2	4	7	8	21	11	2.3	5	1713	1900
IP 6800	42	85	164	5	5	5	8	20	7.6	2	2.6	1527	1800
IP9989	42	89	165	1	3	6	9	21	11	2.3	3	1426	1603l

ICMV 88908	34	75	169	4	4	5	8	20	8	1	1	1407	1497
IP9976	48	95	198	4	4	5	7	21	9	1	1	1076	1195
IP 8856	46	87	155	1	6	4	7	16	9	1	1	957	1083
Range	**21-60**	**71-98**	**110-298**	**1-5**	**4-9**	**2-6**	**5-13**	**14-36**	**5-17**	**1-5**	**1-7**	**810-5203**	**940-4690**
Mean	**37**	**84**	**190**	**3**	**6.6**	**4**	**8.7**	**23**	**10**	**1.7**	**2.8**	**2358**	**2799**
CV%	**13**	**4**	**17**	**21**	**13**	**17**	**16**	**17**	**14**	**35**	**43**	**18**	**14**

KEY: Disease scoring scale, 1 to 8 scale, where score 1, <10% Head area damaged, 8>80% head area damage, where 1- highly resistant, 2-resistant, 3-4- moderately resistant, 5-6 moderately susceptible, 7- susceptible, and 8-highly susceptible; **DAF**= Days to flower, **DAM**= Days to maturity, **YLDSD=**Grain yield tons Ha^{-1}in sprayed , **YLDNSD=**Grain yield tons Ha^{-1}in non sprayed, PHT= Plant height, **DSI**= Disease incidence, **DSS**= Disease Severity, **BRD=** Bird Damage, **VT**= Vegetative tillers, **RT**=Reproductive tillers, **PDM**= Panicle Diameter, **PLT**= Panicle Length, **SWT**= Seed weight.

Genotypes showed significant variability for plant height (Fpr<.001), in this season ranging between 110-298 cm (Table 3.4 and Appendix 1). The tallest genotypes were ICMV 96603, ICMV 221 White, IP7390 IP10470, Tsholotsho Bearded, ICMV221 Bristled, IP7389, ICMV 221 with height ranging from 255-214cm (Table 3.4 and Appendix 1). Majority of the genotypes such as IP 8783 OKASHANA 2, IP9976 KAT PM 1 IP 221-3, Okoa ICMV 91450 ICMV 94136 SDMV 96063 had a height range of 205-181cm. Among the shortest were SDMV 94014 ICMV 221-1 ICMV 88908 SDMV 90031 ICMV 93771 KAT PM2 IP9989 IP 6800 IP 8856 with a range of 155 -176cm (Table 3.4). Days to maturity ranged between 71-98 days showing considerable variability (Table 3.4).Test genotypes were categorized into Super early maturing (<75 days), early (75-80 days), medium maturity (80-85 days), late (85-100 days). Super early maturing genotypes included ICMV 221, ICMV 88908 and KAT PM1. Early maturity genotypes included ICMV white, KATPM2, SDMV 9001 and ICMV221-3. Medium maturing genotypes were the majority including ICMV 94150, ICMV 93771, ICMV 96603, SDMV90031 SDMV 96063, Shibe, Okoa, IP7390 and SDMV 94014. The late maturing were mainly the IPs comprising of IP 6791, IP9986 and IP8856 (Table 3.4).

3.4.3. Head smut disease infestation and grain yield of selected pearl millet genotypes in Marigat Kenya, during short rains (Sept -Dec 2011)

Analysis of Variance (ANOVA) showed significant genotypic variation ($P \leq 0.05$) among test genotypes for all the measured traits (Table 3.5 and Appendix 3). The yield ranged between1.2 -4.9 tons ha^{-1}. The grain yields mean recorded in Marigat was 2.5 tons ha^{-1} in the diseased plots as compared to a mean of 2.7 tons ha^{-1} in the controlled experiment (Table 3.5).

There was less disease in the short rains as compared to the long rains in Marigat as was also the case in Koibatek (Tables 3.4 and 3.5). The disease severity was 2.8 in the short rains in Koibatek as compared to 2.0 in Marigat. The disease incidence ranged from 1-5 and the severity ranged from 1-6 in the short rains in Marigat among genotypes while for the same period in Koibatek the incidence range was 1-5 and severity 2-8 (Table 3.5 and 3.7). In controlled experiment genotype yields were higher compared to the non sprayed experiment. The best performing genotypes; SDMV 90031, ICMV 221-1, IP6791, IP 8783, ICMV96603, IP7390 had yield losses due to disease pressure below 5 % in the short rains but in the long rains the disease pressure on these genotypes increased to 11% (Table 3.5 and 3.7) respectively .

Table 3.5: Mean head smut disease infestation and yield parameters for selected pearl millet genotypes in Marigat (Short rains)

Genotype	DAF	DAM	PHT	BRD	VT	RT	PDM	PLT	1000SWT	DSI	DSS	YLDNSD	YLDSD
SMV 90031	24	79	187	2	5.6	4.6	10	21	14	1	1	4527	4720
SDMV 94014	23	74	245	4	4.6	3.3	7	23	12	1	1	3492	3836
ICMV 93771	30	74.6	226	4.3	5.3	4.3	8	26	12	1	1	3572	3877
ICMV 91450	22	75.5	217	5	6	4,3	10	19	12	2	3	3629	3828
ICMV 221-1	22	75	218	4.3	5	4	10	20	11	2.3	3	3302	3567
ICMV 96603	29	77	302	1	3.3	3	7	22	14	1	1	3404	3685
ICMV Bristled	23	74	240	2.3	6	4.3	11	28	11	2	3	3279	3426
KAT PM 2	21	73	256	5	5.6	3	6	22	9	1	1	3048	3272
IP 8783	25	80	227	1.3	4.6	4	8	31	1	1	1	3108	3345
KAT PM 1	26	74	212	1.3	4.6	3.3	8	25	1	1	1	3054	3272
IP 6791	23	77	228	1	5	4.3	8	26	8.4	1	1	2966	3181
ICMV 94136	37	78	158	4.6	5.3	4	7	21	13	3	5	2760	2944
IP 221-3	26	74	228	4	6.3	4.6	8	20	12	1	1	2558	3056
IP 7390	26	77	218	1	4.3	3.6	11	31	12	1	1	2609	2885
Tsholotsho	30	76	258	1.3	5.3	4a	9	24	8	1	1	2603	2878
IP7389	31	74	257	1	7	4.6	10	35	1	1	1	2432	2682
SDMV 96063	31	76	215	5	6	4.6	9	25	11	1	1	2549	2787
SHIBE	26	77	245	5	6.3	4	9	25	12	1	1	2398	2528
221 WHITE	31	75	155	5	5.3	3.6	9	22	12	6	8	2216	2433
ICMV 221	29	73	195	4.3	6.3	4	7	20	12	2	1	2229	2414
OKOA	22	75	241	5	4	4	8	32	10	1	1	2035	2314
IP9989	31	74	192	1.6	6	5	10	30	7	1	1	1995	2294
IP 8764	22	74	193	2f	4.6	3.6	10	25	11	2	4.6	1970	2266
Okashana 2	31	76	225	5	5.6	3.6	7	20	8.6	1.3	1.3	2024	2213
IP 10471	28	79	212	1	5	4	9	27	8	1	1	2021	2209
ICMV 88908	23	72	182	4.6	6.3	4.3	9	28	10	1	1	1921	2095
IP 6800	24	75.5	228	5	5.6	3.6	8	23	10	2	4	1811	2082
IP 8856	22	76	261	1.6	4.6	3.6	9	23	8	1	1	1699	1839
SDMV 94001	32	75	175	5	7.3	3.6	9	21	8	5.7	8	1591	1714

IP9976	30	81	232	4.3	6	4.3	9	26	10	1	1	1270	1461
Range	**21-38**	**70-80**	**129-305**	**1-5**	**3-8**	**2-5**	**6-14**	**15-38**	**5-17**	**1-6**	**1-8**	**1179-4996**	**1356-5745**
Mean	**27**	**76**	**219**	**3**	**5.3**	**3**	**8**	**24**	**10**	**1.5**	**2**	**2542**	**2693**
CV%	**11**	**2**	**8**	**21**	**14**	**16**	**14**	**16**	**16**	**28**	**39**	**15**	**15**

KEY: Disease scoring scale, 1 to 8 scale, where score 1, <10% Head area damaged, 8>80% head area damage, where 1- highly resistant, 2- resistant, 3-4- moderately resistant, 5-6 moderately susceptible, 7- susceptible, and 8-highly susceptible **DAM**= Days to maturity; **DAF**= Days to Flowering means; **YLDSD=**Grain yield tons Ha^{-1}in sprayed, **YLDNSD=**Grain yield tons Ha^{-1}in non sprayed, **PHT**= Plant height, **DSI**= Disease incidence**, DSS**= Disease Severity**, BRD**= Bird Damage, **VT**= Vegetative tillers, **RT**= Reproductive tillers**, PDM**= Panicle Diameter, **PLT**= Panicle Length, **SWT**= Seed weight.

As compared to Koibatek the disease pressure on yields in Marigat short rains was lower ranging from 1-5 % amongst the best genotypes as compared to 5-10 % in Koibatek for the same season. The commercial checks ICMV221, KATPM1 and KATPM2 had yield losses due to the diseases pressure of ranging from 3%-4% as compared to the susceptible genotypes SDMV 94014 and SDMV 94001 with yield losses of 6% and 13% respectively.

ICMV 221 and ICMV 221 White were the earliest to mature taking 72 and 73 days respectively (Table 3.5). However in Marigat all the genotypes took a shorter time to mature with a range of (70-80 days) and a mean of 76 days as compared to Koibatek with a range of (71-98 days) and an average of 84 days (Table 3.3). There was significant variability for plant height (cm) Fpr<.001, ranging between 129-205 cm and a mean of 219cm (Table 3.5 and Appendix 3) with genotypes ICMV 96603, Tsholotsho, IP7390, IP7389 KAT PM2, SDMV 94014 being the tallest, 305,261,258,257,256,245, respectively (Table 3.5 and Appendix 3). Days to maturity (DAM) ranged from 71 to 98 days showing considerable variability (Table 3.5).

Test genotypes were categorized into super early maturing (<75 days), early (75-80 days), medium maturity (80-85 days), late (85-100 days).The results showed that among the Super early maturing genotypes in Marigat during the short rains included ICMV 221, ICMV 88908 and KAT PM1, ICMV white, KAT PM2, SDMV 9001, ICMV221-3, Okoa, KAT PM1, ICMV91450,ICMV Bristled and ICMV 221-1. Early maturity genotypes were ICMV96603, SDMV96063, Shibe, IP 6791, IP 10471, IP7390, Tsholotsho Bearded, and IP 7389 among others. The medium maturing genotypes were the least including IP9976,IP8783 and IP8856 (Table 3.3) None of the genotypes matured after 85 days in Marigat during the short rains hence there were no genotypes classified as late maturing. Generally all genotypes took long to mature in Koibatek with a mean of 84 days for the short rains as compared to Marigat with a mean of 76 days (Table 3.4 and Table 3.5)

3.4.4 Effect of head smut disease infestation and yield performance of selected pearl millet genotypes in Koibatek Kenya, during long rains

There was significant genotypic variation ($P \leq 0.05$) for all the traits measured among genotypes (Table 3.4 and Appendix 2). These included grain yield (ton ha^{-1}), plant height, days to first flower, days to maturity and disease incidence and severity. A wide range for

yield (0.8 - 4.9 tons ha^{-1}) was observed among the genotypes. The mean grain yield was 2.4 tons ha^{-1} while in the short rains it was 2.3 tons ha^{-1} (Table 3.3 and 3.5).

The disease incidence ranged from 1-5 in the short rains while in the long rains it increased to 1-8 for this site in the long rains. In the controlled experiment genotype yields were higher compared to the non sprayed experiment. The best performing genotypes; SDMV 90031, ICMV 221-1, IP6791, IP 8783, ICMV96603, IP7390 had yield losses due to disease pressure increase to 8 % - 11%.

The commercial checks ICMV221, KATPM1 and KATPM2 had yield losses due to the diseases pressure ranging 6%- 8% in the long rains as compared to their reaction to the disease in the short rains with losses of 4% -5%. Susceptible genotype SDMV 94014 and SDMV 94001 had yield losses of 11% and 14% respectively in the short rains compared to their losses in the long rains which increased to18% and 21% respectively. Disease severity increased in the long rains so was the yield losses due to the disease pressure. The only genotype that matured in less than 75 days and classified as super early in Koibatek for the long rains was ICMV221-3 (Table 3.6). The early maturing were ICMV 221, ICMV WHITE, KATPM2, ICMV Bristled ICMV 88908 taking between 76-80 days to mature (Table 3.5). The medium maturing were the majority and included Okoa, Shibe, Tsholotsho bearded, SDMV90031, IP7390, IP6791, IP7389, ICMV 96603, and ICMV93771 maturing between 80- 90 days. The late maturing were very few ICMV94150, IP10471 and IP 9976 taking between 90-100 days to mature (Table 3.5).

Bird damage ranged from1-5 with and an average of 3 in Koibatek for the long rains. Tested genotypes also showed significant variability for plant height (Fpr<.001), ranging between 110-298 cm (Table 3.5 and Appendix 12). The IP genotypes were among the tallest for example the IP10471, IP7390,IP 7389 and some of the ICMVs like the ICMV 221 white, ICMV221 Bristled, and Tsholotsho Bearded were also among the tallest (Table 3.5 and Appendix 12).

Table 3.6: Mean head smut disease infestation and yield parameters for selected pearl millet genotypes in Koibatek (long rains)

Genotype	DAF	DAM	PHT	BRD	VT	RT	PDM	PLT	1000SWT	DSI	DSS	YLD SD	YLD NSD
SDMV 90031	41	84	188	3	7	6	6	24	7	1	1	4334	4697
ICMV bristled	30	76	228	3	6	5	12	23	11	3	5	4069	4217
ICMV 221-1	25	83	188	5	6	5	8	21	9	4.3	6	3561	3951
SDMV 94014		82	185	5	7	5	9	18	7f	1	1	3560	3763
IP 6791	41	86	213	3.6	5	3	8	22	6.9	1	1	3414	3740
IP 8783	42	89	232	5	9	5	11	31	12	1	1	3189	3403
ICMV 221-3	30	74	206	4.3	7	6	9	19	8	1	1	3074	3280
TSHOLOTSHO	41	87	273	1.6	7	6	7	25	5	1	1	2996	3193
KAT PM 2	35	76	195	5	7	6	8	22	9	1	1	2554	3033
SDMV 96063	35	84	195	4	9.3	6	10	22	9	1	1	2747	2987
KAT PM 1	30	75	195	1	7	5	9	19	10	1	1	2636	2857
ICMV 94136	28	81	192	4.6	7	6	10	19	9	2	5	2488	2627
SDMV 94001	36	79	220	5	7	6	8	22	6	4	5	1961	2480
ICMV 96603	40	85	254	4	8	6	10	24	10	1	1	2446	2733
IP 7390	39	83	242	1	8	7	11	30	10	1	1	2418	2643
ICMV 93771	38	82	188	5	7	6	7	25	6	2	5	2497	2702
SHIBE	39	84	182	5	7	6	10	27	9	1	1	2356	2697
ICMV 91450	32	88	215	5	8	7	9	18	7	4.4	7	2342	2600
OKOA	41	83	208	5	7	5	9	26	7	1	1	2300	2603
ICMV 221	29	76	168	3.6	7	5	9	19	10	1.3	3	2127	2347
IP 8764	38	80	186	1.6	8	6	10	19	11	3	7	2025	2213
ICMV 221 WHITE	28	77	235	5	7	5	8	24	6.9	2.6	7	1962	2101
IP7389	36	83	254	1	7	6	8	34	7	1	1	1842	2173
IP 6800	42	85	178	3.6	8	6	8	29	7	2	7	1724	1993
IP 10471	39	94	223	3	8	5	12	30	11	1	1	1671	1883
OKASHANA 2	33	80	256	5	7	6	8	18	9	3,3	3	1643	1943l
IP9989	42	89	182	1.6	7	6	11	23	12	3	4	1386	1577

ICMV 88908	34	76	193	5	1	7	8	18	6.5	1	1	1372	1557
IP9976	48	96	211	3	7	5	9	20	10	1	1	1292	1600
IP 8856	46	88	183	1.3	10	6	11	21	11	1	1	1104	1390
Range	**21-60**	**70-98**	**115-290**	**1-5**	**4-12**	**3-8**	**5-13**	**13-38**	**4.5-13**	**1-7**	**1-8**	**813-4979**	**1100**
Mean	**37**	**83**	**208**	**3.6**	**7.5**	**6**	**9**	**22**	**9**	**2**	**3**	**2439**	**2931**
CV%	**13**	**4**	12	**13**	**13**	**16**	**14**	**16**	**16**	**33**	**23**	**12**	**11**

KEY: **Disease scoring scale**, 1 to 8 scale, where score 1, <10% Head area damaged, 8>80% head area damage, where 1- highly resistant, 2-resistant, 3-4- moderately resistant, 5-6 moderately susceptible, 7- susceptible, and 8-highly susceptible. **DAM**= Days to maturity; **SC**=susceptible check; **RC=**Resistant check; **YLDSD=**Grain yield tons Ha^{-1}in sprayed, **YLDNSD=**Grain yield tons Ha^{-1}in non sprayed PHT= Plant height, DSI= Disease incidence, **DSS**= Disease Severity, **BRD**= Bird Damage, **VT**= Vegetative tillers, **RT**= Reproductive tillers, **PDM**= Panicle Diameter, **PLT**= Panicle Length, **SWT**= Seed weight.

3.4.5. Head smut disease infestation and grain yield of selected pearl millet genotypes in Marigat Kenya, during short rains (Sept -Dec 2011)

There was significant genotypic variability ($P \leq 0.05$) for all the traits (Table 3.7) measured among genotypes in respect to yield, and disease parameters in Marigat for the long rains. The yield in tons ha^{-1} ranged between 1.1-4.4 in this season with a mean of 2.3 tons ha^{-1} as compared to Koibatek with a range of 0.8-4.9 ha^{-1} and a mean grain yield of 2.4 tons ha^{-1} (Table3.5 and 3.7).

The disease severity mean was 2.0 and ranged between1-6, while the incidence ranged from 1-5. In the controlled experiment genotype yields were higher compared to the non sprayed experiment. The best performing genotypes; SDMV 90031, ICMV 221-1, IP6791, IP 8783, ICMV96603, IP7390 had yield losses due to disease pressure increase from the short rains with yield percent losses ranging from 5-10%. The commercial checks ICMV221, KATPM1 and KATPM2 had yield losses due to the diseases pressure of 10%, 7%, and 7% as compared to 3%, 3%, and 4% losses that were experienced in the long rains (Table 3.5 and 3.7). Susceptible genotype SDMV 94014 and SDMV 94001 had yield losses of 15% and 9% in the long rains as compared to 6% and 13% in the short rains (Table 3.5 and 3.7).

ICMV221, 221 Bristle ICMV white matured early in Marigat in this season taking the shortest time in all the seasons and sites with a range of (73- 75 days). All the genotypes took a shorter time to mature in Marigat as compared to Koibatek with a range of 70-80 days and a mean of 76 days. There was significant variability for plant height (cm) Fpr<.001, ranging between 129-205 cm and a mean of 219cm, The tallest genotypes in the short rains were ICMV 96603, Tsholotsho, IP 8856, ICMV93771 attaining heights ranging from 256-299cm (Table 3.7 and Appendix 10). All the genotypes attained the highest heights in Marigat than in Koibatek for both the seasons (Table 3.3).

Table 3.7: Mean head smut disease infestation and yield parameters for selected pearl millet genotypes in Marigat (long rains)

GENOTYPE	DAF	DAM	PHT	BRD	VT	RT	PDM	PLT	SWT	DSI	DSS	YLDS	YLDNS
ICMV 221	25	73	245	5	7	6	8	22	9	1	1	3224	3569
ICMV 221													2442
White	31	75	168	5	5	4	9	24	8	6	8	2169	
ICMV 91450	26	76	213	5	6	5	10	18	9	2	3	3601	3778
ICMV 93771	27	75	256	4.3	5	4	8	23	7	1	1	3804	4253
ICMV 96603	28	77	299	4.3	5	4	8	24	9	1	1	3590	3882
KAT PM 2	21	73	228	5	6	6	7	16	8	1	1	3132	3367
OKASHANA 2	32	77	241	5	6	4	9	23	7	2	2.3	2640	2762
OKOA	23	75	245	5	6	5	9	33	7	1	1	2696	2827
SDMV 90031	28	79	208	2	7	5	9	23	10	1	1	4705	4962
SDMV 94001	32	75	205	5	7	5	10	22	8	6	8	1562	1844
SDMV 94014	22	74	243	4	5	3	7	24	6	2	7	2839	3114
SDMV 96063	30	76	223	5	9	5	10	26	9	1	1	2839	3174
SHIBE	26	77	240	5	7	5	9	25	7.6	1	1	2553	3012
Tsholotsho	29	76	276	1.3	7	5	9	23	7.6	1	1	2804	3073
ICMV Bristled	21	74	244	1.6	6	5	10	35	10	2	3.3	2492	2704
IP 10471	28	79	223	1	6	5	9	29	8	1	1	2149	2417
IP 7390	26	77	228	1.3	6	5	12	36	11	1	1	2849	3007
IP 8764	22	74	213	2	7	5	11	23	11	3	5.6	2208	2606
IP 8783	25	80	226	1.3	7	4	9	30	1	1	1	3249	3597
KAT PM 1	25	74	218	1.2	6	5	8	24	9	1	1	2808	3014
IP 6791	23	77	233	3.6	6	5	8	27	7	1	1	2992	3294
IP7389	32	77	230	1	6	5	11	37	10	1	1	2350	2655
ICMV 88908	22	73	181	4.6	9	7	10	27	8	1	1	1868	2208
IP9976	29	81	233	4.3	7	5	8	25	9	1	1	1236	1459
ICMV 94136	37	78	163	4.6	6	5	6	20	5	4.6	7	2849	3007
ICMV 221-1	25	77	205	4.3	7	7	11	20	12	3	5	3475	3746
IP 6800	23	75	233	5	7	6	8	25	7.6	2	6	1931	2278
IP9989	25	77	198	1.6	6	5	11	29	11	2	5	2695	2826
IP 221-3	25	74	220	4.6	7	6	8	20	7.6	1	1	2910	3433
IP 8856	22	76	265	1.6	6	5	8	22	9	4.6	7	1660	1958
Range	**21-38**	**70-84**	**145-304**	**1—5**	**4-12**	**3-9**	**6--13**	**15-37**	**5-17**	**1-5**	**1-8**	1000-	1180- 5127

													4345	
Mean	**27**	**76**	**226**	**3.5**	**6**	**5**	**9**	**24**	**10**	**2.1**	**2.6**	**2324**	2859	
CV%	**12**	**2**	**8**	**21**	**15**	**18**	**12**	**15**	**14**	**30**	**36**	**12**		**12**

KEY: Disease scoring scale, 1 to 8 scale, where score 1, <10% Head area damaged, 8>80% head area damage, where 1- highly resistant, 2-resistant, 3-4- moderately resistant, 5-6 moderately susceptible, 7- susceptible, and 8-highly susceptible. **DAM**= Days to maturity; **DAF**= Days to Flowering; **YLDSD=**Grain yield tons Ha^{-1}in sprayed, **PHT**= Plant height, **DSI**= Disease incidence, **DSS=** Disease Severity**, BRD**= Bird Damage, **VT**= Vegetative tillers, **RT**= Reproductive tillers, **PDM**= Panicle Diameter, **PLT**= Panicle Length, **SWT**= 1000 Seed weight in grams .

3.4.6. Estimation of yield loss of test genotypes for both sites and seasons combined (2011/2012)

The grain yield loss was determined by comparing the yield achieved under sprayed with that in the non sprayed experiment as presented in Table 3.8. The overall yield in both sites for both seasons was 20%. The highest yield loss of 28% was recorded in Koibatek during the long rains and 18% in the short rains hence an average yield loss of 23%. Slightly lower yield losses of 14% and 21% in Marigat were recorded with an average of 17.5%. More yield losses were observed in the long rains 23% as compared to 16% in the short rains in both sites combined.

Table 3.8: Mean percentage yield loss for tested genotypes in sprayed and non sprayed experiments for both sites and seasons combined

	% yield loss short rains	% yield loss long rains	Overall % yield loss
ATC-Koibatek	18	28	23
KALRO Marigat	14	21	17.5
Overall % yield loss	16	24.5	20.25

3.4.7. Estimation of yield loss for test genotypes in both sites and seasons combined

Based on yield loss in unprotected plots as compared to protected plots the percent yield loss ranging from 2%-34% were recorded (Table 3.9). The best performing and promising genotypes SDMV 90031, ICMV221-1, IP 8783, IP6791 ICMV96603 and IP7390 were significantly different in response to the disease severity and yield loss. SDMV 90031 had minimal yield losses of 3% with disease severity of 10% while ICMV 221-1 had yield losses of 8% with 45% disease severity while ICMV 96603 had only 4% yield loss with a disease severity of 10 %. IP8783 and IP 6791 were highly resistant recording yield loses of 2% and 10% respectively both with disease pressure of 10%.

The commercial resistant checks ICMV 221, KAT PM1, KATPM2 had <8% of yields losses all with an average disease severity of 10% hence they maintained their resistance resistant (Table 3.9). The susceptible checks SDMV 94014, SDMV 94001 had the most yield losses of 34% and 29% respectively with disease severity of 78% and 65%. Other genotypes that lost significant yield due to the disease are ICMV 221 White, SDMV 96063, ICMV 94136 and IP 8856 with yield loss ranging from15%-30% and disease severity of 30-70% (Table 3.9).

Table 3.9: Estimation of yield loss for test genotypes in both sites and seasons combined

Genotype	% DSS	YLD NS	YLDS	GYL	%GYL loss
SDMV 94014	78	2556	3858	1302	34
SDMV 94001	65	1845	2598	753	29
IP 10470	60	1882	2518	636	25
ICMV 94136	46	2260	2780	520	19
221 WHITE	70	1867	2613	746	29
SDMV 96063	72	2056	2913	857	29
IP 6791	10	3172	3523	351	10
ICMV 221-1	45	3482	3793	311	8
IP 221-3	10	2886	3155	269	9
OKOA	10	2370	2638	268	10
IP 7390	10	2654	2829	175	6
KAT PM 1	10	2833	3096	263	8
OKASHANA 2	25	1963	2223	260	12
IP7389	10	2179	2438	259	11
IP9989	30	1825	2075	250	12
IP 8764	55	2004	2246	242	11
IP 6800	50	1798	2038	240	12
IP 8856	30	1330	1568	238	15
ICMV bristled	40	3199	3427	228	7
ICMV 221	21	2498	2707	209	8
ICMV 88908	10	1642	1838	196	11
IP9976	10	1218	1383	165	12
ICMV 93771	20	3115	3279	164	5
ICMV 96603	10	2970	3097	127	4
SDMV 90031	10	4171	4294	123	3
SHIBE	10	2726	2843	117	4
KAT PM 2	23	2835	2939	104	4
IP 8783	10	3184	3265	81	2
ICMV 91450	50	2932	3013	81	3
TSHOLOTSHO	10	2883	2940	57	2
Range	10-78	810-5203	940-5745	57-691	2-34
Mean	**30**	**2478**	**2798**	**320**	**12**

Key: % DSS = Percent severity, **YLDNS**= Yield in diseased Non Sprayed plots, **YLDS**=Yield in Sprayed plots, **GYL**= Total grain Yield Loss, **%GYL**=Percent Grain Yield Loss

3.4.8 Genotypes classification for resistance/susceptibility to head smut in both sites

Based on disease severity (%) the genotypes were grouped into six categories which included; highly resistant (HR) with < 10% disease infection, resistant (R), 11-30% florets infected, 31-40% florets infected moderately resistant (MR), between 40-50% moderately susceptible (MS), 51-70% florets infected susceptible (S) and 71-100% floret infected as highly susceptible (HS) **(**Table 3.10)

The most resistant genotypes were SDMV90031, IP8783, IP6791, IP7390, KAT PM1, ICMV96603, SHIBE, IP7389, IP10470, and Okoa among others. The resistant were ICMV9771, ICMV221, KAT PM2, IP 9989 and Okashana 2 among others. ICMV221 Bristled was moderately resistant with disease infection at 40% while ICMV 94136, ICMV91450, and IP6800 were moderately susceptible. ICMV 221 White was susceptible with disease infection of 70%. SDMV 94001 was susceptible while SDMV 94014 was highly susceptible (Table 3.10)

Table 3.10: Classification of genotypes for resistance/susceptibility to head smut disease

Genotypes	Category reactions
SDMV 90031, P8783, IP6791 IP7390, OKOA, KATPM1,	Highly resistant
ICMV 96603, SHIBE, IP7389, IP1070, ICMV 221-3,	
ICMV93771, ICMV221, KATPM2, Okashana2, Tsholotsho	Resistant
Bearded, ICMV 88908,IP 9976, IP 8856	
ICMV 221 Bristled, ICMV 221-1, ICMV91450, ICMV	Moderately resistant
94136	
ICMV 94136, IP6800, IP 8764,	Moderately susceptible
SDMV 94001, ICMV White,	Susceptible
SDMV 94014, SDMV 96063	Highly Susceptible

3.4.9 Correlation coefficient of yield, yield components, disease incidences and severity of genotypes in both seasons and sites combined

Significant ($P \leq 0.05$) and inverse correlation (*r*), was observed between grain yield and head smut incidence and severity (*r*=-0.5* and -0.76*), respectively (Table 3.11). There was also a significant inverse correlation between the grain yield and the days to maturity (*r*=-0.42*) (Table 3.11). Positive significant correlation was observed between the thousand seed weight and grain yield in both the protected experiment (*r*=0.52*) and non protected experiment(*r*= 0.48*). Significant ($P \leq 0.05$) and positive relation was also observed between reproductive tillers *(r* =0.04*), with grain yield, (Table 3.9). Positive relationship between the presence of bristles and bird damage was observed (*r*=0.8*) (Table 3.11).

Table 3.11: Correlation coefficient for yield parameters and disease scores in both sites and seasons combined

	1000S	BD	BRSTLS	DM	DSI	DSS	RT	VT	YNS	YS
1000 S	1									
BRD	-0.03*	1								
BRTLS	0.03*	0.8*	1							
DAM	-0.13*	-1*	-0.13*	1						
DSI	-0.17*	-0.2*	-0.14*	-0.7*	1					
DSS	-0.22*	-0.3*	-0.16*	-0.8*	0.8*	1				
RT	-0.39*	-0.6*	-0.22*	-0.1*	-0.2*	-0.46	1			
VT	-0.44*	-0.7*	-0.24*	-0.1*	-0.33*	-0.61*	0.05*	1		
YLD_N,S	0.48*	-0.8*	-0.25*	-0.1*	-0.42*	-0.76*	0.04*	-0.01*	1	
YLD S	0.52*	-0.9*	-0.27*	-0.1*	-0.5	-0.91*	0.03*	-0.02*	-0.13*	

KEY: 1000S= A thousand seed weight **DM**=Days to maturity: **BD**=Bird damage: **BRSTLS**= Presence or absence of Bristles **DSI**= Disease incidence **DSS**= Disease Severity Reproductive tillers **VT**= Vegetative Tillers **YNS**= Yield in non sprayed experiment **Y S**=Yield in the sprayed.* significant at ($P \leq 0.05$ ** significant at ($P \leq 0.001$).

3.4.10: Principal component analysis (PCA) for yield and yield component in test genotypes sites and seasons combined

The genetic diversity of 50 pearl millet genotypes was observed for their yield parameters as a requirement for the pre-selection of varieties for future breeding programs. The principal component analysis grouped the characteristics into grain yield in sprayed and none sprayed experiments, Days to maturity, plant height, resistance to bird damage, 1000 grain weight and the panicle characteristics. The combined analysis of data in both sites showed that four principal components explained 81% variation present within the genotypes (Table 3.11).

PCA 1 accounted for 27.7% of variation and was positively associated with grain yield in the sprayed and non sprayed experiment (0.31), reproductive tillers (0.28), and 1000-grain weight (0.19), and days to maturity (0.39). However, PCA 1 was negatively related to disease incidence (-0.32), disease severity (-0.31), and bird damage (-0.24). PCA 2 accounted for 19.1% of variation. It was positively associated with panicle length and diameter 0.16 and 0.09 respectively, reproductive tillers (0.07, and plant height (0.32). PCA 2 was also negatively related to disease incidence (-0.037), disease severity (-0.39) and bird damage (-0.07). The 3rd and the 4th PCA accounted for 18.5% and 15.6% respectively (Table 3.11). The sign indicates the direction of relationship between the components and the variables. Those with appositive sign indicate that the variables are positively related to the PC while those with a negative sign are negatively related to the PC (Broschat, 1979).

Table 3.12: Principal component analysis (PCA) for yield and yield components in both sites and seasons combined

PC	EV	IND%	Cm%	1000 SWT	BRD	DAF	DAM	DSI	DSS	YN S	YL	PHT	VT	RT	PLT	PDM
1	3.59	27.7	28	0.19	-0.24	0.43	0.39	-0.32	-0.31	0.31	0.31	0.12	0.18	0.08	0.28	0.22
2	2.47	19.1	47	0.37	-0.07	-0.07	-0.02	-0.37	-0.39	0.46	0.45	0.32	0.09	0.07	0.16	0.09
3	2.05	18.5	65	0.09	-0.25	0.16	0.21	0.20	0.20	0.10	0.12	0.14	-0.54	-0.57	0.22	0.27
4	1.45	15.6	81	0.29	-0.19	-0.19	-0.10	0.28	0.26	-0.01	-0.05	-0.19	0.30	0.30	0.33	0.61

Key PC= Principal component, EV= Eigenvalue, IND= Individual %, CUM =Cumulative%, 1000 SWT= A thousand seed weight, BRD= Bird damage, DAF= Days to flowering, DAM= Days to Maturity, DSI= Disease incidence, DSS= Disease severity, YNS=Grain yield Non sprayed experiment, YS= Yield in sprayed experiment, PHT= Plant Height, VT= Vegetative tillers, RT=Reproductive tillers, PLT= Panicle Length, PDM = Panicle Diameter

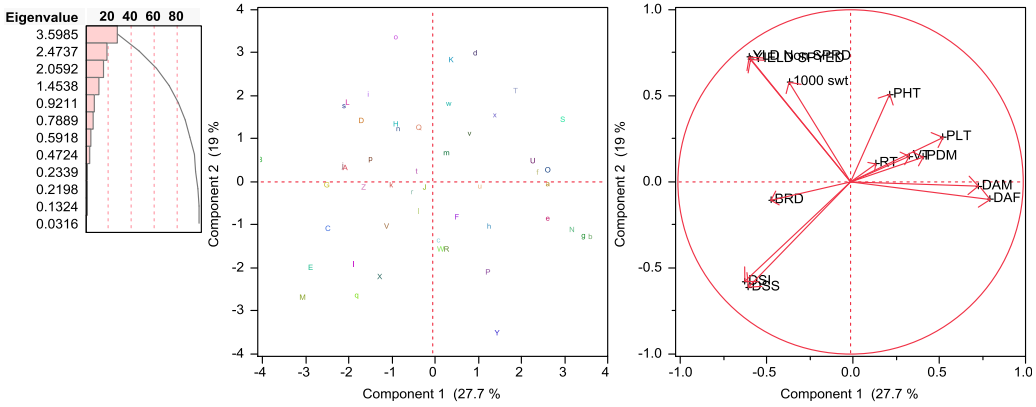

Figure 3.1: Principal Component score plot of PC1, PC2, PC3 and PC4 describing the overall variation among Genotypes estimated using yield components data.

3.5 Discussion

3.5.1. Genotypic performance of test genotypes in both sites.

The findings of the study generally show that there was more head smut disease infestation in Koibatek as compared to Marigat. This was due to high humidity and rainfall amounts in Koibatek as compared to Marigat that was fairly dry. During both the short brains and the long rains, Koibatek received more rainfall than Marigat (Appendices 12 and 13). The results also show that some genotypes were not affected in both the sites while some genotypes were consistently attacked in both the sites for both the seasons. The resistant commercial checks were not affected in both sites and seasons while the susceptible checks were severely affected in both the sites and seasons.

The combined analysis showed that the genotypes differed highly significantly for disease severity, grain yield (kg/ha), days to 50% flowering, plant height, 1000- grain weight, significant days to maturity, plant height and bird damage (Table 3.3). Similar patterns of variability were also reported by Salih *et al*., (2014) and Abuali *et al*., (2012) where they noted that great variability among genotypes are revealed in grain yield indicating the possibility to increase grain production through selection. The promising genotypes identified in this study will provide valuable sources of resistance to head smut and for other consequent breeding activities in pearl millet improvement**.**

Crop performance which is the observed phenotype is a function of genotype, environment and genotype by environment interaction. Genotype by environment interaction is said to occur when different cultivars or genotypes respond differently to diverse environments

(Crossa, 1990). This study thus evaluated fifty pearl millet genotypes in two different environments over two seasons to establish sources of smut resistance and high yield. Knowing the effect of genotype by environment interaction, as well as the estimate of its magnitude relative to the magnitude of genotype and environment effects is very important for efficient evaluation and selection of genotypes. The importance of evaluating many potential genotypes in different environments before selecting desirable ones for release and commercial cultivation has been recognized by breeders (Gupta and Ndoye, 1991). A desirable genotype is one that does not only yield well in its area of initial selection, but also maintains the high yielding ability over a wide range of environments within its intended area of production (Yadav,1996). There were also varying yield losses due to disease pressure among genotypes. Overall mean yield for the short and long rains in the two sites was 2.95 ha^{-1} tons for the sprayed experiment and 2.39 tons ha^{-1} in the diseased plots (Table 3.3) this showed that the disease reduced the yield by 18% similar results were observed by Meena *et al*., (2011).

The two growing seasons in the two sites over which the 50 pearl millet genotypes were evaluated provided a wide range of conditions to assess how grain yield performance and disease severity affected the crop performance Combined analysis of variance showed that the Genotype and location main effects and the genotype by environment interaction were highly significant ($P \leq 0.05$) for grain yield and other traits, indicating differential response of pearl millet genotypes across testing locations and the need for stability analysis such results were also reported by Wedajo, (2014). SDMV90031, ICMV 221-1, ICMV 221 Bristled, IP 8783, IP 6791, SDMV 94014 , ICMV 91450, ICMV221-3, KATPM1, KATPM2, Shibe, SDMV96063, ICMV96603, IP7390, were the best performing in both the sites thus are recommended for further selection and trials across other pearl millet growing regions before they can be commercialized.The varying conditions also provided possible ways of identifying high yielding and smut tolerant genotypes that could be selected for commercial production and in gene introgression, and possible traits that could be expressed during disease resistance and also genotypes that are staple across the environments in both grain yield and disease resistance described by Victor *et al*, (2004).

In the sprayed experiment the genotypes yielded more than the diseased (non sprayed) experiment with an average of 18% yield losses (Table 3.3) an average of these yield losses were also reported by Meena *et al*, (2011).The pooled analysis of variance showed that

genotypes, seasons and sites had significant effects on most measured traits. This demonstrates that the two seasons and two sites exerted different effects on the set of tested genotypes, which was probably due to variability in seasonal rainfall distribution and amounts. The interactions were probably because of differences in weather changes (mainly rainfall) at different sites and seasons, which influenced the genotypes to respond differently. For example, in 2011 (Aug-Nov) 2012 and (March-Aug) growing period), at ATC and Marigat, the crop received a total rainfall of 211mm and in 2012 (March-June) growing season the same location received a total of 334.9mm, while in Marigat short rains 2011 the crop received a total of 123mm and 192mm in the long rains (March –June 2012). In 2011/12, growing seasons, at ATC which is higher, cooler and wetter than Marigat rainfall received increased to 660mm (2010) and 530mm (2012), while in Marigat rainfall received also increased to 427mm (2011) but reduced to 264mm in 2012 (Appendices 12 and 13).

From the rainfall data during the two growing periods it shows that Koibatek was wetter and humid compared to Marigat during both the growing seasons, hence the reason for more disease development in this site. Similar results were also reported by Syed and Yasen, (2013) for head smut. The results also revealed that the virulence of the disease in pearl millet was affected by days to maturity of the crop to some extent. Early and late maturing genotypes were mostly affected unlike the medium maturing as was discovered also by Siddig *et al,* (2014). Medium maturing genotypes escape infection because they flower when disease spores and inoculum concentration is low. Such genotypes are described as resistant by escape mechanism (Siddig *et al*., 2014).

Other challenges in Marigat that affected the grain yield were insect pests and bird damage. These were more severe compared to Koibatek. Highly significant genotypic x environmental (GE) interaction, Fpr<.001 (Appendix 6) was observed for all the traits measured across the environments showing the importance of carrying out multi environmental trials across the sites and different agro-ecological zones to establish suitable environments for such genotypes. Thakur *et al*., (1986) reported similar results when an evaluation of a different set of pearl millet genotypes across different environments.

Significant genotypic by season interaction (G×S) was also observed (Appendix 4 and5) across the long and short rains in both the sites for all the traits studied. Differences in performance across sites and seasons indicate that genotypic differences exist in adaptation.

Individual genotypes are also environment specific in adaptation and hence the need to carry out adaptation trials across the environments (Thakur *et al*, 1986).

Different genotypes responded differently to bird damage. Generally genotypes with bristles were less affected by bird as compared to those without any bristles. Genotypes IP7390, IP7389, IP 10470 and Tsholotsho Bearded have conspicuously long bristles and they were not affected by birds attaining 100% grains yield per panicle where genotypes without any bristles were damage up to 100 % grain loss per panicle such genotypes included ICMV221, KAT PM1 ,KAT PM2 Shibe and Okoa. However some genotypes with medium length bristle such as SDMV 90031, IP 8764 and IP 8856 were not badly damaged with damages ranging from 20-50 % (Table 3.3).

It was noted that birds preferred the genotypes without bristles as compared to those with bristles because the bristles types caused them trouble while feeding by puncturing their eyes. It is thus important to note this trait in pearl millet breeding considering the fact that birds cause high yield losses that goes up to 100% in Baringo Kenya where farmers grow pearl millet in isolation and the commercial released varieties don't have bristles. This is the most single important factor that discourages farmers from growing pearl millet in Kenya. The Bristles genotypes genes could be introduced to the high yielders and disease resistant genotypes to maximize yields.

3.5.2. Genotypic responses to the disease infection in the field

A consistent trend in response to the disease was noted and grain yield performance was observed for some genotypes. In the sprayed experiment with no disease pressure the yields were much higher compared to the non sprayed experiment Overall mean yield for short and long rains in the two sites was 2.95 ha^{-1} tons for the sprayed experiment and 2.39 tons ha^{-1} in the diseased plots Table 3.3. This confirms results by Thakur (1989) that smut cause yield losses of between 15-60 % in pearl millet productivity. In individual genotypes the disease pressure had different results for every genotype.

According to Rao *et al*., (2006) pearl millet genotypes can be grouped into six groups in relation to their reactions to head smut disease. Head smut disease causes significant yield losses to susceptible genotypes compared to resistant genotypes. The most resistant genotypes had less than 10% infected florets with only less than 10% disease incidence thus

causing insignificant yield losses with SDMV 90031 having the minimum yield loss of 0.5% , and IP 6791, IP 8783, ICMV 93771, IP7390 with yield losses of 1.5%, 2.4% , 5.2%and 6% respectively. The susceptible genotypes on the other hand had the greatest yield losses with SDMV 94001, SDMV 94014, SDMV 96063 and ICMV White having yield losses of 26%, 19%, 15% and 20% respectively. Genotypes like ICMV 221-1 was high yielding but susceptible to head smut disease such genotypes should be considered for further breeding with other genotypes that showed high disease resistance but very poor in yield like IP 9989, ICMV88908, IP8856 these genotypes carry the gene for resistance to the disease but poor in yield performance.

3.5.3 Yield losses due to Head smut disease on genotype in both sites and seasons combined

The overall percentage yield losses from to the disease severities are summarized in Table 3.8. The overall yield loss due to disease in both sites for both seasons was 20%. The highest yield loss of 28% was observed in Koibatek during the long rains and 18% in the short rains giving an average yield loss of 23% for this site. There were low yield losses of 14% and 21% in Marigat for the short and long rains respectively giving an average of 17.5% yield losses in this site. More yield losses were observed in the long rains 23% as compared to 16% in the short rains.

Overall grain yield losses (20%) were observed when data was pooled and combined for both Koibatek and Marigat. Higher yield losses in Koibatek (28%) were observed compared to Marigat (21%). High humidity and disease severity and the pressure could have caused these high yield losses such results were also discovered by Rao *et al*., (2006). Yield losses ranging from 14-28% are close to those recorded by Jain *et al*., (1997) who observed 6 – 40%. The commercial checks ICMV 221, KAT PM1, KAT PM2 lost 8%, 4 %, 8% of yields respectively all with average disease severity of 10% the checks were thus resistant. Maximum loss in grain yield resulted from high incidence and severity of the disease as also evident from disease severity per genotype such results were also reported by Salih *et al*., (2014). This was true for the highly susceptible genotypes SDMV 94014, SDMV 94001 with the highest severity of 65 and 78% and yield losses of 29% and 34% respectively. It is thus evident that high severity of head smut consequently leads to high yield losses as reported by Rao *et al*., (2006). Other genotypes that lost significant yield due to the disease are ICMV 221 White that had 29% yield loss with disease severity of 70%, SDMV 96063 with 29%

yield loss and disease severity of 72%, ICMV 94136 19% yield loss with disease severity of 46% and IP 8856 having 15 % yield loss and severity of 30% all these genotypes were classified as susceptible genotype.

3.5.4 Analysis of correlation coefficient (r) between yield, yield components, disease incidence and severity

Correlation coefficient shows interrelationships between pairs of quantitative characters. In plant breeding it is one of the guides facilitating interpretation of the obtained results and may form foundation for planning breeding programmes for increased genetic gains. Pearson coefficient of correlation (*r*) between two traits revealed that seed yield (tons ha^{-1} was positively and significantly related to biomass (r = 0.79), number of reproductive tillers (r = 0.72)

3.5.5 Principal component analysis (PCA) for yield and yield component for genotypes in both sites and seasons

Principal components analysis is a multivariate analysis used to study the kind of variation present in a selected population (Toker, 2004) and multivariate polymorphism (Mallikarjuna *et al.,* 2003). The first and the second principal components normally accounts for the first and second highest amount of variance (Broschat, 1979). Principal component analysis across the sites and seasons when data was pooled indicated that, only four principal components were significant. According to Hair *et al.,* (1998) Eigenvalues greater than 1 are considered significant and component loadings greater than ± 0.3 were deemed meaningful. The sign indicates the direction of relationship between the components and the variables. Those with appositive sign indicate that the variables are positively related to the PC while those with a negative sign are negatively related to the PC (Broschat, 1979).

As a result, only the first four principal components were considered in this study and traits with loadings greater than ±0.3 were taken to represent the corresponding principal axis. Similar results were obtained by Kiprotich *et al.*, (2015) when they analyzed 60 pearl millet genotypes for their biochemical composition. In this study 4 PCAs accounted for a total variation of 81% with PCA 1 accounting for 27.7% and PCA 2 accounting for 19.1%. PCA 3 accounted for 18.5 and the 4^{th} PCA accounting for 15.6%. These results were similar to those achieved by Wedajo, (2014) who found out that four principal components were significant in his study. Wedajo, (2014) found out that first PC was closely associated with days to

maturity, days to 50% flowering and days to 50% maturity when he evaluated 16 pearl millet genotypes.

The PCA for 50 pearl millet genotypes evaluated in this study, indicate that the number of reproductive tillers, 1000 seed weight, days to maturity and panicle characteristics are all important traits to be considered in breeding for grain yield in pearl millet. All these traits accounted for the first and the most important PCA1. The results also indicate that disease incidence, severity, and bird damage all in the PCA1.

3.6 Conclusion

Genotypes SDMV 90031, IP7390, IP6791, ICMV93771, ICMV 221, ICMV221 Bristled, ICMV96603, SDMV 96063 and ICMV 91450 were resistant to head smut and had high yields. They were highly ranked in both experiments I and II (yield components and head smut evaluation). These genotypes have a high potential of being developed into varieties hence should be considered for National performance trials (NPT) and commercial production in Kenya. The most resistant genotypes were IP 8783,IP9946, ICMV 221-3, ICMV 91450, ICMV 88908, ICMV 94151, IP 8783 though not among the highest in yield should be icluded in a breeding programme for genetic studies on resistance to *Tolyposporium penicillarie*.

3.7 Recommendations

1. Genotypes SDMV 90031, IP7390, IP6791, ICMV93771, ICMV 221, ICMV221 Bristled, ICMV 96603, SDMV 96063 and ICMV 91450 are recommended for National performance trials (NPT) and commercial production in Kenya as well as multi location evaluation trials.
2. The most resistant genotypes; IP 8783, IP9946, ICMV 221-3, ICMV 91450, ICMV 88908, ICMV 94151, IP 8783 should be icluded in a breeding programme for genetic studies on resistance to *Tolyposporium penicillarie*.
3. Research on a suitable and economical IPM package to manage *Tolyposporium penicillarie* to include a package on judicious use of fungicides

CHAPTER FOUR

CHARACTERIZATION OF HEAD SMUT (*T. penicillariae*) PREVALENCE FROM MAJOR PEARL MILLET GROWING AREAS IN KENYA

4.0. Abstract

Diseases are a major constraint limiting pearl millet productivity with head smut caused by *Tolyposporium penicillarie* being the most important disease in Kenya. Slow progress in developing head smut resistant varieties has been due to limited availability of sources of resistance to the disease and information on the incidence, distribution and reaction of local and improved varieties against the disease prevalence in the pearl millet growing regions in the country. To characterize the occurrence and severity of the pathogen twenty selected pearl millet genotypes were evaluated for their resistance/tolerance to three head smut isolates from major growing areas of Kenya (Koibatek, Makueni, and Mbeere). The study was carried out in Egerton University under controlled conditions in the glass house. The selected genotypes were high yielding showing high tolerance in Expt I and included tolerant, susceptible and the resistant commercial checks. These included SDMV 90031, ICMV91450, ICMV 96603, Shibe , IP 6791, and 2 resistant checks (KAT PM1 and ICMV 221), 3 susceptible checks (SDMV 94014, 96063, 94001), early maturing and high yielding ICMV 9377, ICMV 96603, Okoa).Bristled genotypes (Tsholotsho Bearded, ICMV 221 Bristled, IP 7390, IP8783, Okashana2) susceptible low yielders were (ICMV 221 White, IP 8764, IP10470).

Data on severity indicated that of the three isolates, Makueni isolate was the most virulent with average Area under Disease Progress Curve (AUDPC) of 108 followed by Mbeere and Koibatek with AUDPC of 68 and 45 respectively. Genotypes ICMV 93771, IP 6791, Tsholotsho, Shibe, SDMV 90031, ICMV 96603, and ICMV 91450 exhibited resistance with the most virulent isolate with infections ranging from (32% -38%).

Key words: Virulent; Isolate; Severity; Susceptible; smut resistant.

4.1. Introduction

Head smut is a very important pathogen common in the semi-arid tropics of the world widespread in India, Pakistan, Africa and the United States (Leslie, 2003). The disease is confined to the inflorescence where the infected ovaries are converted to oval or pear shaped *sori* (Rachie and Majmudar, 1980; Leslie, 2003). Pearl millet is protogynous i.e. stigmas emerge and mature before the stamens making it highly cross pollinated. This fact predisposes the crop to the pathogen infection during pollination and flower formation (Thakur *et al.,* 1986; Thakur, 1989). Apart from reducing the grain yield, the disease lowers the grain quality by producing smut *sori* on them. Smut severity in a field ranges from 1 to 30% when a crop is infected it can lead to 50-75% field infection, with a damage of up to 100% in individual panicles (Thakur and King, 1988).

Several strategies have been recommended to control head smuts including the use of fungicides as seed dressings and foliar sprays, crop rotation, use of tolerant genotypes like KAT PM1, KAT PM2, and the ICMV 22I. Among these host plant resistance is the best option because it is environmentally friendly and cost effective under subsistence conditions as compared to other options. Cultural control measure could have been easier on-farm option but it rarely achieves desired results since the pathogen is both soil borne and airborne (through spores) and infections occur despite measures such as crop rotation and or use of clean seed.

Despite its importance there is little information on the number and types of strains/isolates of head smut in the current pearl millet growing areas in Kenya. There is also limited information on the incidence, distribution and reaction of local and improved varieties against the disease prevalence in the pearl millet growing regions. This experiment was therefore set to screen selected pearl millet genotypes for resistance to head smut and determined the range of available isolates and also assessed severity levels of the disease amongst the genotypes. The experiment also identified promising adaptable high yielding improved genotypes resistant to the disease for possible release as commercial varieties in Kenya.

4.2. Objective

The objective of this experiment was to characterize the occurrence of *Tolyposporium penicillariae* isolates prevalent in major growing areas of Kenya using severity on selected genotypes

4.3 Materials and methods

This experiment was carried out at Egerton University glass house where twenty genotypes selected from the field experiment were evaluated. The selections were based on grain yield, maturity, disease resistance, susceptibility and tolerance to bird damage from field evaluation in experiment I. The most high yielding genotypes across the environments and seasons selected were (SDMV 90031, ICMV91450, ICMV 96603, Shibe , IP 6791) , resistant checks (KAT PM1 and ICMV 221), susceptible checks (SDMV 90014 and 94001). Early maturing and high yielding genotypes in the selection were (ICMV 91450, ICMV 93771 ICMV 96603 and Okoa) while bristled with tolerance to bird damage were (Tsholotsho Bearded, ICMV 221 Bristled, IP 7390, IP8783 and Okashana2) susceptible low yielders were (ICMV 221 White, IP 8764 and IP10470). The isolates were collected from major pearl millet growing areas of Kenya (Baringo/Koibatek, Makueni, Tharaka/Mbeere).

Table 4.1: List of Selections for Experiment II

Genotype	Attributes	Remarks
ICMV 221	Resistant Check	Early maturing
KAT PM 1	Resistant check	Early Maturing
IP 6791	High yielding	Bristled- Tolerant to birds
ICMV 221 WHITE	Large white	White seeded
ICMV 91450	High yielding	Early maturing
IP 10470	Late Maturing	Low yielding
IP 7390	High yielding	Bristled
IP 8764	Susceptible late maturity	Low yielding
SDMV 96063	Medium maturity	Medium yielding
SHIBE	High yielding	Medium maturing
TSHOLOTSHO	Bristled- Tolerant to birds	Medium yielding
ICMV 93771	Early maturing	Average yields
IP 8783	Bristled- Tolerant to birds	Medium yielding
SDMV 94001	Susceptible check	Low yielding
SDMV 94014	Susceptible check	Low yielding
ICMV 96603	High yielding	Early maturing
ICMV BRISTLED	Bristled- Tolerant to birds	Early maturing
SDMV 90031	Highest yielder	Medium maturing
OKASHANA 2	Bristled- Tolerant to birds	Average yields
OKOA	Average yield	Medium maturing

Three isolates were obtained from naturally infected pearl millet collected from different pearl millet growing regions (Koibatek, Mbeere, and Makueni). The isolates were randomly

collected from infected pearl millet fields and cultured at Egerton Biological labs on potato Dextrose Agar (PDA). Medium was steam sterilized in 15 1b pressure (121^0 C) for 20 minutes then poured in to Petri dishes.

Mature non-broken *sori* collected from infected pearl millet panicles from the respective sites were then surfaced sterilized with 1% mercuric chloride for 2 minutes and rinsed with distilled water 3 times to remove any traces of mercuric chloride. The *sori* were then ruptured using sterilized forceps and transferred to the PDA medium in the petri-dishes then inoculated at 35^0 C for 5 days (Wells *et al.*, 1987; Thakur and King, 1988). The medium with the sporidia suspension was then mixed with distilled water and adjusted to 10^6 conidia ml^{-1} using a hemacytometer. The emerging sporidia were of two types (+ve and –ve), when the positive and negative strains are deposited at the boot of the plants, they unite and produce a dicaryotic mycelium that infects the florets (Rao *et al.,* 2006).

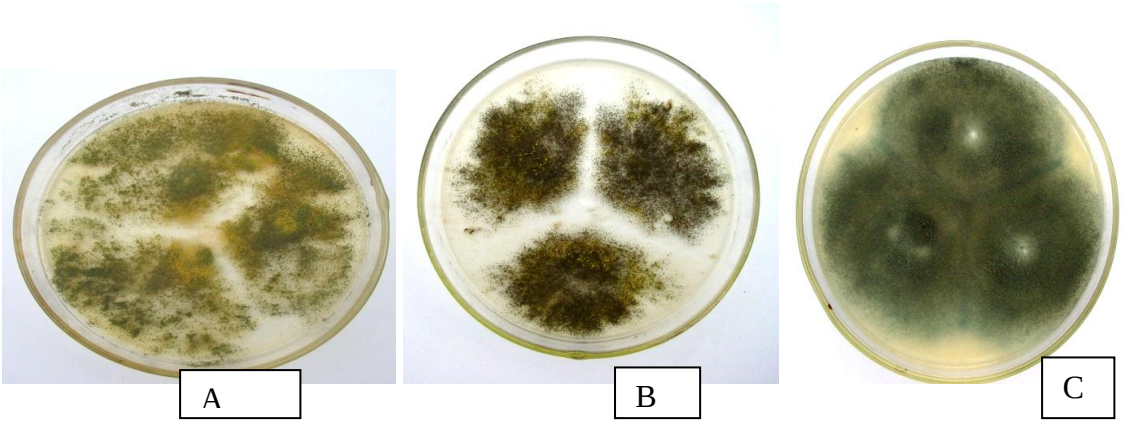

Plate 4.1: Cultured sporidia A: Koibatek, B: Mbeere and C: Makueni

From the results in experiment I a disease differential was established consisting of resistant, moderately resistant, moderately susceptible and susceptible groups (Thakur *et al.*, 1986) from which representatives from every group were selected. The 20 test genotypes were planted in pots in three replicates in a completely randomized design. Test plants were raised on a sterilized mixture of black soil (Vertisols). Before sowing the soil was autoclaved at 121^0C at 15 pounds pressure and then filled into medium-sized pots (30 cm in diameter, 30 cm in depth). Seeds were then sown 2 cm below the soil surface and watered regularly. All the seeds were planted on 15th June 2012.

One plant was retained per pot at 10 day after emergence. The genotypes were inoculated at boot stage with 7 ml of the sporidial suspension of the isolates from the different pearl millet

growing regions following the standard procedure then covered with white parchment bags as illustrated in plate 3.2.

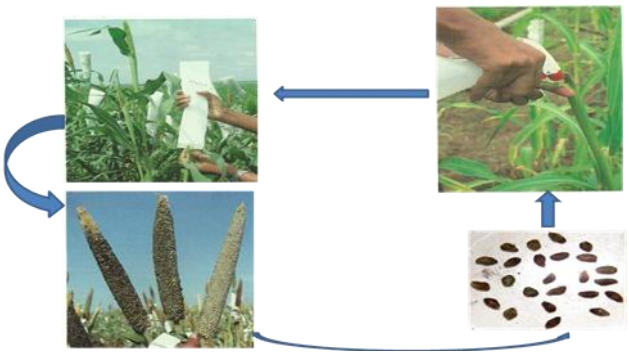

Plate 4.2: Procedure for head smut inoculation

The glass house conditions were maintained at above 80% RH and temperatures at 20-22^{0}C. After 7 days the parchment bags were removed and observation made for disease symptoms as the first observation and subsequently observations were made at intervals of 7 days up to the 4th observation (Wells *et al*., 1987; Rao *et al.,* 2006.)

4.4 Data on pathogen diversity

Data on, disease incidence, severity and virulence levels was collected for the genotype reactions with the isolates from different regions. Disease severity was estimated as in experiment one using the disease severity scale (Plate 3.1). Severity was determined by looking at the percentage infection of the individual panicles using the disease rating scale. Four observations were made for each genotype after inoculation at boot stage (Boko *et al*., 2010). The first observations were made seven days after the inoculation consecutive observations were made at intervals of seven days.

The dates of inoculation and observation for each genotype varied due to the difference in maturity periods that dictated the boot stage in all the genotypes (Table 4.2). Disease infection and severity on the florets were estimated using the standard smut severity scale (Thakur *et al.,* 1992) on a scale of 1-8. Where 1= highly resistant, 2 = resistant, 3-4 = moderately resistant, 5-6 = moderately susceptible 7= susceptible, and 8 highly susceptible. Any plants with <10% of florets infected were considered highly resistant, between 11-20% florets infected - resistant, 21-40% florets infected - moderately resistant, between 41-60% ,moderately susceptible, 61-80% florets infected susceptible and 81-100% floret infected as highly susceptible (Rao *et al.,* 2006). The area Under the Disease Progress Curve (AUDPC)

was calculated for all genotypes according to the following function (Shaner and Finney 1977):

$$AUDPC = \sum_{i=1}^{n-1} 0.5(x_{i+1} + x_i)(t_{i+1} - t_i)$$

Where Xi = the cumulative disease severity expressed as a proportion at the i^{th} observation

t_i = the time (days after inoculation) at the i^{th} observation

n = total number of observations.

The genotype that showed the highest AUDPC signified more disease hence highly susceptible

4.5. Results

4.5.1 Reactions of pearl millet genotypes to different isolates combined

Data in Table 4.3 show that the highest percentage of disease severity and Area under Disease Progress Curve (AUDPC) was between the susceptible genotype SDMV 94014, SDMV 94001and IP8764 with AUDPC of 117,134 and 104 respectively. The average AUDPC for Makueni was the highest followed by Mbeere and Koibatek respectively 108, 68 and 45 respectively (Table 4.3). This shows that the most virulent isolate was Makueni with the highest Area under Disease Progress Curve. Mbeere isolate was less virulent with average AUDPC of 68 while the isolate from Koibatek was the least virulent (AUDPC 45).Response of pearl millet genotypes to the three isolates infection signified variability in terms of severity for the isolates regionally (Tab 4.3). Resistant check KAT PM1 was resistant to infection by any of the isolates while the other check ICMV 221 was moderately resistant with initial infection of 9% and 31% respectively and AUDPC figures of 44 and 82 respectively (Table 4.3).

The resistant check KAT PM1 exhibited resistance with AUDPC of 44 and 29% infection rate at the 4^{th} observation, ICMV221 the other check was moderately susceptible with disease infection rate of 47% at the 4^{th} stage and AUDPC value of 80 (Table 4.3). Other genotypes that exhibited resistance were ICMV 93771, IP 6791, Tsholotsho, Shibe, SDMV 90031, ICMV 96603, and ICMV 91450 with percent disease infection of 32, 33, 36, 37, 37, 38, 38, at the fourth stage and 51, 56, 54, 58, 62, 58, and 62 AUDPC figures respectively (Table 4.3). Susceptible checks SDMV 94001 and SDMV 94014 exhibited high infection rates after the

first inoculation and high severity after the last observation of 80% and 73% respectively with the highest AUDPC values of 134 and 117 respectively (Table 4.3).

There was no complete resistance among the 20 genotypes tested as all developed the disease after inoculation however there were those that just inhibited the symptoms at first observation and resisted the disease in the subsequent observation like KAT PM 1, ICMV93771, IP6791 and Shibe. Of the 20 genotypes tested in the glass house two; KAT PM1 and ICMV 93771 exhibited resistance, six exhibited moderate resistance IP 6791, Tsholotsho, Shibe, SDMV 90031, ICMV 96603, and ICMV 91450. Six (Okoa, IP 10471, KAT PM2, IP 7390, ICMV Bristled and ICMV 221) were moderately susceptible and four were susceptible i.e IP 8783, SDMV 96063, IP8764 and ICMV 221 White. Only the susceptible checks were highly susceptible (SDMV 94014 and SDMV 94001).

Table 4.2 Genotypic reactions with isolates combined

Genotype	**1st Obs**	**2nd Obs**	**3rd obs**	**4th obs**	**AUDPC**
KAT PM 1	1a	1.7	2.3	2.6	44
ICMV 93771	1.3	2	2.6	2.9	51
IP6791	1.4	2.1	2.9	3	56
ICMV 96603	1.6	1.3	2.9	3.4	58
IP 10471	1.6	2.4	3.0	3.9	64
Tsholotsho	1.6	2	2.7	3.2	54
KAT PM 2	1.7	2.4	3.3	4.1	66
IP 7390	1.8	2.7	3.4	4.1	69
OKOA	1.8	2.2	3.0	3.8	62
SHIBE	1.8	2	2	3.3	58
ICMV 91450	1.9	2.2	3	3.4	62
SDMV 90031	1.9	2.4	2.9	3.3	62
ICMV bristle	2.1	3.2	3.7	4.3	77
IP 8783	2.2	2.8	3.9	4.7	79
ICMV 221	2.8	3.1	3.7	4.2	82
IP 8764	2.9	4	5	5.9	104
SDMV 96063	2.9	3.8	4.4	5.3	96
Icmv221white	3.2	4	5	5.9	106
SDMV 94014	3.4	4.4	5.3	6.6	117
SDMV 94001	4.1	5.2	6.1	7.2	134
Range	**1-5**	**1-6**	**1-7**	**1-8**	**44-134**
Mean	**2.1**	**2.8**	**3.6**	**4.2**	**75**
CV%	**17**	**22**	**19**	**18**	**22**

Key: Obs= Observation, **% sev=** Total percent disease severity, **AUDPC=**Area under Disease Progress Curve

4.5.2 Reactions of pearl millet genotypes to individual isolates Koibatek, Makueni and Mbeere

The results for Makueni, Koibatek and Mbeere isolates are shown in table 4.4. 4.5 and 4.6 respectively Overall the isolate from Makueni was the most virulent with an average AUDPC of 108 against all the tested genotypes and an average of 53% disease infection at the 4th stage of observation (Table 4.4). The Koibatek and Mbeere isolates were the second and third virulent respectively with AUDPC of 70 and 68 respectively and percent infection of 45 and 43 respectively (Table 4.5 and 4.6) . The severity and the virulence of the three isolates and their relationship with the selected genotypes is illustrated graphically in figure 4.1.

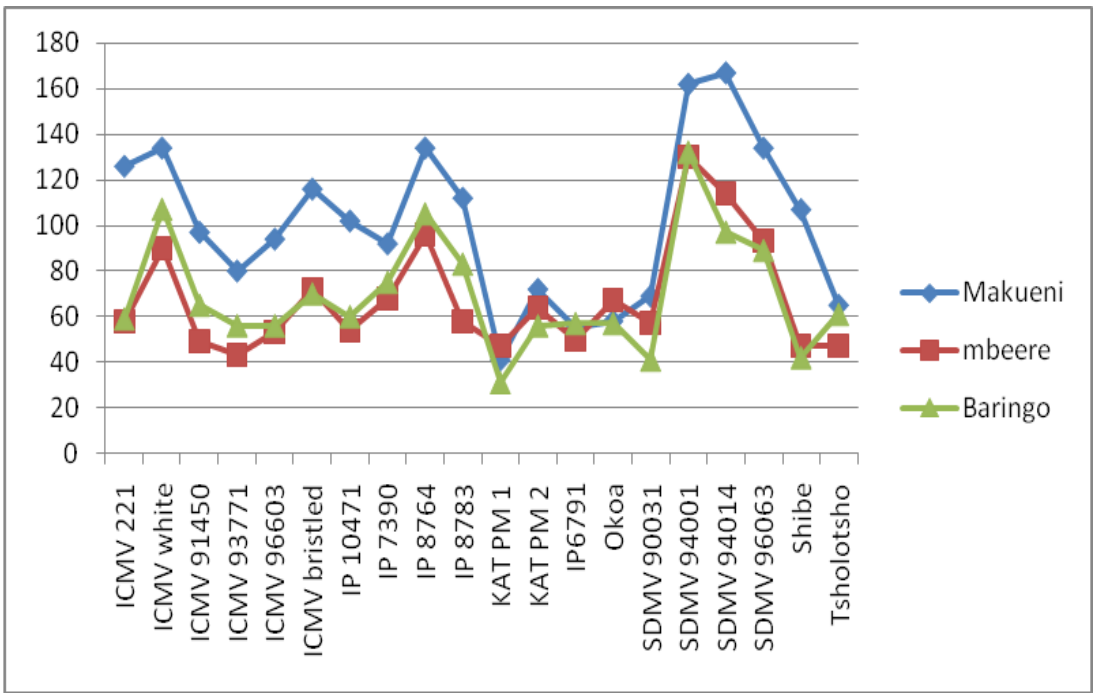

Figure 4.1: (AUDPC) genotypic reactions with the isolates (Scale: 1 cm= 40 units of AUDPC)

Makueni isolate had the highest disease infections with the susceptible checks SDMV9001, 94014, and 96063 with 162, 167, and 134 AUDPC respectively. The resistant checks KAT PM1, KAT PM2 and ICMV 221 showed the highest disease infection with the Makueni isolate of 41 72 and 126 respectively as compared to their reaction with isolate from Koibatek and Mbeere. The checks had 31, 56, and 59 with the Koibatek isolate and 47, 64 and 58 AUDPC with the Mbeere isolate. The isolate from Mbeere was the least virulent compared to the other two isolates. The most promising and high yielding genotypes reacted differently with the 3 isolates SDMV 90031, IP 6791, IP8783, and IP 7390 showed moderately

resistance with the most virulent isolate from Makueni giving AUDPC value of 65, 59, 112, and 92 respectively (Table 4.4). The Bristled genotype behaved differently with ICMV 221 Bristled succumbing to the disease having AUDPC of 116 with the Makueni isolate and Tsholotsho Bearded had an AUDPC of 65 hence moderately resistant to the most virulent isolate from Makueni. Other important genotypes Okoa and Shibe were moderately resistant and moderately susceptible respectively giving AUDPC of 58 and 107 with the most virulent isolate.

Table 4.3 Genotypes reactions to Makueni isolate

Genotype	**1st Obs**	**%sev**	**2nd Obs**	**%sev**	**3rd obs**	**%sev**	**4th obs**	**%sev**	**AUDPC**
ICMV 221	3.7	41	4.3	48	4.3	48	5.7	63	126
ICMV white	3.7	41	4.7	52	4.7	52	6.7	74	134
ICMV 91450	2.3	26	2.7	30	2.7	30	3.7	41	97
ICMV 93771	1.7	19	2.0	22	2.0	22	3.0	33	80
ICMV 96603	1.7	19	2.7	30	2.7	30	4.0	44	94
ICMV bristled	2.7	30	3.7	41	3.7	41	5.0	56	116
IP 10471	2.0	22	3.0	33	3.0	33	4.7	52	102
IP 7390	1.7	19	2.7	30	2.7	30	3.7	41	92
IP 8764	3.0	33	4.3	48	4.3	48	6.3	70	134
IP 8783	2.7	30	3.7	41	3.7	41	5.7	63	112
KAT PM 1	1.0	11	1.7	19	1.7	19	3.0	33	41
KAT PM 2	2.0	22	3.0	33	3.0	33	4.7	52	72
IP6791	1.7	19	2.3	26	2.3	26	3.0	33	55
Okoa	2.0	22	2.3	26	2.3	26	3.3	37	58
SDMV 90031	2.0	22	3.0	33	3.0	33	3.7	41	69
SDMV 94001	4.3	48	5.3	59	5.3	59	7.7	85	162
SDMV 94014	4.3	48	5.3	59	5.3	59	7.3	81	167
SDMV 96063	3.3	37	4.0	44	4.0	44	6.0	67	134
Shibe	2.7	30	3.0	33	3.0	33	4.7	52	107
Tsholotsho	1.3	15	2.3	26	2.3	26	3.7	41	65
Mean	**2.5**	**28**	**3.3**	**37**	**3.3**	**37**	**4.8**	**53**	**108**

Key: Obs= Observation, **% sev**= Total percent disease severity, **AUDPC**=Area under Disease Progress Curve

Table 4.4 Genotypes reactions to Koibatek isolate

Genotype	Ob1	S1	Ob2	S2	Ob3	S3	Ob4	S4	AUDPC
ICMV 221	2.1	23	2.3	26	2.7	30	2.7	30	59
ICMV white	3.3	37	4	44	5.0	56	6.0	67	107
ICMV 91450	1.7	19	2.3	26	3.3	37	4.0	44	65
ICMV 93771	1.3	15	2.3	26	2.7	30	3.3	37	56
ICMV 96603	1.3	15	2.0	22	3.0	33	3.3	37	56
ICMV bristled	1.7	19	2.7	30	3.7	41	4.0	44	70
IP 10471	1.3	15	2.3	26	3.0	33	3.7	41	60
IP 7390	2.0	22	2.7	30	3.7	41	4.7	52	75
IP 8764	3.0	33	4.0	44	5.0	56	6.0	67	105
IP 8783	2.3	26	3.0	33	4.0	44	5.0	56	83
KAT PM 1	1.0	11	1.3	15	1.4	16	1.5	17	31
KAT PM 2	1.3	15	2.0	22	2.7	30	4.0	44	56
IP 6791	1.3	15	2.3	26	3.0	33	3.0	33	57
OKOA	1.7	19	2.0	22	2.7	30	3.7	41	57
SDMV 90031	1.4	16	1.7	19	1.8	20	1.9	21	41
SDMV 94001	4.0	44	5.3	59	6.0	67	7.0	78	132
SDMV 94014	2.7	30	3.7	41	4.7	52	5.7	63	97
SDMV 96063	2.7	30	3.7	41	4.0	44	4.7	52	89
SHIBE	1.3	15	1.3	15	2.0	22	2.7	30	42
TSHOLOTSHO	2.0	22	2	22	3.0	33	3.3	37	61
Mean	**2.0**	**22**	**2.7**	**30**	**3.4**	**38**	**4.1**	**45**	**70**

Key: Ob= Observation, **S=** Total percent disease severity, **AUDPC=**Area under Disease Progress Curve

Table 4.5 Genotypes reactions to Mbeere isolate

Genotype	Ob1	S1	Ob2	S2	Ob3	S3	Ob4	S4	AUDPC
CMV 221	2	22	2	22	2.7	30	3.3	37	58
ICMV Wh	2.7	30	3.3	37	4.3	48	5.0	56	90
ICMV 91450	1.7	19	1.7	19	2.3	26	2.7	30	49
ICMV 93771	1.0	11	1.7	19	2.3	26	2.3	26	43
ICMV 96603	1.7	19	2.0	22	2.3	26	3.0	33	53
ICMV brs	2.0	22	3.0	33	3.3	37	4.0	44	72
IP 10471	1.3	15	2.0	22	2.7	30	3.3	37	54
IP 7390	1.7	19	2.7	30	3.3	37	4.0	44	68
IP 8764	2.7	30	3.7	41	4.7	52	5.3	59	96
IP 8783	1.7	19	2.0	22	3.0	33	3.3	37	58
Kat PM 1	1.0	11	2.0	22	2.3	26	2.7	30	47
Kat PM 2	1.7	19	2.3	26	3.3	37	3.7	41	64
IP6791	1.3	15	1.7	19	2.7	30	3.0	33	50
OKOA	1.7	19	2.3	26	3.3	37	4.3	48	67
SDMV 90031	2.0	22	2.0	22	2.7	30	3.0	33	57
SDMV 94001	4.0	44	5.0	56	6.0	67	7.0	78	130
SDMV 94014	3.3	37	4.3	48	5.3	59	6.7	74	114
SDMV 96063	2.7	30	3.7	41	4.3	48	5.3	59	93
SHIBE	1.3	15	1.7	19	2.3	26	2.7	30	47
Tsholotsho	1.3	15	1.7	19	2.3	26	2.7	30	47
Mean	2	22	2.6	28	3.2	37	4	43	**68**

Key: Ob= Observation, **S=** Total percent disease severity, **AUDPC=**Area under Disease Progress Curve

4.6 Discussions

4.6.1. Genotypic reactions to Head smut isolates

The isolates from the three regions reacted differently with the tested genotypes. These results are similar to those discovered by Gutachew, *et al.,* (2013). The isolate from Makueni was the most virulent followed by Mbeere and finally the Koibatek isolate. Isolates from different regions showed different virulent levels when inoculated to the genotypes in the glass house. Any pathogen as the ability to produce new races this was observed by Paraschivu *et al.*, (2013) and that humidity plays a key role in most pathogen virulence. The 3 isolates from Koibatek Makueni and Mbeere behaved distinctly different when inoculated to the selected pearl millet genotypes proving they are different races of *Tolyposporium penicillariae*.

To establish resistant genotypes to a pathogen it is important to carry out multi environment trials for one to be conclusive that the genotypes resistance is stable across the environments.

Severity of pearl millet head smut vary across the regions also affecting the yield in different levels as was discovered by Mene *at al*., (2011). Pearl millet head smut severity levels showed that the isolate from Makueni was the most virulent hence the most potential to cause more yield losses compared to the pathogen from Mbeere and Koibatek. Similar results were reported by Jain *et al*., (1997).

Severity is an important component of predicting yield loses according to Mene *et al*., (2011). For this study genotypes that were severely affected both in the field and in the glass house such as SDMV 94014, SDMV 94001 and IP8764 will have greatest yield losses from head smut. The most resistant genotypes KAT PM1, ICMV 93771 with the least AUDPC values and severity reactions with the most virulent race from Makueni were considered the most resistant genotypes to the disease and hence will have the greatest yield potential with minimum losses. Amongst 20 genotypes tested in the glass house KAT PM1 and ICMV 93771 showed high resistance 6 of them IP 6791, Tsholotsho Bearded, Shibe, SDMV 90031, ICMV 96603, ICMV 221 and ICMV 91450 exhibited moderate resistance while another 6 genotypes exhibited moderate susceptibility; Okoa, IP 10471, KAT PM2, IP 7390, ICMV bristled. Four genotypes were susceptible; IP 8783, SDMV 96063, IP8764 and ICMV 221 White while the susceptible checks; SDMV 94014 and SDMV 94001 were highly susceptible.

4.6.2. Reactions of pearl millet genotypes to individual isolates (Koibatek, Makueni and Mbeere)

Considering the severity of each isolate with the genotypes it was possible to conclude that the most virulent isolate was the one collected from Makueni having the highest severity index and the Area under Disease Progress Curve. The isolate from Makueni had the highest AUDPC with both the resistant and the susceptible genotypes as compared to the other isolates from Koibatek and Mbeere. This showed that this isolate was the most severe among the three and therefore will cause more yield losses as compared to the other two. Smut severity varies from region to region but any severity above 10% causes significant yield losses as reported by Rai and Thakur, (1996).

High smut infection and severity in a region can significantly cause yield loses that can lead to epidemics if not controlled such results were reported by Lubadde *et al.*, (2014) with 34% smut severities under field conditions.The average severity for the isolates were 53% 45%, and 43 % for Makueni, Mbeere and Koibatek respectively under controlled conditions. These

severities are high but in the field conditions might be lower but still cause serious yield losses to the crop.

4.7 Conclusion

The most virulent isolate was from Makueni while the least is the Koibatek isolate.It is therefore concluded that Makueni isolate can cause more yield losses compared to the other isolates two isolates from Mbeere and Koibatek.The most resistant genotypes from this experiment to head smut were IP 8783,IP9946, ICMV 221-3, ICMV 91450, ICMV 88908, and ICMV 94151.Genotypes SDMV 90031, IP7390, IP6791, ICMV93771, ICMV 221, ICMV221 Bristled, ICMV96603, SDMV 96063 and ICMV 91450 are resistant to the disease. All the most resisitant and the resistant genotypes in the glass house were highly resistant in the field experiment. In the glass house experiment however, there was no genotypes that were highly resistant. This confirms that glass house experiment with defined conditions gives more accurate results.

4.8 Recommendations

1. The most resistant genotypes; IP 8783,IP9946, ICMV 221-3, ICMV 91450, ICMV 88908, and ICMV 94151 are ecommended for further field evaluations and final release as commrecial varieties in Kenya
2. Resistant genotypes like SDMV 90031, IP7390, IP6791, ICMV93771, ICMV 221, ICMV221 Bristled, ICMV96603, SDMV 96063 and ICMV 91450 that also had high yields in the field experiment are also recommended for further trials and release as commercial varieties.
3. It is recommended that for accurate results inoculation and close monitoring in an enclosed environment (glasshouse) experiments should always be done to confirm field results.

CHAPTER FIVE
CONFIRMATION OF RESISTANCE/TOLERANCE OF PEARL MILLET GENOTYPES TO HEAD SMUT IN THE GREENHOUSE

5.0. Abstract

Host plant resistance defines a host that posses qualities enabling it to resist or tolerate a disease. It is the most sustainable and effective management option for any disease or pest in crop production. It is cheap to the farmers, does not pollute the environment, has no adverse effects on the non-target organisms and is compatible with other methods of disease management. Resistant genotypes can be identified under field conditions but a confirmatory result is vital. To obtain these results it's necessary to carry out disease inoculation and observation in restricted environment and conditions.This experiment was therefore carried out at Egerton University glass house to determine the levels of resistance of the 50 pearl millet genotypes and also confirm the resistance levels of the test genotypes to the most virulent isolate identified in experiment II. This experiment was a confirmation since in the glass house the environment and initial level of infestation were uniform among all the genotypes .The 50 genotypes were planted in pots in three replicates each and allowed to grow up to the most sensitive stage (booting stage) then inoculated with spores of *T. penicillariae* cultured from the most virulent isolate (Makueni- isolate). The results for combined analysis showed significant genotypic variation for disease severity against this isolate for all the fifty genotypes tested. The most promising genotypes SDMV 90031, IP 6791, ICMV 91450 and ICMV96603 had resistance with infections ranging from (26% - 47%). The most resistant genotypes were IP 8783, IP9946, ICMV 221-3, ICMV 91450, ICMV 88908, ICMV 94151, IP 8783 with disease severity range of (22%-33%). The most susceptible genotypes were SDMV 94009, SDMV 94001, SDMV 96063, SDMV94005, ICMV 221, ICMV 221-1, ICMV 221 White, IP 8766, IP 8767, and IP 8768 with the highest disease severity ranging from (53%-89%). The Commercial checks (ICMV 221 and KAT PM1) responded diffrently with the isolate. KAT PM1 displayed high levels of resistance with disease severity of being among the most resistant while ICMV221 was moderately resistant with disease severity of 34%.

Key words: Host plant resistance; confirmatory results; promising genotypes; Virulent Isolate; Severity.

5.1 Introduction

Pearl millet head smut is both seed borne and soil borne thus posing a challenge in controlling it. Smutted pearl millet panicles become the primary source of inoculum when they fall to the soil (Subba Rao and Thakur, 1983).The infection occurs at flowering through young fresh stigmas (Bhatt, 1946; Thakur, 1989). The primary inoculum source is sporeballs in the soil from the previous infected crop and surface contaminated seed used for sowing (Thakur *et al.*, 1986). The pathogen is not internally seed borne, but external contamination of seed with sporeballs from ruptured *sori* in the field and on the threshing floor infects the seed. Teliospores remain viable in the soil (soil depths of up to 22.5 cm for about 12 months) where basidiospores and sporidia are produced (Thakur and King, 1988). The teliospores then germinate following rain showers and produce numerous airborne sporidia that infect the pearl millet crop at flowering (Thakur, 1989). Two sporidia of compatible mating types (+ve and –ve) are required to form a dikaryotic infection hypha. Infection occurs through young emerging stigmas and is prevented or reduced by rapid pollination (Diagne-Leye *et al.*, 2010).

For these reasons it becomes difficult to control head smut through common cultural practices like crop rotation except by using certified seed and resistant genotypes. This is so because other control measures such as fungicide control and cultural measures are not effective considering the nature of spread of the disease (airborne). Furthermore fungicides use under regular regime becomes very expensive to farmers. Breeding for disease resistance is thus the best option but there is need to identify sources of resistance.

The identified genotypes should have a high level of resistance that is stable across environments (King, 1992). Resistance to head smut is identified by screening large numbers of germplasm accessions using an effective field-based screening technique and confirming the resistance in control environments (Thakur and King, 1988). Identification of diverse and stable source of resistance to head smut disease is thus a prerequisite to developing resistant genotypes. In this study therefore, to confirm the field results from experiment I all the 50 genotypes were screened in a controlled environment with the most virulent isolate identified in experiment II.

5.2. Objective

The objective of this experiment was to screen the resistance/tolerance of the selected pearl millet genotypes against head smut in greenhouse at the most sensitive stage (booting stage).

5.3 Materials and methods

This experiment was carried out at Egerton University glass houses to determine the levels of resistance of the 50 genotypes and also confirm the resistance levels of the test genotypes to the major strains/isolates identified. The experiment was confirmatory because in the glass house the environment and initial level of infestation are uniform in all genotypes tested. The 50 genotypes were planted in pots in three replicates each and allowed to grow up to the most sensitive stage (booting stage) when they were all inoculated with spores of *T. penicillariae* cultured from the most virulent isolate determined in experiment two. The isolate from Makueni was the most virulent among the three isolates (Koibatek, mbeere and Makueni). The pathogen was cultured in Egerton university biological science laboratories. Mature non-broken *sori* collected from infected pearl millet panicles from Makueni. They were then surfaced sterilized with 1% mercuric chloride for 2 minutes before rinsing with distilled water 3 times to remove any traces of mercuric chloride. After sterilizing the *sori* were ruptured using sterilized forceps and transferred to the PDA medium in the petri-dishes for inoculation at 35^0 C for 5 days (Wells *et al.,* 1987; Thakur and King, 1988). The medium with the sporidia suspension was then mixed with distilled water and adjusted to 10^6 conidia ml^{-1} using a hemacytometer. The emerging sporidia were of two types (+ve and –ve).When the positive and negative strains were deposited at the boot of the genotypes, they united and produced a dicaryotic mycelium that infected the florets.

All the genotypes were then inoculated following the standard procedure (Thakur *et al*., 1992) at the booting stage. In this experiment conditions that influence disease development were controlled i.e. at relative humidity at 80% and 20-22^0c. The amount of disease was measured using a hemacytometer for uniform disease pressure and each of the 50 genotypes inoculated with 7Ml of the inoculate.

5.3.1. Data collected

The plants were scored for disease infection and severity using the standard smut severity scale (Thakur, 1983; Rao *et al.,* 2006) on a scale of 1-8. Where 1= highly resistant, 2 = resistant, 3-4 = moderately resistant, 5-6 = moderately susceptible 7= susceptible, and 8 highly susceptible. Any plants with <10% of florets infected were considered highly resistant, between 11-20% florets resistant, 21-30% florets infected moderately resistant, between 35-

50% moderately susceptible, 51-75% florets infected susceptible and 76-100% floret infected as highly susceptible (Thakur *et al.*, 1986; Rao *et al.*, 2006).

5.4 Results

5.4.1 Reaction of all genotypes to the most virulent isolate (Makueni)

The results for combined analysis showed significant genotypic variation for disease severity against the Makueni isolate in all the fifty genotypes tested. The most high yielding genotypes reacted at diffrent levels with the disease with the most promising genotypes SDMV 90031, IP 6791, ICMV 91450 and ICMV96603 showing resistance with disease severity ranging from (26% - 41%) (Table 5.1).The most resistant genotypes were IP 8783, IP9946, ICMV 221-3, ICMV 91450, ICMV 88908, ICMV 94151, IP 8783 with disease severity ranging from (22%-33%) at the 4th observation (Table 5.1). Early maturing genotypes ICMV 93771, ICMV 96603 exhibited high levels of resitance both having a disease severity of 33% (Table 5.1).

Bristled genotypes ICMV 221 Bristled, IP 7390, IP8783 and Tsholotsho Bearded showed diffrent levels of disease reactions with ddisease severity of between (33% - 48%). The most susceptible genotypes were SDMV94009, SDMV 94001, SDMV 940014, SDMV94005, with disease severities of 81%, 74%, 89% and 78% respectively. Other susceptible genotypes were ICMV 221-1, ICMV 221 White, IP 8766, IP 8767, and IP 8768 with the high severities of 70%, 74% 63%, 67, %, and 63% respectively. All these genotypes were moderately susceptible under field conditions. The Commercial checks ICMV 221, KAT PM1 and KAT PM 2 responded variedly with the isolate. KAT PM1 displayed high levels of resistance with Severity of 25% being among the most resistant genotypes while ICMV221 was moderately resistant (34%) disease severity while KAT PM 2 succumbed to the disease having Severities a 53% disease severity (Table 5.1)

Table 5.1 Reaction of all genotypes with the most virulent isolate from Makueni

Genotype	Ob1	S1	Ob2	S2	Ob3	S3	Ob4	S4	AUDPC
ICMV 221	3	31	3.1	33	3.1	33	3.3	34	114
ICMV 221-1	4.3	48	5.0	56	5.7	63	6.3	70	127
ICMV 221-2	3.0	33	3.7	41	4.0	44	5.0	56	92
ICMV 221-3	1.0	11	1.7	19	2.0	22	2.0	22	40
ICMV 221-4	2.7	30	3.3	37	4.3	48	5.3	59	91
ICMV 88908	1.0	11	1.7	19	2.3	26	2.3	26	43
ICMV 91450	1.0	11	2.0	22	2.0	22	2.3	26	43
ICMV 93771	1.7	19	2.0	22	2.3	26	3.0	33	53
ICMV 94136	2.7	30	2.7	30	2.7	30	3.7	41	69
ICMV 94151	1.0	11	2.0	22	2.0	22	3.0	33	46
ICMV 96603	2.3	26	2.0	22	2.3	26	3.0	33	57
ICMV bristl	2.0	22	2.7	30	2.7	30	3.7	41	64
ICMV white	4.0	44	4.7	52	5.7	63	6.7	74	124
IP 10470	1.0	11	1.7	19	2.3	26	3.3	37	47
IP 10471	1.3	15	2.0	22	3.0	33	3.7	41	57
IP 5876	2.7	30	3.7	41	3.7	41	4.7	52	86
IP 6791	1.3	15	2.0	22	3.0	25	3.4	29	57
IP 6800	2.3	26	3.0	33	4.0	44	4.0	44	79
IP 7389	2.3	26	2.3	26	3.7	41	4.3	48	74
IP 7390	1.3	15	2.7	26	3.3	27	4.3	28	67
IP 8761	2.0	22	3.0	33	4.0	44	5.0	56	81
IP 8764	3.0	33	3.7	41	4.7	52	5.0	56	97
IP 8765	2.3	26	3.3	37	3.7	41	4.0	44	79
IP 8766	3.3	37	4.0	44	5.0	56	5.7	63	106
IP 8767	3.3	37	4.0	44	5.0	56	6.0	67	107
IP 8768	3.3	37	4.3	48	5.0	56	5.7	63	109
IP 8772	1.0	11	2.0	22	2.7	30	3.3	37	51
IP 8773	1.0	11	1.0	11	2.0	22	2.7	30	37
IP 8774	1.0	11	2.3	26	2.3	26	3.0	33	50
IP 8783	1.0	11	1.7	19	2.3	26	3.0	33	46
IP 8856	2.3	26	3.0	33	3.7	41	4.7	52	79
IP 9946	1.3	15	1.7	19	2.7	30	2.7	30	49
IP 9976	1.3	15	2.0	22	2.0	22	3.0	33	48
IP 9989	1.7	19	3.0	33	4.0	44	4.3	48	76
KAT PM1	1.0	11	1.7	19	1.7	19	2.7	25	40
KAT PM2	3.7	41	4.3	48	5.0	52	5.2	53	111
Okashana 1	2.7	30	3.0	33	3.7	41	4.7	52	82
Okashana 2	1.7	19	2.3	26	2.7	30	3.0	33	57
Okoa	2.3	26	3.3	37	4.3	48	4.7	52	86
PMV 3	1.7	19	2.0	22	2.7	30	3.7	41	57
SDMV 90031	1.7	19	2.7	24	2.7	25	3.3	26	61
SDMV 93032	3.3	37	4.0	44	4.3	48	5.0	56	99
SDMV 94001	3.3	37	5.0	56	6.3	70	7.3	81	128
SDMV 94005	4.7	52	5.3	59	5.7	63	6.7	74	133
SDMV 94014	5.7	63	6.3	70	7.0	78	8.0	89	161
SDMV 95009	5.0	56	5.7	63	6.0	67	7.0	78	141
SDMV 96053	4.0	44	5.0	56	5.3	59	6.3	70	123
SDMV 96063	3.7	41	4.3	48	5.0	56	5.7	63	111
Shibe	1.7	19	2.0	22	3.3	37	4.0	44	63
Tsholotso	1.0	11	2.3	26	3.3	37	4.3	48	62
Range	**1-6**	**11-63**	**1-7**	**11-70**	**2-7**	**22-78**	**3-8**	**30-89**	**37-161**
Mean	**2.4**	**26**	**3.1**	**34**	**3.7**	**41**	**4.4**	**49**	**79**

Key: Ob= Observation, **S=** Total percent disease severity, **AUDPC=**Area under Disease Progress Curve

5.4.2 Genotypes classification for resistance/susceptibility to head smut in glass house

Based on disease severity (%) the genotypes were grouped into six categories i.e. highly resistant (HR) with < 10% disease infection, resistant (R), 11-30% florets infected, 31-40% florets infected moderately resistant (MR), between 40-50% moderately susceptible (MS), 51-70% florets infected susceptible (S) and 71-100% floret infected as highly susceptible (HS) **(**Table 5.2). In the glass house there were no highly resistant genotypes. Resistant genotypes were ICMV22-3, ICMV88908, SDMV90031, IP 6791, ICMV91450 and KAT PM1 with 11%-30% disease infection at the fourth observation. Moderately resistant genotypes were ICMV9771, ICMV221, IP 9989 and Okashana 2 among others. ICMV221 Bristled ICMV 94136, ICMV91450, KAT PM2 and IP6800 were moderately susceptible while ICMV 221 White, SDMV 94001, SDMV 94014 were highly susceptible (Table 5.2)

Compared to field results, (Table 3.10) the genotypes had varied levels of disease compared to the glass house results giving different levels of resistance and susceptibility to the disease similar results were obtained by Rao *et al*., 2006. It was evident that genotypes reacted variedly to disease under controlled condition as compared to field conditions such results were also recorded by Thakur., (1992). Some genotypes like IP7390, IP6791, KAT PM1 and 90031 that were highly resistant in the field developed disease severities ranging from (11%-30%) hence confirmed as resistant. The resistant commercial checks KATPM1 and ICMV 221 had varied results with KAT PM1 maintaining resistance with 25% disease severity while ICMV 221 became moderately resistant with 34% disease severity. Genotypes that were highly resistant in the field (<10%) disease became resistant with (11-30%) disease severity (Table 3.10 and 5.2).

Table 5.2: Classification of genotypes for resistance/susceptibility in glass house

Genotypes	Category reactions
None	Highly resistant
SDMV 90031, P8783, IP6791, IP7390, KATPM1, ICMV 96603, SHIBE, IP7389, IP1070, ICMV 221-3, ICMV 88908	Resistant
ICMV 221, ICMV93771, ICMV221, KATPM2, Okashana2, Tsholotsho Bearded, ,IP 9976, IP 8856	Moderately resistant
ICMV 221 Bristled, ICMV 221-1, ICMV91450, ICMV 94136	Moderately susceptible
ICMV 94136, IP6800, IP 8764, Okoa	Susceptible
SDMV 94014, SDMV 96063 SDMV 94001, ICMV 221 White,SDMV94005,SDMV 95009	Highly Susceptible

5.5 Discussions

5.5.1. Reaction of All genotypes with Makueni Isolate

From the results of all tested genotypes with the most virulent isolate from Makueni it was possible to group the fifty genotypes into groups of most resistant to the most susceptible genotypes. There was no genotype that was highly resistant unlike the situation in the field this is because all the genotypes were exposed to equal measure of the disease and there were no chances of escape as is the case under field conditions. All the genotypes developed the disease at different levels with resistance lines ICMV 88908 developing 26% disease at the fourth stage and ICMV221-3 22%, ICMV 91450 developed 26% severity at the fourth stage. Other resistant genotypes that were also resistant under field conditions were IP9946, ICMV93771, ICMV96603, IP8783, SDMV90031, Okashana 2, and IP 10470 all with less than 40% disease severity at 4^{th} stage. Similar results were reported by Jain *et al*., (1997).

The most susceptible genotypes under field conditions were also highly susceptible in the restricted conditions with SDMV 96063, SDMV94001, SDMV94014, and ICMV White all having disease infection above 60% of 63%,81%, 89%, 74% respectively. The commercial checks ICMV221, KAT PM1 and KAT PM2 gave different confirmatory result with KAT PM2 succumbing to the disease at 63% severity, ICMV 221 was moderately resistant with 34% severity while KAT PM1 was resistant developing 30% disease severity at the 4^{th} stage of observation compared to the field conditions where both varieties were highly resistant with < 10% infection.

5.6 Conclusion

A confirmation experiment in restricted conditions is necessary in order to make the right conclusions. The most resistant genotypes; SDMV 90031, P8783, IP6791, IP7390, KAT PM1, ICMV 96603, SHIBE, IP7389, IP1070, ICMV 221-3, ICMV 88908 in the field became resistant in the glass house under uniform monitored conditions. These genotypes thus can be confirmed to be resistant to head smut disease. Genotypes; ICMV 221, ICMV93771, ICMV221, KATPM2, Okashana2, Tsholotsho Bearded, IP 9976, IP 8856 are moderately resistant after confirmation in the glass house. The checks; ICMV 221, KAT PM1 and KAT PM2 were moderately resistant as well.

5.7 Recommendation

1. Genotypes SDMV 90031, P8783, IP6791, IP7390, KAT PM1, ICMV 96603, SHIBE, IP7389, IP1070, ICMV 221-3, and ICMV 88908 are recommended for national performance trials and release as commercial varieties in Kenya.
2. Genotypes ICMV 221, ICMV93771, ICMV221, KATPM2, Okashana2, Tsholotsho Bearded, IP 9976, IP 8856 were moderately resistant and high yielding in the field experiment they are thus recommended for further trials and release as commercial varieties in Kenya
3. It is recommended to always carry out a confirmatory experiment in measured conditions to confirm field results

CHAPTER SIX
GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Genotypes SDMV 90031, IP7390, IP6791, ICMV93771, ICMV 221, ICMV221 Bristled, ICMV96603, SDMV 96063 and ICMV 91450 were resistant to head smut and high yielding. They were highly ranked in both experiments I and II (yield components and head smut evaluation). These genotypes have a high potential of being developed into varieties hence should be considered for National performance trials (NPT) and commercial production in Kenya. The most resistant genotypes were IP 8783,IP9946, ICMV 221-3, ICMV 91450, ICMV 88908, ICMV 94151, IP 8783 though not among the highest in yield should be icluded in a breeding programme for genetic studies on resistance to *Tolyposporium penicillarie*. Unlike other cereals like rice, wheat, barley and maize which are used both for food and industrial purposes pearl millet has so far remained a traditional food crop for subsistent farmers in Kenya and many other dry regions of Africa and Asia. This crop should thus be included in the national programs as a food security crop because of it's benefits. The crop is also a source of excellent feed for livestock hence genotypes like IP 7390, IP 7389 are good for further studies for dual purpose.

The results suggested that there is adequate genetic variability present in the genotypes evaluated. In the broad sense heritability, genetic advance and correlation among traits it was found out that the selection for disease resistance, yield (kg/ha), plant height, 1000- grain weight, days to maturity and number of reproductive tillers would be more effective traits in boosting grain yield performance of Pearl millet genotypes.

Considering also its hardiness and genetic enhancement prospects, the crop has the potential of becoming an important component of intensive agriculture especially in Kenya. Breeding work on the various aspects of this crop and sustained cultivation need to be encouraged. The greatest challenge to farmers in these regions apart from diseases is the bird menace but bristled varieties like ICMV 221 Bristled, IP 7390, Tsholotsho Bearded can be a better solution since the bristles reduced bird damage and yield losses. Further research should be geared towards getting high yielding varieties that are resistant to important diseases like head smut and also breeding for varieties that are bird tolerant with long bristles that easily detach during threshing.

6.2 Recommendations

1. Genotypes SDMV 90031, IP7390, IP6791, ICMV93771, ICMV 221, ICMV221 Bristled, ICMV 96603, SDMV 96063 and ICMV 91450 are recommended for National performance trials (NPT) and commercial production in Kenya as well as multi location evaluation trials.
2. The most resistant genotypes were IP 8783,IP9946, ICMV 221-3, ICMV 91450, ICMV 88908, ICMV 94151, IP 8783 should be icluded in a breeding programme for genetic studies on resistance to *Tolyposporium penicillarie*.
3. Research on a suitable and economical IPM package to manage *Tolyposporium penicillarie* to include a package on judicious use of fungicides
4. More breeding and genetic studies should be carried out on genotypes ICMV 221 Bristled, IP 7390, Tsholotsho Bearded, to include them on commercial varieties for their bristled nature that prevent bird damage.
5. More genetic studies should be carried out by breeders on biomass, panicle size and 1000 seed mass to establish their usefulness in breeding for both grain yield and livestock feed.

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APPENDICES

Appendix 1: Analysis of variance (ANOVA) for Yield and disease components for Koibatek season I (Short rains)

	Mean squares							
Source of variation	**DAF**	**DAM**	**YLD**	**1000 SW**	**PHT**	**DSI**	**DSS**	**BRD**
Rep	2	139.2*	3711	19.67*	1054	0.56	1.82	0.72
Genotypes	49	99.48*	1866731*	18.66*	2255.2*	2.4524*	16.167	7.97*
Error	98	12.98	149166	3.07	998	0.36	1.53	0.69
Total	149							

KEY: *= significant at 0.05 probability level; **DAF** = Day to first flower; **DAM**= Days to maturity; **YLD**= Grain yield tons ha^{-1}; 1000 **SW**· = Weight of 1000 grains in Kg, **PHT** Plant height in cm, **DSI**= Disease incidence **DSS**= Disease Severity; **BRD**= Bird damage.

Appendix 2: Analysis of variance (ANOVA) for Yield and disease components for Koibatek season II (Long rains)

	Mean squares							
Source of variation	**DAF**	**DAM**	**YLD**	**1000 SW**	**PHT**	**DSI**	**DSS**	**BRD**
Rep	2	146.65	15816	2.462	749.9*	0.3267	4.34	0.98
Genotypes	49	98.73*	1855267*	9.436*	2248.4*	2.789*	16.28*	6.706*
Error	98	12.5	85934	1.909	667.9	0.3335	1.68	0.8031
Total	149							

KEY: *= significant at 0.05 probability level; **DAF** = Day to first flower; **DAM**= Days to maturity; **YLD**= Grain yield tons ha^{-1}; 1000 **SW**· = Weight of 1000 grains in Kg, **PHT**= Plant height in cm; **DSI**= Disease incidence **DSS**= Disease Severity; **BRD**= Bird damage

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Appendix 3: Analysis of variance (ANOVA) for yield and disease components and bird damage for Marigat season I (Long rains)

	Means squares								
Source of variation	**DAF**	**DAM**	**YLD**	**1000 S**	**PHT**	**DSI**	**DSS**	**DRD**	**BRT**
Rep	2	32.9*	572437	2.26	1134.3	0.14	1.12	0.82	0.006
Genotypes	49	18.7*	1190853*	7.037*	2000*	4.485*	15.067*	7.373	0.7085*
Error	98	2.87	82496	1.5	343.5	0.28	0.915	0.54	0.006
Total	149								

KEY: *= significant at 0.05 probability level; **ENV**= Environment; **DAF** = Day to first flower; **DAM**= Days to maturity; **YLD**= Grain yield tons ha^{-1}; 1000 **SW**· = Weight of 1000 grains in Kg, **PHT**= Plant height in cm; **DSI**= Disease incidence **DSS**= Disease Severity; **BRD**= Bird damage

Appendix 4: Analysis of variance (ANOVA) for yield and disease components and bird damage for Marigat season II (Short rains)

	Mean squares							
Source of variance	**DAF**	**DAM**	**YLD**	**1000 S**	**PHT**	**DSI**	**DSS**	**BRD**
Rep	2	34.96*	572437	2.56	1334.3	0.16	1.18	0.82
Genotypes	49	17.787*	1190783*	6.037*	2100.8*	4.4746*	15.0508*	7.307
Error	98	3.87	81566	1.5	343.8	0.45	0.765	0.674
Total	149							

KEY: *= significant at 0.05 probability level; **ENV**= Environment; **DAF** = Day to first flower; **DAM**= Days to maturity; **YLD**= Grain yield tons ha^{-1}; 1000 **SW**· = Weight of 1000 grains in Kg, **PHT**= Plant height in cm; **DSI**= Disease incidence **DSS**= Disease Severity; **BRD**= Bird damage

Appendix 5: Analysis of variance (ANOVA) for Yield and Disease components for season I both sites combined (Short rains)

Means squares

Source	**DF**	**DAM**	**YLD**	**1000 S**	**PHT**	**DSI**	**DSS**	**BRD**	**BRT**
Rep	2	123.536	699473	20.91	722.8	0.0677	4.485	1.2073	0.0047
ENV	1	4251.6*	13441	4.464	59303*	1.0796	38.13*	1.54*	0.0083
Genotypes	49	91.141*	25095*	27.07*	2522*	4.078*	20.5*	14.47*	1.426*
Genotype*ENV	49	27.623*	40854*	2.8	2412*	2.141*	7.402*	1.332*	0.0035
Error	198	7.756	160742	2.8	670.7	0.2889	1.107	0.5908	0.0038
Total	299								

KEY: *= significant at 0.05 probability level; **DAF** = Day to first flower; **DAM**= Days to maturity; **YLD**= Grain yield tons ha^{-1}; 1000 **S**· = Weight of 1000 grains in Kg, **PHT**= Plant height in cm; **DSI**= Disease incidence **DSS**= Disease Severity; **BRD**= Bird damage

Appendix 6: Analysis of variance (ANOVA) for yield, days to maturity disease incidence, disease severity plant height and bird damage for season 1 both sites combined ,(Long rains April- July 2012)

	Means squares								
Source of variation	**DF**	**DAF**	**DAM**	**YLD**	**SW**	**PHT**	**DSI**	**DSS**	**BRD**
Rep	2	76.44	158.64	199465	3.764	514.4	0.41	4.93	1.7633
ENV	1	374*	4294*	19272	0.001	2647*	0.22	10.03	0.6533
Genotypes	49	98.6*	91.23*	249542*	12.768*	2725*	5.5*	27.84*	12.545*
G*ENV	49	27.18	26.28*	496578*	3.705*	1523*	1.8*	3.48*	1.4697*
Error	198	15	7.83	87291	1.701	514.4	0.31	1.29	0.6691
Total	299								

KEY: *= significant at 0.05 probability level; **G**= Genotype, **ENV**= Environment; **DAF** = Day to first flower; **DAM**= Days to maturity; **YLD**= Grain yield tons ha^{-1}; **SW**· = Weight of 1000 grains in grams, **PHT**= Plant height in cm; **DSI**= Disease incidence **DSS**= Disease Severity; **BRD**= Bird damage

Appendix 7: Means of yield and its component traits for both sites and seasons

Genotype	SWT	BRD	DAF	DAM	DSI	DSS	YLDNS	PHT	VT	RT	PLT	PDM
ICMV 221	10.9	4.3	27.0	74.0	1.4	2.2	2499.6	205.6	6.6	4.8	19.9	8.0
ICMV 221-1	10.9	4.7	25.3	80.4	3.6	5.5	3481.9	195.8	6.5	5.0	20.2	9.1
ICMV 221-2	10.2	4.7	30.0	76.3	2.8	4.9	2488.0	197.3	6.3	4.2	20.3	8.9
ICMV 221-3	9.9	4.5	27.5	74.8	1.0	1.0	2885.7	211.9	7.2	5.2	19.5	8.1
ICMV 221-4	8.7	3.3	30.5	75.3	3.2	7.0	2790.7	180.4	5.8	4.6	20.9	8.8
ICMV 88908	8.3	4.8	28.7	74.4	1.0	1.0	1642.0	181.6	8.4	5.7	23.2	8.8
ICMV 91450	10.5	5.0	29.5	81.3	3.1	5.0	2932.2	208.1	6.7	5.0	18.7	9.1
ICMV 93771	9.2	4.7	32.7	78.8	1.0	2.0	3115.2	216.5	6.2	4.8	24.7	7.9
ICMV 94136	9.6	4.7	32.8	79.7	2.9	4.7	2560.4	175.0	5.7	4.6	20.5	8.4
ICMV 94151	9.0	2.9	31.0	77.7	1.0	1.0	2238.3	197.5	6.2	4.5	21.4	8.4
ICMV 96603	11.0	2.7	34.7	81.5	1.0	1.0	2970.1	277.6	6.0	4.3	23.3	9.0
ICMV bristled	10.5	2.7	25.7	75.2	2.5	4.1	3198.5	233.9	6.2	4.6	28.2	11.2
ICMV white	9.5	4.8	29.8	76.0	4.2	7.0	2100.9	199.3	5.7	4.1	23.3	8.5
IP 10470	8.1	4.8	37.3	86.2	1.0	1.0	1379.1	213.9	6.5	4.7	29.0	9.3
IP 10471	8.7	2.0	33.8	86.8	1.0	1.0	1881.8	219.3	6.6	4.2	28.7	10.1
IP 5876	8.0	4.7	33.7	81.2	1.9	4.3	1435.5	210.2	6.8	4.7	28.2	9.0
IP 6791	7.9	2.3	32.2	81.7	1.1	1.0	3172.3	220.7	5.7	4.2	23.8	8.0
IP 6800	8.9	4.3	33.2	80.7	2.1	4.9	1797.8	201.0	7.0	5.3	26.3	8.3
IP 7389	9.1	1.0	34.5	80.5	1.0	1.0	2178.6	239.4	7.2	5.2	34.7	9.8
IP 7390	10.5	1.2	32.7	80.3	1.0	1.0	2562.8	226.8	6.6	4.9	31.0	11.5
IP 8761	8.9	1.3	32.8	82.2	1.0	1.0	1888.8	229.2	8.2	5.1	22.8	9.3
IP 8764	11.2	1.8	30.2	77.3	2.7	5.6	2004.0	190.4	6.7	4.8	22.5	9.9
IP 8765	9.1	3.3	34.5	80.8	2.8	4.8	2000.5	205.6	6.9	5.0	20.7	10.0
IP 8766	7.5	1.0	30.3	75.5	2.7	6.0	2149.0	202.5	5.4	4.2	23.0	9.3
IP 8767	6.6	1.0	34.0	85.0	2.5	4.5	1305.8	194.3	6.3	4.7	21.5	8.3
IP 8768	10.7	4.3	34.3	81.3	2.3	5.0	2890.1	209.8	5.4	4.1	21.5	9.2
IP 8772	8.5	1.5	35.8	87.2	1.0	1.0	2007.4	219.4	6.0	4.7	23.2	10.2
IP 8773	9.2	1.2	38.8	87.3	1.0	1.0	1468.9	168.8	6.7	4.5	24.8	10.7

IP 8774	8.6	4.8	33.8	81.7	1.0	1.0	1724.8	203.4	6.3	4.9	14.7	6.9
IP 8783	11.6	3.2	33.5	84.8	1.0	1.0	3183.9	222.7	7.2	4.5	31.2	9.5
IP 8856	8.3	1.5	34.0	81.8	1.0	1.0	1329.9	216.3	7.3	4.8	22.5	9.6
IP 9946	9.9	3.7	36.8	87.7	1.0	1.0	2076.4	205.7	6.1	4.4	27.3	10.2
IP 9976	8.7	3.7	39.0	88.3	1.0	1.0	1218.3	218.8	7.0	4.8	23.0	8.7
IP 9989	9.5	1.7	34.0	81.7	2.0	3.2	1825.3	184.2	6.8	4.7	26.8	10.0
KAT PM1	12.5	1.2	28.2	74.8	1.0	1.0	2833.1	205.0	6.1	4.5	22.3	8.6
KAT PM2	9.1	5.0	28.0	74.8	1.3	2.3	2834.5	198.5	6.9	5.1	19.7	7.7
Okashana 1	9.9	3.8	31.8	79.8	2.4	4.2	2499.6	235.5	6.3	4.4	22.0	9.1
Okashana 2	9.0	5.0	32.7	78.8	1.6	2.5	1963.0	230.8	6.4	4.5	20.3	8.0
OKOA	9.3	5.0	32.3	79.0	1.0	1.0	2370.2	220.8	5.7	4.6	29.3	8.7
PMV 3	9.2	4.3	31.0	77.3	1.1	1.2	2936.7	218.1	7.0	5.1	19.0	8.8
SDMV 90031	11.0	2.5	35.0	81.8	1.0	1.0	4271.0	187.9	6.8	5.1	22.7	9.0
SDMV 93032	9.6	4.5	30.0	76.7	1.8	2.7	2837.6	211.6	7.0	5.0	21.3	8.4
SDMV 94001	7.7	5.0	29.5	77.0	3.3	5.5	1906.5	202.1	6.7	4.7	22.0	8.0
SDMV 94005	8.6	4.7	30.0	74.2	1.8	3.3	2178.4	229.6	6.7	4.7	26.8	9.4
SDMV 94014	9.7	4.5	29.5	78.5	1.0	1.0	3140.7	212.7	6.2	3.9	20.7	7.7
SDMV 95009	9.3	4.8	31.7	81.5	1.9	4.2	2734.3	227.3	6.3	4.4	27.2	9.6
SDMV 96053	9.4	4.3	33.2	84.3	1.9	2.3	2389.3	214.6	6.5	4.9	25.8	10.3
SDMV 96063	9.9	4.5	32.8	80.2	1.0	1.0	2652.8	203.8	7.9	5.4	24.0	9.5
Shibe	10.4	5.0	32.3	80.5	1.0	1.0	2726.0	219.6	7.0	5.2	26.4	9.5
Tsholotso bearded	7.4	1.5	35.3	81.7	1.0	1.0	2883.2	259.8	6.6	4.8	24.7	8.3
Range	**4.2-18**	**1-6**	**21-60**	**70-98**	**1-7**	**1-8**	**810-5203**	110-305	3-12	2-9	13-38	5-14
Mean	**9.4**	**3.4**	**32.2**	**80.1**	**1.6**	**2.6**	**2391**	211.2	6.5	5	23	9
CV%	**22.7**	**25.4**	**17.2**	**4.2**	**46**	**26**	**18.1**	14	14	18	15	13

KEY: **DAF**= Days to Flowering; **DAM**= Days to maturity; **YLDNS**= Yield in diseased Non Sprayed plots, **PHT**= Plant height, **DSI**= Disease incidence, **DSS**= Disease Severity, **BRD**= Bird Damage, **VT**= Vegetative tillers, **RT**= Reproductive tillers, **PDM**= Panicle Diameter, **PLT**= Panicle Length, **SWT**= 1000 Seed weight in grams.

Appendix 8: Means of yield and its component traits for Marigat short rains

GENOTYPE	DAF	DAM	PHT	DSI	DSS	BRD	VT	RT	PLT	PDM	SWT	YLDS	YLDSD
ICMV 221	29.0	73.0	194.7	2.0	1.3	4.3	6.3	4.0	20.3	7.2	12.0	2099.0	2414
ICMV 221-1	22.0	75.0	218.3	2.3	3.0	4.3	5.0	4.0	20.0	10.0	11.2	3102.0	3567
ICMV 221-2	31.0	75.7	149.3	3.7	3.0	4.3	7.3	3.7	19.0	9.3	10.1	2652.7	3051
ICMV 221-3	26.3	74.0	228.0	1.0	1.0	4.0	6.3	4.7	20.7	8.0	12.2	2657.7	3056
ICMV 88908	22.7	72.7	181.7	1.0	1.0	4.7	6.3	4.3	28.0	8.7	9.6	1821.3	2095
ICMV 91450	22.7	75.7	216.7	2.0	3.3	5.0	6.0	4.3	19.3	10.0	11.9	3328.7	3828
ICMV 93771	30.3	74.7	226.7	1.0	1.0	4.3	5.3	4.3	25.7	8.3	11.6	3371.7	3877
ICMV 94136	37.0	78.0	158.3	3.0	4.7	4.7	5.3	4.0	21.3	7.3	12.8	2560.3	2944
ICMV 94151	28.3	76.3	221.7	1.0	1.0	1.0	5.0	4.0	21.3	9.0	10.5	2324.7	2673
ICMV 96603	28.7	77.3	301.7	1.0	1.0	1.0	3.3	3.0	22.0	7.3	13.8	3204.3	3685
ICMV Bristled	23.3	74.3	240.0	2.0	2.7	2.3	6.0	4.3	28.3	11.3	10.7	2979.3	3426
ICMV White	31.7	75.0	155.0	6.0	8.0	4.7	5.3	3.7	22.0	9.0	12.4	2116.0	2433
IP 10470	31.0	80.3	238.3	1.0	1.0	5.0	6.0	4.7	28.3	8.0	7.9	1513.3	1740
IP 10471	28.3	79.7	211.7	1.0	1.0	1.0	5.0	4.0	27.3	8.7	7.9	1920.7	2209
IP 5876	21.7	73.0	248.3	1.0	2.7	5.0	4.7	3.3	28.7	8.3	8.1	1379.0	1586
IP 6791	23.3	77.0	228.3	1.0	1.0	1.0	5.0	4.3	25.7	8.0	8.4	2766.3	3181
IP 6800	23.7	75.7	228.3	2.0	4.0	5.0	5.7	3.7	23.0	8.0	10.1	1810.7	2082
IP 7389	31.0	79.0	256.7	1.0	1.0	1.0	7.0	4.7	35.0	9.7	9.8	2332.0	2682
IP 7390	26.0	77.0	218.3	1.0	1.0	1.3	4.3	3.7	31.0	11.3	12.2	2509.0	2885
IP 8761	24.3	77.7	220.0	1.0	1.0	1.7	5.7	4.7	23.0	8.3	7.9	1751.3	2014
IP 8764	22.0	74.0	193.3	2.0	4.7	2.0	4.7	3.7	25.3	9.7	11.3	1970.0	2266
IP 8765	33.3	76.7	194.0	3.0	5.7	3.7	5.3	3.0	24.0	10.3	9.3	1823.3	2097
IP 8766	27.7	74.0	201.7	2.7	6.7	1.0	4.7	3.7	23.3	9.0	7.3	2131.7	2451
IP 8767	26.7	78.0	218.3	2.3	3.3	1.0	5.3	4.3	22.0	8.3	6.5	1276.0	1467
IP 8768	27.7	76.7	223.3	2.0	4.7	5.0	4.7	3.3	25.3	9.0	11.0	2481.3	2854
IP 8772	29.0	83.0	231.7	1.0	1.0	1.0	4.0	3.3	23.7	10.7	7.8	2183.0	2510
IP 8773	29.3	79.7	193.3	1.0	1.0	1.0	5.0	4.0	28.7	10.7	7.5	1453.0	1671

IP 8774	28.0	78.0	191.7	1.0	1.0	4.0	5.0	4.3	16.0	7.3	9.0	1599.3	1839
IP 8783	24.7	80.7	226.7	1.0	1.0	1.3	4.7	4.0	31.3	7.7	11.8	2908.3	3345
IP 8856	22.0	76.0	261.7	1.0	1.0	1.7	4.7	3.7	23.3	9.3	7.6	1599.3	1839
IP 9976	29.7	81.0	231.7	1.0	1.0	4.3	6.0	5.0	26.0	8.7	10.2	1270.0	1461
IP 9989	25.3	74.3	191.7	1.0	1.0	1.7	6.0	5.0	30.3	9.7	7.6	1994.7	2294
KAT PM1	25.7	74.0	211.7	1.0	1.0	1.3	4.7	3.3	25.0	7.7	14.6	2845.0	3272
KAT PM2	21.0	73.0	208.3	1.0	1.0	5.0	5.7	4.7	17.0	6.3	9.2	2948.3	3391
OKASHANA 1	22.7	75.3	245.0	1.0	1.0	3.7	5.3	4.7	24.7	9.3	9.6	2475.3	2847
OKASHANA 2	30.7	76.7	225.0	1.3	1.3	5.0	5.7	3.7	20.0	7.0	8.6	1924.0	2213
OKOA	23.7	75.0	241.7	1.0	1.0	5.0	4.0	4.0	32.0	8.3	9.7	2035.3	2341
PMV 3	27.3	75.7	210.0	1.0	1.0	4.0	5.7	4.7	19.3	8.3	11.4	2948.0	3390
SDMV 90031	28.7	79.7	186.7	1.0	1.0	2.0	5.7	4.7	21.3	9.7	13.7	4627.3	5321
SDMV 94001	32.0	75.0	175.0	5.7	8.0	5.0	7.3	3.7	21.7	8.5	7.9	1490.7	1714
SDMV 94005	22.3	71.3	238.3	1.0	1.0	5.0	5.3	3.7	29.3	9.7	9.3	2825.3	3249
SDMV 94014	22.7	74.3	245.0	1.0	1.0	4.0	4.7	3.3	23.0	7.0	12.3	2292.3	2636
SDMV 95009	23.3	75.0	265.0	1.0	1.0	4.7	4.7	4.0	26.3	9.7	11.4	2302.7	2648
SDMV 96063	30.7	76.3	215.0	1.0	1.0	5.0	6.0	4.7	25.0	9.0	10.9	2249.3	2587
SHIBE	25.7	77.0	245.0	1.0	1.0	5.0	6.3	4.0	25.7	8.7	12.0	2198.3	2528
TSHOLOTSO	29.3	76.0	258.3	1.0	1.0	1.3	5.3	4.0	24.3	9.3	8.2	2503.0	2878

KEY: **DAF**= Days to Flowering; **DAM**= Days to maturity; **YLDNS**= Yield in diseased Non Sprayed plots, **YLDS**=Yield in Sprayed plots **PHT**= Plant height, **DSI**= Disease incidence, **DSS**= Disease Severity, **BRD**= Bird Damage, **VT**= Vegetative tillers, **RT**= Reproductive tillers, **PDM**= Panicle Diameter, **PLT**= Panicle Length, **SWT**= 1000 Seed weight in grams.

Appendix 9: Means of yield and its component traits for Marigat long rains

GENOTYPE	DAF	DAM	PHT	DSI	DSS	BRD	VT	RT	PLT	PDM	SWT	YLDS	YLDNS
ICMV 221	25.7	73.3	245.0	1.0	3.0	5.0	7.3	6.0	22.0	8.4	9.4	3024.3	3569
ICMV 221-1	25.0	77.0	205.0	3.0	5.3	4.3	7.7	6.7	20.3	11.0	12.0	3174.9	3746
ICMV 221-2	31.3	74.3	180.7	3.3	5.7	4.7	7.3	5.3	20.0	9.6	10.6	2569.4	3032
ICMV 221-3	25.3	74.0	220.0	1.0	1.0	4.7	7.7	6.3	20.3	8.6	7.6	2909.7	3433
ICMV 221-4	28.7	74.0	203.3	3.0	6.3	3.3	6.7	5.3	21.2	9.7	7.7	2631.9	3106
ICMV 88908	22.7	73.3	181.7	1.0	1.0	4.7	9.3	7.7	27.0	10.1	8.1	1868.1	2204
ICMV 91450	26.7	76.7	213.3	2.0	3.0	5.0	6.0	5.0	18.0	9.7	8.7	3201.4	3778
ICMV 93771	27.3	75.3	256.7	1.0	1.0	4.3	5.7	4.7	23.0	8.3	7.3	3604.2	4253
ICMV 94136	37.0	78.0	163.3	4.7	6.7	4.7	6.3	5.0	20.3	6.8	5.8	2548.6	3007
ICMV 94151	28.3	75.7	206.7	1.0	1.0	4.7	6.7	5.7	22.3	8.8	7.8	2347.2	2770
ICMV 96603	28.7	77.3	299.0	1.0	1.0	4.3	5.3	4.0	24.0	6.8	5.8	3289.9	3882
ICMV Bristled	21.3	74.3	244.0	2.0	3.3	1.7	6.0	4.7	35.3	10.6	9.6	2291.7	2704
ICMV White	31.7	75.0	168.3	6.0	8.0	4.7	5.3	4.3	24.0	9.3	8.3	2069.4	2442
IP 10470	31.0	80.3	241.7	1.0	1.0	5.0	6.0	5.0	30.3	8.3	7.3	1479.2	1745
IP 10471	28.3	79.7	223.3	1.0	1.0	1.0	6.3	4.7	29.3	9.0	8.0	2048.6	2417
IP 5876	21.7	73.0	248.3	2.7	5.3	5.0	6.7	5.0	30.7	8.6	7.6	1430.6	1688
IP 6791	23.3	77.0	233.3	1.0	1.0	3.7	6.3	5.3	27.7	8.3	7.3	2791.7	3294
IP 6800	23.7	75.7	233.3	2.3	6.0	5.0	7.7	6.7	25.0	8.6	7.6	1930.6	2278
IP 7389	32.3	77.7	230.0	1.0	1.0	1.0	6.7	5.3	36.7	11.1	10.1	2250.0	2655
IP 7390	26.0	77.0	228.3	1.0	1.0	1.3	6.3	5.3	31.7	12.1	11.0	2548.6	3007
IP 8761	24.3	77.7	220.0	1.0	1.0	1.7	11.3	6.0	21.0	9.7	8.3	1819.4	2147
IP 8764	22.0	74.0	213.3	3.3	5.7	2.0	7.0	5.0	23.3	10.9	11.0	2208.3	2606
IP 8765	33.3	76.7	238.3	3.3	6.3	3.7	7.7	5.7	22.0	11.3	8.3	1812.5	2139
IP 8766	27.7	74.0	211.7	2.7	6.0	1.0	5.7	4.3	21.3	9.2	8.0	2118.1	2499
IP 8767	26.7	78.0	218.7	2.3	4.0	1.0	6.3	5.0	20.0	7.9	8.7	1284.7	1516
IP 8768	27.7	76.7	231.7	2.3	3.3	5.0	5.7	4.7	24.3	9.9	10.8	2500.0	2950
IP 8772	29.0	83.0	233.7	1.0	1.0	1.0	6.7	5.7	22.7	10.5	8.3	2229.2	2630

IP 8773	29.3	79.7	211.7	1.0	1.0	1.0	6.3	5.0	27.7	11.3	12.3	1180.6	1393
IP 8774	28.0	78.0	187.0	1.0	1.0	4.0	6.7	5.3	15.0	7.5	8.5	1666.7	1967
IP 8783	24.7	80.7	226.7	1.0	1.0	1.3	7.3	4.3	30.3	8.9	9.9	3048.6	3597
IP 8856	22.0	76.0	265.0	1.0	1.0	1.7	6.7	5.0	22.3	8.0	9.0	1659.7	1958
IP 9946	24.3	81.3	238.3	1.0	1.0	5.0	7.0	4.3	25.7	10.6	11.6	2423.6	2860
IP 9989	25.3	74.3	198.3	2.0	5.0	1.7	6.3	5.3	29.3	10.9	11.9	2395.0	2826
KAT PM1	25.7	74.0	218.3	1.0	1.0	1.3	6.0	5.0	24.0	8.5	9.5	2808.2	3314
KAT PM2	21.0	73.0	228.3	1.0	1.0	5.0	7.7	6.0	16.0	7.5	8.5	3131.9	3696
Okashana 1	22.7	75.3	265.0	2.0	4.0	3.7	7.0	5.0	23.7	10.0	11.0	2659.7	3138
Okashana 2	32.3	77.0	241.7	2.0	2.3	5.0	6.0	4.7	23.0	8.8	9.8	2340.3	2762
OKOA	23.7	75.0	245.0	1.0	1.0	5.0	6.0	5.0	33.0	9.0	7.5	2395.8	2827
SDMV 90031	28.7	79.7	208.3	1.0	1.0	2.0	7.7	5.7	22.3	9.3	7.8	4205.3	4962
SDMV 93032	25.3	74.3	236.3	1.0	1.0	4.0	7.3	5.3	24.7	9.2	7.7	3095.3	3652
SDMV 94001	32.0	75.0	205.0	5.7	8.0	5.0	6.7	5.0	22.7	9.6	8.1	1562.5	1844
SDMV 94005	22.3	71.3	246.7	1.0	1.0	5.0	6.3	4.7	30.3	10.5	9.0	2944.4	3474
SDMV 94014	22.7	74.3	243.3	1.0	1.0	4.0	5.7	3.7	24.0	7.9	6.4	2638.9	3114
SDMV 96063	30.7	76.3	223.3	1.0	1.0	5.0	8.7	7.0	26.3	10.3	8.8	2638.9	3114
SHIBE	25.7	77.0	240.0	1.0	1.0	5.0	7.0	5.7	25.0	9.1	7.6	2552.6	3012
Tsholotso	29.3	76.0	276.3	1.0	1.0	1.3	7.0	5.7	23.7	9.0	7.5	2604.2	3073

KEY: **DAF**= Days to Flowering; **DAM**= Days to maturity; **YLDS**=Grain yield tons Ha^{-1} **PHT**= Plant height, **DSI**= Disease incidence, **DSS**= Disease Severity, BRD= Bird Damage, **VT**= Vegetative tillers, **RT**= Reproductive tillers, **PDM**= Panicle Diameter, **PLT**= Panicle Length, **SWT**= 1000 Seed weight in grams.

Appendix 10: Means of yield and its component traits for Koibatek Short rains

GENOTYPE	DAF	DAM	PHT	DSI	DSS	BRD	VT	RT	PLT	PDM	SWT	YLD
ICMV 221	25	74	215	1.3	1.3	4.3	5.7	4.0	18.3	7.2	11.6	2409
ICMV 221-1	29	86	172	4.7	7.3	5.0	6.7	4.0	19.3	7.0	11.3	3790
ICMV 221-2	29	77	250	2.0	7.0	5.0	4.7	3.7	20.7	7.3	9.8	2265
ICMV 221-3	29	77	194	1.0	1.0	5.0	7.0	4.0	17.3	7.0	11.7	2802
ICMV 88908	35	75	170	1.0	1.0	5.0	8.0	3.7	19.3	8.0	8.9	1407
ICMV 91450	36	85	187	4.0	7.0	5.0	7.0	4.0	19.0	8.3	14.3	2657
ICMV 93771	35	83	195	1.0	1.0	5.0	6.0	4.3	24.7	7.7	11.9	2888
ICMV 94136	29	81	187	2.0	2.7	4.7	4.3	3.3	20.7	10.0	11.3	2445
ICMV 94151	34	79	168	1.0	1.0	1.0	6.7	3.3	22.0	8.3	11.2	1983
ICMV 96603	41	86	256	1.0	1.0	1.0	7.3	4.0	22.7	10.8	14.7	2741
ICMV Bristled	28	76	223	3.0	5.0	3.0	6.0	4.0	26.0	10.8	10.7	3354
ICMV White	28	77	238	2.0	5.0	5.0	5.3	3.7	22.7	7.7	10.4	2156
IP 10470	44	92	162	1.0	1.0	4.7	7.0	4.0	27.7	10.3	7.5	1114
IP 10471	39	94	218	1.0	1.0	3.0	7.0	3.0	28.0	11.3	8.5	1787
IP 6791	41	86	208	1.3	1.0	1.0	6.3	3.7	20.0	7.7	8.8	3617
IP 6800	43	86	164	2.0	2.7	3.7	6.3	4.3	27.7	8.0	10.6	1527
IP 7389	38	82	217	1.0	1.0	1.0	7.7	4.3	32.3	10.0	9.3	2091
IP 7390	39	84	219	1.0	1.0	1.0	7.3	4.0	31.0	11.2	8.1	2576
IP 8764	38	81	168	2.3	5.3	1.7	7.0	4.7	21.7	8.7	11.7	1713
IP 8765	36	85	183	2.3	3.7	3.0	6.7	5.3	19.3	8.7	9.9	2207
IP 8766	33	77	193	2.7	5.7	1.0	5.3	3.7	24.7	9.3	7.2	2208
IP 8767	41	92	168	2.7	5.3	1.0	6.0	3.7	23.0	8.3	4.9	1343
IP 8768	41	86	177	2.3	6.0	3.7	4.7	3.3	18.7	9.7	9.8	3163
IP 8772	43	91	203	1.0	1.0	2.0	6.3	4.0	23.7	9.7	6.9	1875
IP 8773	48	95	128	1.0	1.0	1.3	7.3	3.0	22.0	10.0	5.5	1576
IP 8774	40	85	211	1.0	1.0	5.7	6.3	4.3	14.3	6.0	9.5	1786
IP 8783	42	89	206	1.0	1.0	5.0	8.0	4.3	32.0	10.0	12.4	3390

IP 8856	46	88	155	1.0	1.0	1.3	8.0	4.7	22.7	10.3	4.7	957
IP 9946	49	94	123	1.0	1.0	2.3	6.0	4.7	29.0	11.0	9.0	1756
IP 9989	43	89	165	2.3	3.0	1.7	7.3	3.0	24.3	9.0	7.1	1426
KAT PM1	31	76	195	1.0	1.0	1.0	6.3	4.3	20.7	9.0	15.4	2944
KAT PM2	35	77	166	2.0	6.3	5.0	7.0	4.0	23.3	8.7	9.5	2304
Okashana 1	41	84	172	3.3	6.0	4.0	6.0	3.3	20.0	8.0	9.0	2035
Okashana 2	35	81	200	1.7	3.3	5.0	6.7	4.0	19.7	8.3	8.5	1845
OKOA	41	83	188	1.0	1.0	5.0	5.7	4.0	25.7	8.3	12.3	2550
SDMV 90031	41	84	168	1.0	1.0	3.0	6.3	4.0	23.0	8.0	14.9	4501
SDMV 94001	27	79	208	1.0	1.0	5.0	5.7	4.0	21.3	6.0	8.2	2212
SDMV 94005	38	77	187	2.7	5.7	4.3	7.0	4.3	23.3	8.7	8.8	1395
SDMV 94014	36	83	177	1.0	1.0	5.0	7.0	3.3	17.3	7.3	12.9	3802
SDMV 96063	35	84	182	1.0	1.0	4.0	7.7	3.7	22.7	8.7	11.3	2876
SHIBE	39	84	212	1.0	1.0	5.0	7.3	5.0	27.7	10.0	13.4	2997
Tsholotso Bearded	41	87	232	1.0	1.0	1.7	6.3	3.7	25.3	8.0	8.5	3329

KEY: **DAF**= Days to Flowering; **DAM**= Days to maturity; **YLD**=Grain yield tons Ha^{-1} **PHT**= Plant height, **DSI**= Disease incidence, **DSS**= Disease Severity, **BRD**= Bird Damage, **VT**= Vegetative tillers, **RT**= Reproductive tillers, **PDM**= Panicle Diameter, **PLT**= Panicle Length, **SWT**=1000 Seed weight in grams.

Appendix 11: Means of yield and its component traits for Koibatek long rains

GENOTYPE	DAF	DAM	PHT	DSI	DSS	BRD	VT	RT	PLT	PDM	SWT	YLD
ICMV 221	29	76	168	1.3	3.0	3.7	7.0	5.3	19.0	9.4	10.4	2227
ICMV 221-1	26	84	188	4.3	6.3	5.0	6.7	5.3	21.0	8.2	9.2	3861
ICMV 221-2	29	78	209	2.3	4.0	4.7	6.0	4.3	21.7	9.2	10.2	2465
ICMV 221-3	30	74	206	1.0	1.0	4.3	7.7	5.7	19.7	8.9	7.9	3174
ICMV 221-4	32	76	175	3.3	7.7	3.3	6.3	5.3	21.0	9.1	7.1	2896
ICMV 88908	35	77	193	1.0	1.0	5.0	10.0	7.0	18.3	8.6	6.6	1472
ICMV 91450	32	88	215	4.3	6.7	5.0	8.0	6.7	18.3	8.5	7.2	2542
ICMV 93771	38	82	188	1.0	5.0	5.0	7.7	6.0	25.3	7.2	6.2	2597
ICMV 94136	29	81	192	2.0	4.7	4.7	7.0	6.0	19.7	9.5	8.5	2688
ICMV 94151	34	80	193	1.0	1.0	5.0	6.3	5.0	20.0	7.5	6.5	2299
ICMV 96603	41	86	254	1.0	1.0	4.3	8.0	6.3	24.7	10.9	9.9	2646
ICMV bristled	30	76	228	3.0	5.3	3.7	6.7	5.3	23.0	12.1	11.1	4169
ICMV White	28	77	236	2.7	7.0	5.0	7.0	4.7	24.7	8.0	7.0	2063
IP 10470	44	92	213	1.0	1.0	4.7	7.0	5.0	29.7	10.6	9.6	1410
IP 10471	39	94	224	1.0	1.0	3.0	8.0	5.3	30.0	11.6	10.6	1771
IP 5876	46	89	179	2.0	4.7	4.3	8.3	5.7	27.7	9.6	8.6	1472
IP 6791	41	86	213	1.0	1.0	3.7	5.3	3.7	22.0	8.0	7.0	3514
IP 6800	43	86	178	2.0	7.0	3.7	8.3	6.7	29.7	8.5	7.5	1924
IP 7389	37	83	254	1.0	1.0	1.0	7.7	6.3	34.7	8.4	7.4	2042
IP 7390	39	84	242	1.0	1.0	1.0	8.3	6.7	30.3	11.5	10.5	2618
IP 8761	41	87	248	1.0	1.0	1.0	9.0	6.0	22.7	10.1	10.3	1993
IP 8764	38	81	187	3.0	6.7	1.7	8.3	6.0	19.7	10.1	10.7	2125
IP 8765	36	85	207	2.7	3.7	3.0	8.0	6.0	17.3	9.7	9.0	2160
IP 8766	33	77	203	2.7	5.7	1.0	6.0	5.0	22.7	9.8	7.7	2139
IP 8767	41	92	172	2.7	5.3	1.0	7.7	5.7	21.0	8.7	6.3	1319
IP 8768	41	86	207	2.3	6.0	3.7	6.7	5.0	17.7	8.1	11.0	3417
IP 8772	43	91	209	1.0	1.0	2.0	7.0	5.7	22.7	10.2	11.2	1743
IP 8773	48	95	142	1.0	1.0	1.3	8.3	6.0	21.0	10.7	11.7	1667
IP 8774	40	85	224	1.0	1.0	5.7	7.3	5.7	13.3	6.7	7.7	1847

IP 8783	42	89	232	1.0	1.0	5.0	9.0	5.3	31.0	11.3	12.3	3389
IP 8856	46	88	184	1.0	1.0	1.3	10.0	6.0	21.7	11.0	12.0	1104
IP 9946	49	94	223	1.0	1.0	2.3	6.0	4.3	28.0	9.0	10.0	1681
IP 9976	48	96	212	1.0	1.0	3.0	7.3	4.7	20.0	9.0	10.0	1292
IP 9989	43	89	182	2.7	3.7	1.7	7.7	5.7	23.3	10.5	11.5	1486
KAT PM1	31	76	195	1.0	1.0	1.0	7.3	5.3	19.7	9.5	10.5	2736
KAT PM2	35	77	192	1.0	1.0	5.0	7.3	5.7	22.3	8.3	9.3	2954
OKASHANA 1	41	84	260	3.3	6.0	4.0	7.0	4.7	19.7	9.0	10.0	2829
OKASHANA 2	33	81	257	1.3	3.0	5.0	7.3	5.7	18.7	8.0	9.0	1743
OKOA	41	83	208	1.0	1.0	5.0	7.0	5.3	26.7	9.1	7.6	2500
PMV 3	35	79	227	1.0	1.0	4.7	8.0	6.0	18.7	8.6	7.1	2965
SDMV 90031	41	84	188	1.0	1.0	3.0	7.7	6.0	24.0	9.1	7.6	4634
SDMV 93032	35	79	200	2.7	3.7	5.0	8.0	6.3	19.0	8.6	7.1	2674
SDMV 94001	27	79	220	1.0	5.0	5.0	7.0	6.0	22.3	7.9	6.4	2361
SDMV 94005	38	77	247	2.7	5.7	4.3	8.0	6.0	24.3	9.0	7.5	1549
SDMV 94014	36	83	186	1.0	1.0	5.0	7.7	5.3	18.3	8.7	7.2	3660
SDMV 95009	40	88	202	2.7	6.3	5.0	7.7	5.3	28.0	9.0	7.5	3194
SDMV 96053	37	89	193	2.3	3.0	4.7	6.7	5.7	24.0	10.3	8.8	2431
SDMV 96063	35	84	195	1.0	1.0	4.0	9.3	6.3	22.0	10.0	8.5	2847
SHIBE	39	84	182	1.0	1.0	5.0	7.3	6.0	27.3	10.3	8.8	2556
TSHOLOTSO	41	87	273	1.0	1.0	1.7	7.7	6.0	25.3	7.0	5.5	3096

KEY: **DAF**= Days to Flowering; **DAM**= Days to maturity; **YLD**=Grain yield tons Ha^{-1} **PHT**= Plant height, **DSI**= Disease incidence, **DSS**= Disease Severity, **BRD**= Bird Damage, **VT**= Vegetative tillers, **RT**= Reproductive tillers, **PDM**= Panicle Diameter, **PLT**= Panicle Length, **SWT**= 1000 Seed weigh in grams.

Appendix 12: Monthly total Rainfall (mm) from 2009-2012 at ATC Koibatek

Month Year	Jan	Feb.	March	April	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Total
2009	9.2	48.1	95.8	47.4	31.2	24	34.5	67.2	56.5	20	89.9	10.7	534.5
2010	9.6	18.8	50.9	98	33.4	47	34.7	82.8	77.4	59.1	65.5	133.4	710.6
2011	17.1	12	42.2	243	226	79.8	47.9	65.9	24.5	63.6	57.5	33.5	913
2012	68.2	5.9	107.3	80	79	78.6	76.7	55.3	58.5	29	154	17.1	809.6

Appendix 13: Monthly total Rainfall (mm) for 2009- 2012 at KALRO Marigat

Month Year	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
2009	162	32	61	202	24	52	33	80	70	54	70	2	842
2010	103	53	92	162	262	40	15	18	30	30	50	114	969
2011	14	12	60	35	205	25	5	22	25	33	43	5	484
2012	22	30	35	85	54	18	23	34	33	15	62	8	419

Appendix 14: Inoculation and first Observation dates for Experiment II

Genotype	**Date Of Planting**	**Inoculation Date**	**1st Observation**
ICMV 221	15th June	7th July	14th July
KAT PM 1	15th June	9th July	16th July
IP 6791	15th June	11th July	18th July
ICMV 221 WHITE	15th June	7th July	14th July
ICMV 91450	15th June	8th July	15th July
IP 10470	15th June	13th July	20th July
IP 7390	15th June	14th July	21st July
IP 8764	15th June	19th July	26th July
SDMV 96063	15th June	14th July	21st July
SHIBE	15th June	13th July	20th July
TSHOLOTSHO	15th June	20th July	27th July
ICMV 93771	15th June	8th July	15th July
IP 8783	15th June	19th July	26th July
SDMV 94001	15th June	15th July	22nd July
SDMV 94014	15th June	15th July	22nd July
ICMV 96603	15th June	9th July	16th July
ICMV BRISTLED	15th June	7th July	14th July
SDMV 90031	15th June	14th July	21st July
KAT PM2	15th June	14th July	21st July
OKOA	15th June	13th July	20th July